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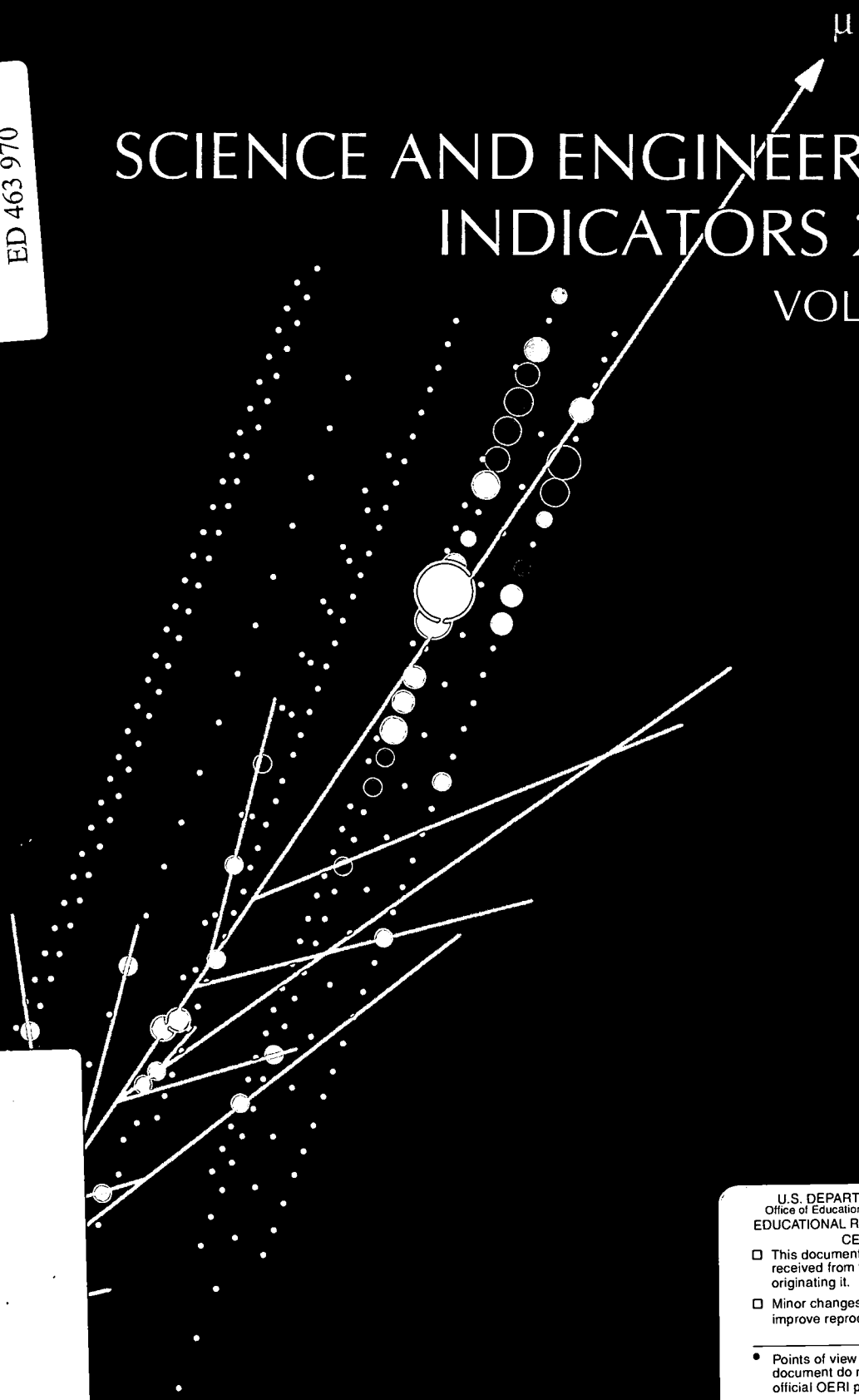
ABSTRACT

This publication is the fifteenth in the series of biennial Science Indicators reports. The Science Indicators series was designed to provide a broad base of quantitative information about U.S. science, engineering, and technology for use by public and private policymakers. Because of the spread of scientific and technological capabilities around the world, this report presents a significant amount of material about these international capabilities and analyzes the U.S. position in this broader context. Science and Engineering Indicators; 2002 contains quantitative analyses of key aspects of the scope, quality, and vitality of the Nation's science and engineering enterprise. The report presents material on science, mathematics, and engineering education from the elementary level through graduate school and beyond; the scientific and engineering workforce; U.S. and international research and development (R&D) performers, activities, and outcomes; U.S. competitiveness in high technology; public attitudes and understanding of science and engineering; and the significance of information technologies for science and for the daily lives of our citizens in schools, the workplace, and the community. An overview chapter presents the key themes emerging from these analyses. A CD-ROM version of the report is included (Contains approximately 230 references.) (MM)

SCIENCE AND ENGINEERING INDICATORS 2002

VOLUME 1



NATIONAL SCIENCE BOARD

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National Science Board

National Science Board Subcommittee on Science & Engineering Indicators – 2002

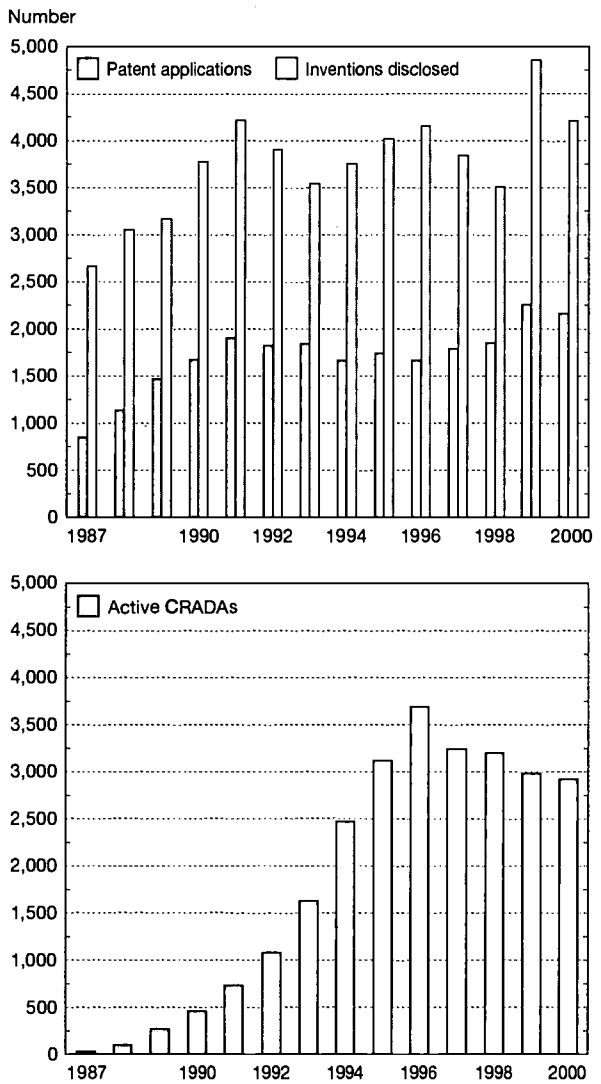
Science and Engineering Indicators – 2002

Errata

Chapter 4, Figure 4-18.

In the top frame, the bars for 1999 and 2000 are incorrect; both shading and order of the bars are reversed. The corrected figure appears below. Data in the text and in appendix table 4-35 are correct as printed. The corrected figure appears on the Science and Engineering Indicators website and CD.

Figure 4-18.
Federal technology transfer indicators: 1987–2000



CRADA = Cooperative Research and Development Agreement

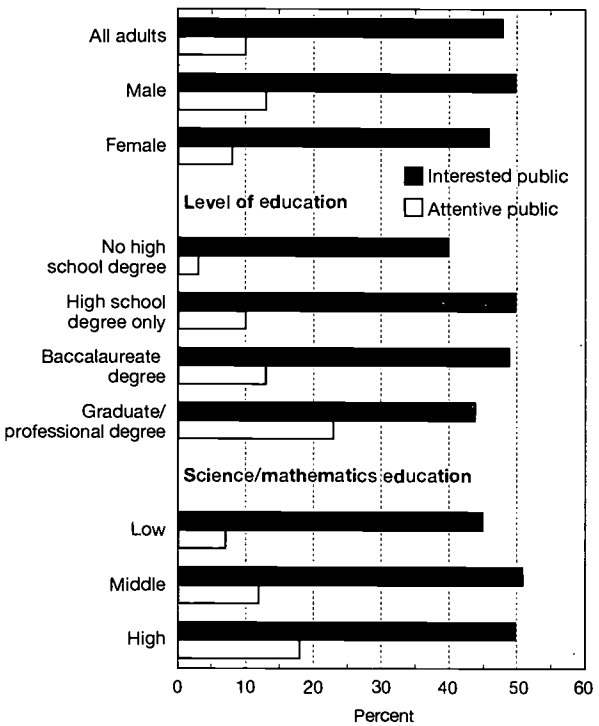
See appendix table 4-35.

Science & Engineering Indicators – 2002

Chapter 7, Figures 7-3 and 7-19.

The figures as printed reflect data calculated using preliminary weights. The corrected figures, using final weights, are shown below. Data in the text and in appendix tables 7-8, 7-43 and 7-44 are correct as printed. The corrected figures appear on the Science and Engineering Indicators web site and CD.

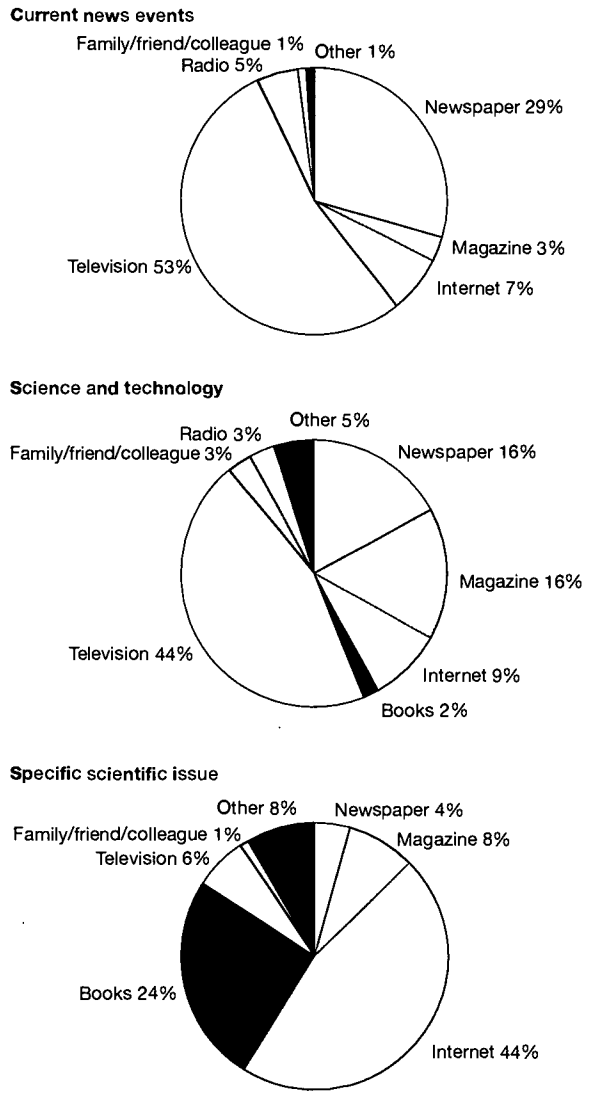
Figure 7-3.
Public attentiveness to science and technology issues, by sex and level of education: 2001



NOTES: "Attentive" public are people who (1) express high level of interest in a particular issue; (2) feel well informed about that issue, and (3) read a newspaper on a daily basis, read a weekly or monthly news magazine, or frequently read a magazine highly relevant to the issue. "Interested" public are people who express high level of interest in a particular issue but do not feel well informed about it. The attentive public for science and technology is a combination of the attentive public for new scientific discoveries and the attentive public for new inventions and technologies. Anyone who is not attentive to either of these issues, but who is a member of the interested public for at least one of these issues, is classified as a member of the interested public for science and technology. Survey respondents were classified as having a "high" level of science/mathematics education if they took nine or more high school and college math/science courses. They were classified as "middle" if they took six to eight such courses, and "low" if they took five or fewer.

See appendix table 7-8. *Science & Engineering Indicators – 2002*

Figure 7-19.
Leading source of information: 2001



NOTE: Percentages may not sum to 100 because "Don't know" responses are not shown.

See appendix tables 7-42, 7-43, and 7-44.
Science & Engineering Indicators – 2002

SCIENCE & ENGINEERING INDICATORS 2002

VOLUME 1

NSB NATIONAL SCIENCE BOARD

The Cover:

The cover image shows the path of a neutrino, as recorded by the Antarctic Muon and Neutrino Detector Array (AMANDA), at the South Pole, supported by the National Science Foundation, the manager of the US Antarctic Program. AMANDA was designed to detect and measure neutrinos produced in cosmic sources within our galaxy and beyond, yielding important new information about cosmic objects, both poorly understood or previously unknown. The detector consists of over 500 photomultipliers buried between 1,400 and 2,400 meters deep in the ice sheet covering the region of the South Pole in Antarctica.

Image Credit: Department of Physics, University of Wisconsin, Madison, Wisconsin.

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National Science Board

NATIONAL SCIENCE BOARD
4201 Wilson Boulevard
ARLINGTON, VIRGINIA 22230

January 15, 2002

The Honorable George W. Bush
The President of the United States
The White House
Washington, DC 20500

Dear Mr. President:

It is my honor to transmit to you, and through you to the Congress, the fifteenth in the series of biennial Science Indicators reports, *Science and Engineering Indicators – 2002*. The National Science Board submits this report in accordance with Sec. 4(j)1 of the National Science Foundation Act of 1950, as amended.

The Science Indicators series was designed to provide a broad base of quantitative information about U.S. science, engineering, and technology for use by public and private policymakers. Because of the spread of scientific and technological capabilities around the world, this report presents a significant amount of material about these international capabilities and analyzes the U.S. position in this broader context.

Science and Engineering Indicators – 2002 contains quantitative analyses of key aspects of the scope, quality, and vitality of the Nation's science and engineering enterprise. The report presents material on science, mathematics, and engineering education from the elementary level through graduate school and beyond; the scientific and engineering workforce; U.S. and international R&D performers, activities, and outcomes; U.S. competitiveness in high technology; public attitudes and understanding of science and engineering; and the significance of information technologies for science and for the daily lives of our citizens in schools, the workplace, and the community. An overview chapter presents the key themes emerging from these analyses.

Much in this report demonstrates that science thrives on the open flow of ideas. The scientific community values reason, experimentation, and evidence, and it transcends national boundaries and cultural and political differences. In the wake of the events of September 11, which demonstrated that the enemies of openness stand ready to subvert science and technology for malevolent ends, preserving and enhancing open scientific discourse becomes an acute concern. However, it is the proponents of openness, not its enemies, who are in the best position to exploit the fruits of science.

I hope that you, your Administration, and the Congress will find the new quantitative information and analysis in the report useful and timely for informing thinking and planning on national priorities, policies, and programs in science and technology.

Respectfully yours,

Eamon M. Kelly

Eamon M. Kelly
Chairman

Acknowledgments

The National Science Board extends its appreciation to the staff of the National Science Foundation for preparing this report. Organizational responsibility for the volume was assigned to the Directorate for Social, Behavioral and Economic Sciences, Norman M. Bradburn, Assistant Director.

Primary responsibility for the production of the volume was assigned to the Science and Engineering Indicators Program under the direction of Rolf Lehming, Division of Science Resources Statistics (SRS); Lynda Carlson, Division Director; Mary J. Frase, Deputy Division Director.

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Chapter 3.	R. Keith Wilkinson, Mark C. Regets, SRS
Chapter 4.	John E. Jankowski, Francisco A. Moris, SRS; Steven Payson, formerly SRS
Chapter 5.	Rolf Lehming, Alan I. Rapoport, Derek Hill, SRS
Chapter 6.	Lawrence M. Rausch, SRS
Chapter 7.	Melissa Pollak, SRS
Chapter 8.	David Cheney, SRI International, under contract to SRS

Rolf Lehming, Thomas M. Smith, and Alan I. Rapoport directed the physical production of the volume which benefited from extensive contributions from SRS staff. The Division's senior staff and survey managers assured timely availability of data under often stringent deadlines: Richard J. Bennof, Joan S. Burrelli, Leslie J. Christovich, Mary J. Golladay, Susan T. Hill, John E. Jankowski, Kelly H. Kang, Nirmala Kannankutty, Mary M. Machen, Ronald L. Meeks, Melissa F. Pollak, John Tsapogas, and Raymond M. Wolfe. Mary J. Frase and Ronald S. Fecso provided advice with statistical and data presentation issues. Deborah A. Collins, Vellamo Lahti, Rajinder Raut, Felicia Hairston, Terri Smith, and Martha M. James rendered logistical support. John R. Gawalt managed editorial, printing, and Web support, and Wayne K. Thomas oversaw the project's contractual aspects.

Members of the National Science Board's Science and Engineering Indicators Subcommittee, chaired by Richard M. Tapia, provided guidance and support throughout the preparation of this report. Mary F. Poats, Executive Secretary, ensured smooth coordination with the Subcommittee. However, the report also benefited from the close involvement of all NSB members, from development of narrative outlines to intensive reviews. The Board members' generous contribution of time, effort, and expertise under often stringent schedules is gratefully acknowledged.

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Overall editing and coordination of the report was performed by Beverly Cook and associates of Aspen Systems Corporation. Eileen Kessler and the staff of OmniDigital Studio, Inc., provided desktop publishing and composition services. Mary J. Frase and John R. Gawalt produced special Information Cards, and John R. Gawalt was responsible for making this publication available on the World Wide Web <www.nsf.gov/sbe/srs/seind02/start.htm>. Web design, programming, and HTML coding were performed by De Vo, Bridget Tuthill, Marjorie Silvernail, Jennifer Nowak, Elise Manalang, and Jason Shaffer of Compuware Corporation.

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Contents

Overview

The United States in a Changing World

As the 21st century begins, the United States occupies a position of strength in the support and conduct of research and development (R&D). U.S. R&D expenditures equal the combined total expenditures of Japan, the United Kingdom, Canada, France, Germany, and Italy. U.S. scientists and engineers produce nearly one-third of the articles published in the world's most influential technical journals. U.S. researchers participate in a wide range of international collaborative research efforts, and the results of these efforts are widely cited by scientists in other countries, attesting to their quality and usefulness.

The United States has managed to turn its R&D strengths to its economic and commercial benefit. Industry's recognition of the importance of research and development to profit growth is reflected in the strong expansion of its own R&D spending. Firms have also invested heavily in information and communication technology that enables them to accelerate product development cycles. Industry has formed joint ventures with other companies, universities, and international partners. Moreover, industry spinoffs and underwriting of new ventures have become more common. A large and flexible venture capital industry has provided both capital and managerial assistance for many new enterprises.

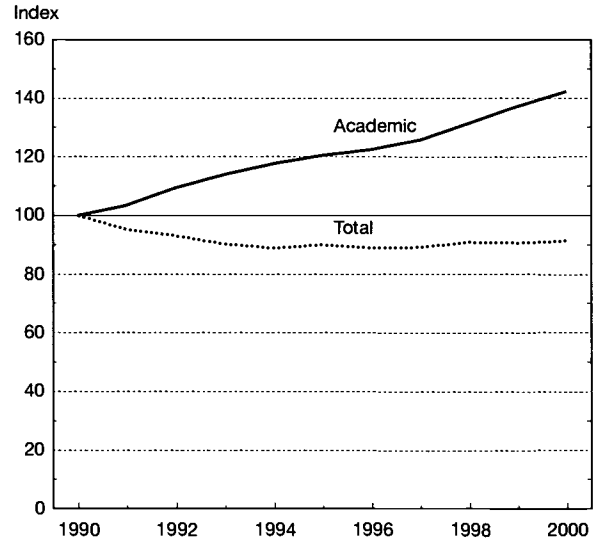
The Federal government has fostered a broad base of research activity, especially in academia, where Federal funds represent about 60 percent of total R&D spending. The nation's universities and colleges train new generations of researchers and also perform nearly half of the nation's basic research, which underlies the many technological innovations. Although overall inflation-adjusted Federal R&D funding declined by about 9 percent during the 1990s, it increased by 42 percent for academic R&D—a rise driven largely by increases in the life sciences. (See figures O-1 and O-2.) During the same period, however, funding for the physical sciences and engineering slowed, a development which has sparked critical commentary by many in the scientific and science policy communities.

To foster the transfer of knowledge from academia to industry, the U.S. government has encouraged universities to patent their inventions and to collaborate with industry. University patenting has grown rapidly, particularly in the life sciences, and during much of the past decade academic research articles were increasingly cited on U.S. patents. (See figure O-3.) Industry-university collaboration has taken many forms, from traditional faculty consulting to special R&D contracts, licensing arrangements, R&D joint ventures, and spinoff firms established by academic institutions.

Governments and firms around the world have taken note of these perceived U.S. strengths. Governments have initiated broad national and regional efforts to capture similar benefits. In addition to emphasizing market forces and liberalization of investment and labor market rules, their strategies have included strong investments in education and training. In the latter part of the 1990s, these developments have reflected a growing conviction that some kind of new economic reality was coming into existence—a "knowledge-based" economy, marked by the systematic generation, distribution, and use of research knowledge for economic gain. This notion, emanating from the United States, seemed to be underscored by the positive U.S. economic performance in the latter half of the 1990s.

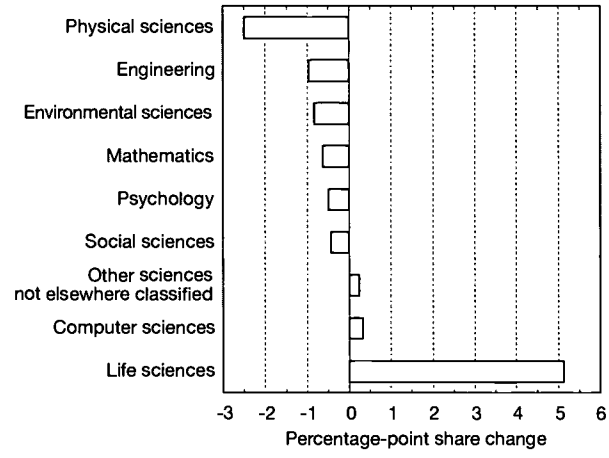
Government and industry efforts in other nations may foreshadow the eventual creation of new centers of scientific, technological, and engineering excellence. The resulting international knowledge flows may benefit all nations but will

Overview Figure 1.
Inflation-adjusted Federal total and Federal academic R&D: 1990–2000



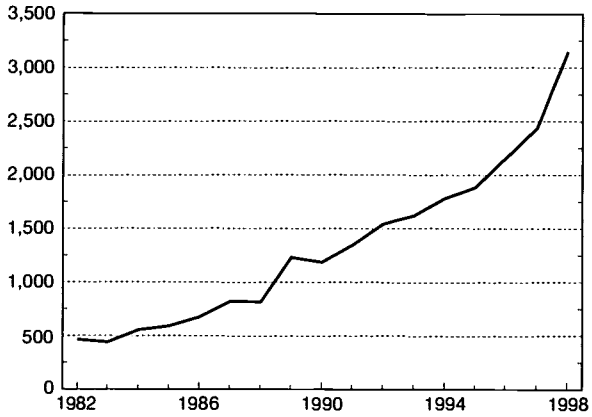
NOTE: 1990 index = 100.
See appendix table 4-6.
Science & Engineering Indicators – 2002

Overview Figure 2.
Changes in share of Federal academic research obligations, by field: 1990–99

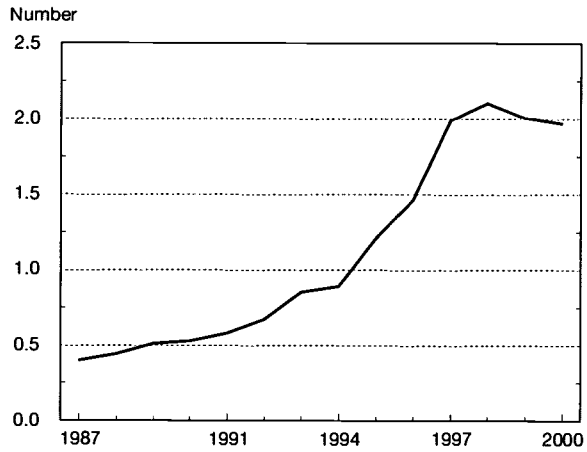


SOURCE: NSF/SRS, Survey of Federal Funds for Research and Development
Science & Engineering Indicators – 2002

Overview Figure 3.
Patents granted to U.S. universities: 1982–98



Average number of citations to scientific and technical articles per U.S. patent: 1987–2000



See appendix tables 5-54 and 5-56.

Science & Engineering Indicators – 2002

also pose challenges to those seeking to exploit these flows effectively. Trends that afford a glimpse of key future aspects of the world context for the U.S. science and technology (S&T) enterprise are examined within this framework.

Education, Demographics, and World Labor Markets

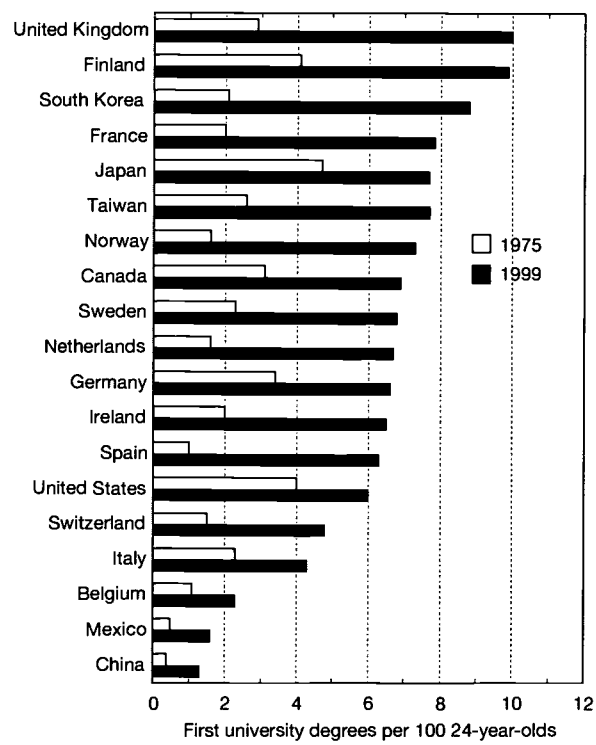
The sine qua non of a modern economy is a well-educated, versatile workforce able to conduct R&D and to convert its results into innovative products, processes, and services. In many nations, government investment in education has resulted in broadening the base of their populations with education beyond the high school level. As a result, rates of postsecondary degree conferral in these nations began increasing in the 1970s and accelerated further in the 1990s in the scientific and technical fields.

Within science and engineering (S&E), the fields of natural sciences and engineering (NS&E) command special attention because of their importance to the conduct of much of the nation's R&D and to the development of industrial innovation. Other countries are building up the NS&E capabilities of their younger cohorts at a greater rate than the United States has been able to achieve. They have been able to raise—by large increments—the rate at which their college-age youth earn first university NS&E degrees. By contrast, in the United States, this rate has fluctuated between 4 and 5 percent of the Nation's 24-year olds for the past four decades and barely reached 6 percent in the late 1990s. (See figure O-4.)

Combining these trends—an emphasis on international mobility of highly educated personnel, continued support for broader access to higher education, and an emphasis on NS&E training—with a shift to more market-driven economies, liberalized investment and labor markets, may lead to the development of new world-class centers of excellence around the globe. In pursuit of this goal, governments are adopting specific policies to imitate and improve on aspects of others' S&T systems and practices.[1]

[1]See, for example, European Commission, *Towards a European Research Area* (2000).

Overview Figure 4.
Ratio of natural science and engineering first university degrees awarded to 24-year-old population, by country/economy



NOTES: Natural sciences include physics, chemistry, astronomy, earth, atmospheric, ocean, biological, agricultural, as well as mathematics and computer sciences. The ratio is the number of natural science and engineering degrees to the 24-year-old population. China's data are for 1985 and 1999. Other countries' data are for 1975 and 1998 or 1999.

See appendix table 2-18. *Science & Engineering Indicators – 2002*

Although these developments appear to pose little short-term challenge for the United States, they may be important in the long term:

- The United States may face increased international competition for highly educated personnel. Furthermore, its relative attractiveness may erode as living standards rise in developing countries and as other industrialized nations intensify their international recruitment efforts.
- U.S. preeminence in S&T may erode as competing centers of excellence are established elsewhere. Foreign graduates may find returning home more attractive than staying in the United States after their training, and industry may locate increasingly sophisticated functions overseas.

Both developments have technology transfer implications for the United States.

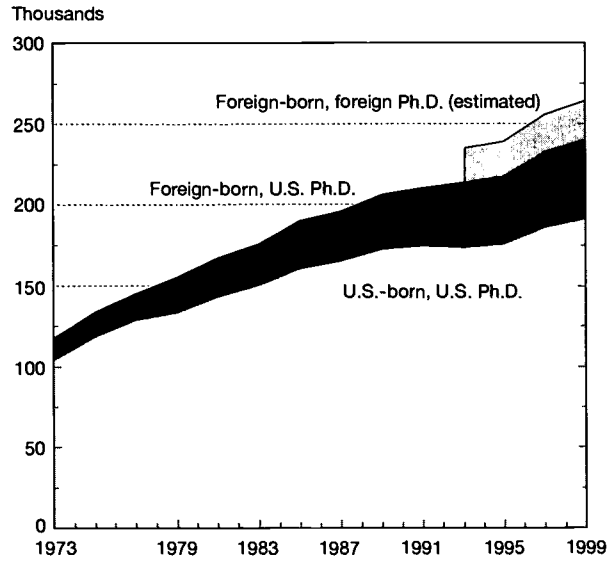
U.S. Reliance on Foreign-Born Scientists and Engineers

The United States has long relied heavily on scientists and engineers who were born abroad, and increasingly so in the closing years of the 20th century. Many of them earned their highest degrees in the U.S., others entered the country with degrees earned abroad. This reliance rises the more advanced the degree. In the United States in 1999, 10 percent of those holding baccalaureate degrees in S&E were born abroad. This figure was 20 percent for master's degree recipients and 25 percent or greater for doctorate-holders (much higher in some engineering and computer science fields). These estimates are conservative in that they fail to reflect the strong upswing in immigration during the 1990s, those who entered the United States on temporary visas during the 1990s, and those in health-related fields. (See figure O-5 for academic employment.)

If other countries and regions build up their indigenous S&T capabilities, they may diminish the relative attractiveness of the United States as a destination country. Although such a decline would be difficult to quantify, anecdotes suggest that experienced scientists and engineers, particularly those originally from Asia, are even now returning to their native countries. They may be drawn not only by the potential to gain wealth and prestige but also by the desire to contribute to the economic development of their home countries. On the other hand, more than half of the younger foreign students who have earned S&E doctorates in the United States stay in the U.S., and this trend has changed little over time.

As more countries seek to develop a knowledge-based economy, demographic factors will come into play. For many advanced industrial nations, this means aging—and, in the case of Japan and Germany, declining—populations and shrinking pools of young people. In fact, a broad international dialog[2] has begun to focus on the reality of and potential for broader international mobility of scientists, engineers, and other highly trained technical workers. If other countries begin looking abroad to supplement their labor pools, particularly in high-technology areas, the United States may have more difficulty attracting and retaining foreign scientists and engineers.

Overview Figure 5.
Academic employment of native and foreign-born doctoral scientists and engineers: 1973–99



NOTE: Data on foreign-born foreign-earned Ph.D.s unavailable before 1993.

See text table 5-6. *Science & Engineering Indicators – 2002*

Actions by countries that have supplied personnel ("donor" countries) form the other part of this development. If they can build indigenous S&T infrastructures and economies to exploit the fruits of S&T, domestic labor market needs may entice more of their scientists and engineers to stay at home rather than to seek work abroad. They may also attract investments from foreign firms seeking access to their labor and markets. Thus, traditional donor countries may be able to moderate the outflow of their scientists and engineers.

The large unknown factor is the action of multinational firms as they expand their role in international business activities. Many of these firms maintain R&D, technical, and design centers worldwide, drawing on local strengths but also allowing highly trained personnel to rotate to other parts of the world. These activities mean that technological know-how is being transferred around the globe and will become part of other nations' economic development strategies. The inevitable transfer of technological know-how and the possible relocation of high-end activities from the United States (and other mature industrial nations) to newer centers of excellence bear watching.

Growing global competition for experts may be the eventual result of improved living standards in countries around the world; the rise of competing international centers of scientific, technical, and engineering excellence; and the need of many industrialized nations to augment their own techni-

[2]In such forums as the Organisation for Economic Co-operation and Development (OECD), the European Union, and a broad range of national discussions.

cal labor pools from abroad. Increasingly, industry may need to locate near a generous supply of highly trained, reasonably priced personnel. Information technology (IT) developments may further enhance the ability to tie together globally distributed laboratories and firms.

In this situation, one challenge for the United States would seem to be to provide a well-trained domestic S&T workforce. Gordon Moore, cofounder of Fairchild Semiconductor and the Intel Corporation, commented in the *New York Times* (2001): "[W]e're in danger of exporting a lot of technological advantage because we're not training enough people here. Education, that's our Achilles' heel." Several factors affect a possible expansion in the number of S&E degrees earned by U.S. citizens.

U.S. Elementary and Secondary Education: International Perspective

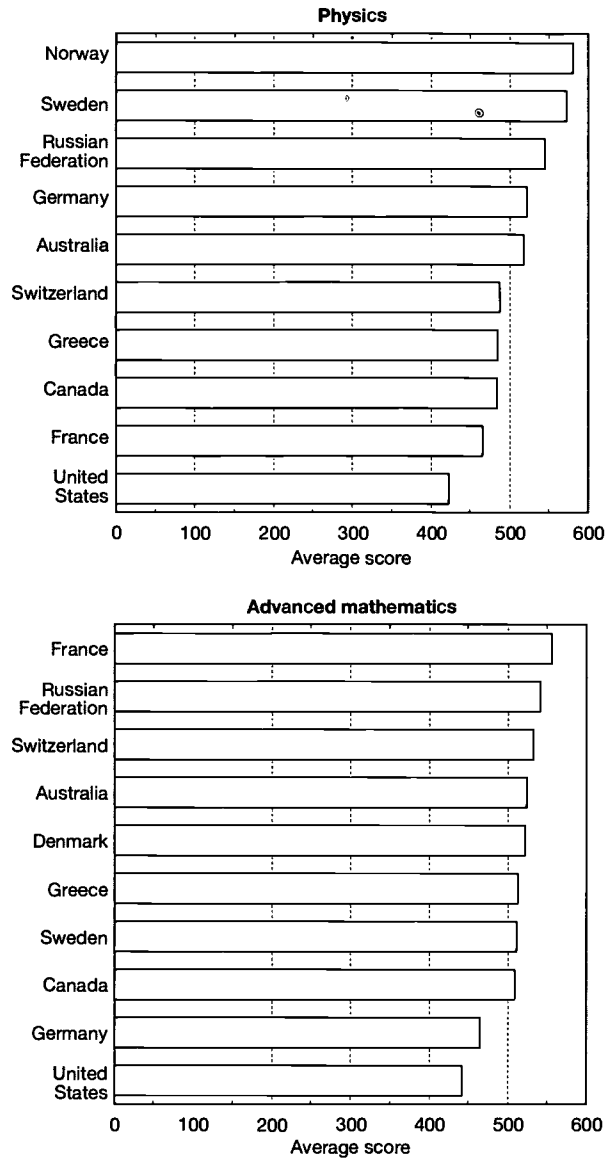
How can the United States produce more high-quality homegrown scientists and engineers? The question leads one to focus on the U.S. elementary and secondary education system. Long-standing concerns about the overall quality of the system, and of mathematics and science education in particular, have prompted various reform efforts predating the 1983 report, *A Nation At Risk*. In international comparisons, these reforms have yet to fully demonstrate their intended results.

U.S. students in the early grades tend to do well in cross-national comparisons of mathematics and science achievement. However, toward the end of high school, U.S. students tend to fall below international averages and to rank substantially below students in a number of other countries. (See figure O-6.) In some advanced subjects, such as advanced calculus, performance by the top 5 percent of U.S. students is matched by the top 10–20 percent of students in several other countries.

Universal education in the United States does not appear to account for the discrepancy in international test performance. Many countries have raised their age cohort rates of producing natural scientists and engineers to levels exceeding those of the United States. A prerequisite for this development is quality mathematics and science education in the primary and secondary grades, which is being provided by many countries, according to international test results.

In the United States, the transition from high school to college presents another puzzle. State mandates emphasizing academics have expanded, and more mathematics and science courses are required for graduation. Yet, as more students have taken these courses, including advanced ones, the need for remedial instruction at the college level has continued to expand. A number of universities have begun to limit credits given for advanced-placement courses, considering some of them to fail to meet college-level standards.

Overview Figure 6.
Performance of students in last year of high school: 1994–95



NOTE: U.S. score in physics is significantly lower than all other countries listed, and lower than all but Germany for advanced mathematics.

SOURCE: Mullis, I., et al., 1998. Mathematics and Science Achievement in the Final Year of Secondary School. Boston, MA, Boston College, TIMSS International Study Center.

Science & Engineering Indicators – 2002

U.S. Higher Education

The U.S. higher education system has continually produced a growing number of people with bachelor's, master's, and doctoral degrees. In the past quarter century, the number of bachelor's degrees conferred in all fields has risen from 955,000 to nearly 1.2 million annually; master's degrees, from 278,000 to 420,000; and doctorates, from 33,800 to 45,700. In the 1990s, about 35 percent of the bachelor's degrees, 30

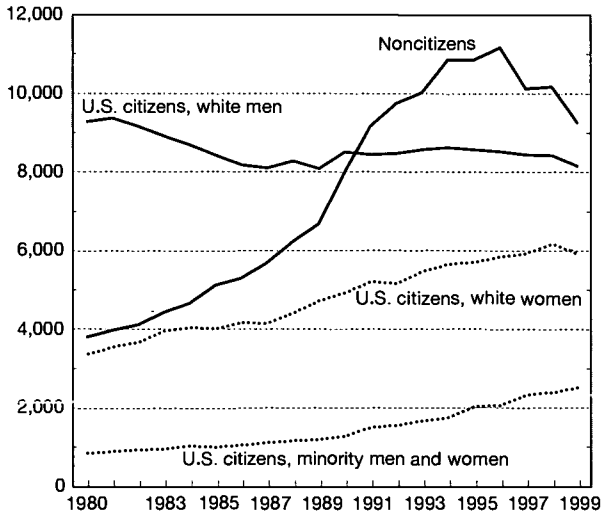
percent of the master's degrees, and more than 60 percent of the doctorates were awarded in S&E fields.

The number of doctorates awarded in S&E rose rapidly after the mid-1980s, but little growth was seen in the number of doctorates awarded to U.S. citizens. The increase from 20,000 in 1986 to almost 29,000 in 1998 (followed by a dip to 27,000 in 1999) mostly reflected the growing number of degrees awarded to foreign-born individuals. This trend was especially pronounced in the natural sciences and engineering, where the share of doctorates earned by U.S. citizens (including naturalized citizens) dropped from 70 to 56 percent over the past 25 years. For all of S&E, including the social sciences and psychology, the U.S. share fell from 74 to 61 percent.

Virtually all growth of doctorates earned by U.S. citizens reflected degrees earned by white women and minority students of both sexes. (See figure O-7.) A particularly compelling example is offered by the increase in S&E doctorate-holders who were U.S. citizens, from 14,200 in the mid-1970s to 16,700 in 1999. The entire increase is attributable to the rise in the number of women and minorities earning S&E doctorates; the number of U.S. men obtaining these degrees actually declined from about 12,000 in the mid-1970s to 9,700 late in the century. In 1999, women earned 42 percent of these U.S. citizen S&E doctorates, up from 18 percent 25 years earlier; minorities earned 15 percent, up from less than 5 percent. The percentages for U.S. citizen doctorates in the narrower category of natural sciences and engineering (i.e., without social sciences and psychology) show similar trends.

In short, at the highest level of S&E training, the United States has relied heavily on noncitizens, U.S. women, and small but growing numbers of minority students of both sexes to sustain its degree production without whose increasing participation the number of S&E doctorates would have stagnated or declined. The reasons for the relative disappearance of U.S. majority males from these fields, including lack of interest and the attractiveness and availability of alternatives, remain largely unexplored.

Overview Figure 7.
S&E doctorates earned by U.S. citizens and noncitizens: 1980–99



SOURCE: NSF/SRS, Survey of Earned Doctorates.

Science & Engineering Indicators – 2002

Status of U.S. S&E Workforce

In the late 1990s, the active U.S. S&E workforce numbered about 11 million out of a civilian labor force of about 140 million. It included 10.5 million people with a bachelor's or higher degree in S&E and 600,000 people with degrees in other fields but working in an S&E occupation, narrowly defined.[3] The relatively small size of the S&E workforce so defined, about 8 percent of the total, belies its importance to a knowledge-based economy. Scientists and engineers are essential to the conduct of R&D, and they contribute heavily to technological innovation and the economic growth it generates.

Industry, the largest job source for scientists and engineers, employs 75 percent of those with S&E bachelor's degrees, more than 60 percent of master's degree holders, but less than one-third of those with doctorates. Overall, the academic sector has been the second largest employer of scientists and engineers but the largest employer of S&E doctorate-holders. The Federal Government attracted only 4–5 percent of bachelor's and master's degree recipients, with engineering graduates more likely than science graduates to find Federal employment.

In 1999, only about 3.3 million of the 11 million S&E labor force worked in the core S&E occupations defined here, less than 3 percent of total civilian employment. Almost three-quarters of those 3.3 million had jobs as engineers (39 percent) and computer scientists and mathematicians (33 percent). Although most S&E degree-holders work in non-S&E occupations, the interpretation that these highly trained individuals are not using their special skills is incorrect.

Technologically oriented economies increasingly rely on scientific and technical skills in a broad range of occupations, in high-technology sectors and elsewhere. Many S&E-trained individuals are being hired into occupations classified as non-S&E in both high-technology industries and other segments of the economy, where they contribute to converting the results of R&D into innovative products, processes, and services. These employment patterns indicate the spread of jobs across the economy that are filled by those with scientific or technical skills.

What are these jobs? Most jobs in non-S&E occupations are in management or administration, in sales or marketing, and various teaching positions. At the baccalaureate level, one-third of engineering graduates, half of the computer science and mathematics graduates, and most of the life science, social science, and psychology graduates work in such non-S&E occupations. However, 9 out of 10 regarded their training as related

[3]S&E occupations include those classified as engineers and as computer and mathematical, life, physical, and social scientists. This is a narrow definition which excludes scientists and engineers teaching high school, working as managers, and the like.

to the nature of their jobs, and in the judgment of the incumbents, many of these jobs had some S&E skill component.

Over the past two decades, the number of people in S&E occupations has expanded faster than the growth of the overall civilian U.S. labor force, and the Bureau of Labor Statistics predicts continued rapid growth in these occupations. (See figure O-8.). Current incumbents engaged in these occupations tend to have more advanced degrees than those in non-S&E jobs: 14 percent of incumbents held a science or engineering doctorate versus 3 percent of those in non-S&E jobs, 29 percent held a master's degree versus 15 percent of those in non-S&E jobs, and 56 percent held a bachelor's degree versus 80 percent of those in non-S&E jobs. Thus, further expansion of the employment share in S&E occupations rests on the availability of a sufficient number of people with the requisite degrees, especially because of the expected rise in the number of retiring scientists and engineers.

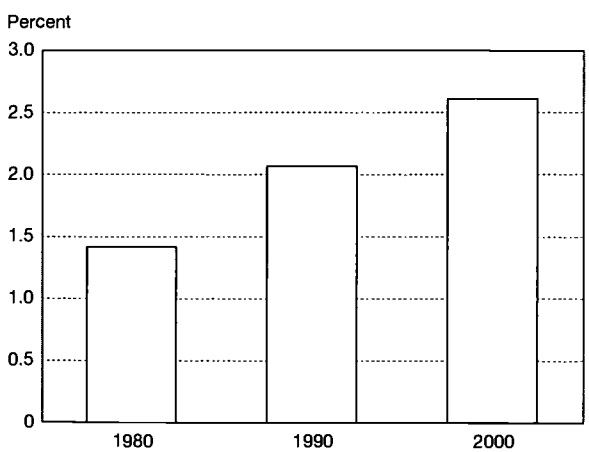
Foreign-Born Scientists and Engineers in the U.S. Workforce

The United States has benefited from the infusion of non-U.S. scientists and engineers for many years and in many areas, including access to valuable skills and a greater ability to exploit the development of new knowledge abroad. U.S. industry has also increasingly relied on R&D performed abroad and, in turn, has benefited from economic growth around the world. However, the country's international economic competitiveness ultimately rests on the capacity of its own labor force for innovation and productivity.

The percentage of foreign-born individuals among U.S. scientists and engineers is growing at all degree levels, in all sectors, and in most fields. By the end of the decade, one in four S&E doctorate-holders had been born abroad. Especially high percentages were found in engineering (45 percent), computer sciences (43 percent), and mathematics (30 percent), fields that have shown little or no growth in domestic Ph.D. production.

Figures for industry employment of foreign-born Ph.D.-holders were higher than these national averages. (See figure O-9.) At the end of the twentieth century, one-third of all S&E Ph.D.-holders working in industry were born abroad. Among computer scientists, the proportion was half, and among engineers it was more than half, with specific engineering specialties showing higher percentages. In mathematics, the share of foreign-born individuals exceeded one-third.

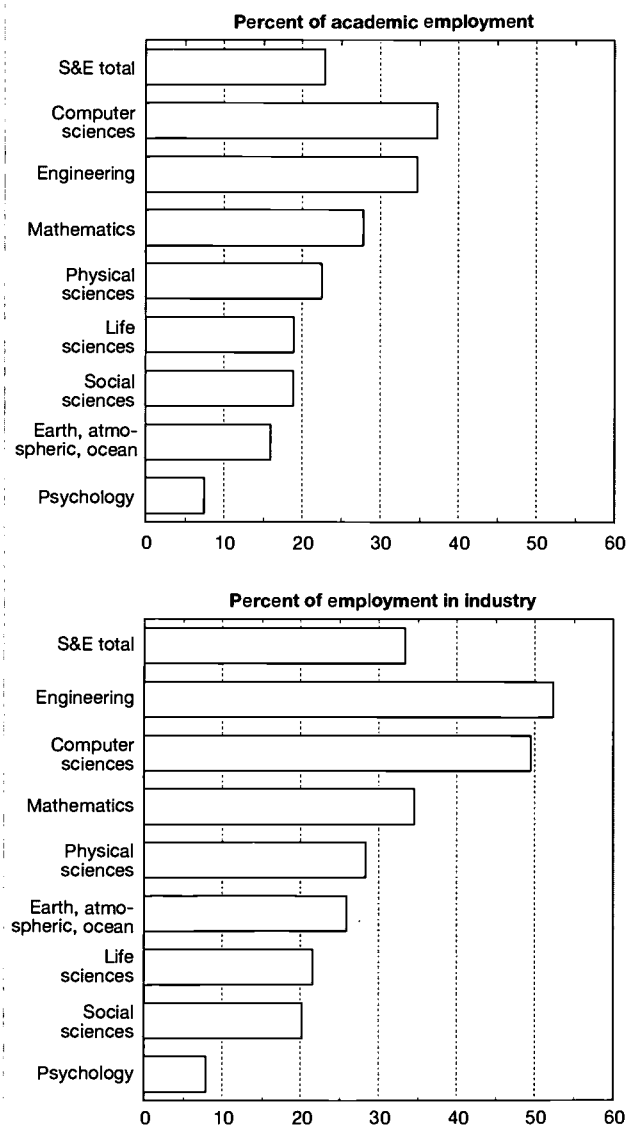
Overview Figure 8.
Employment in S&E occupations as percentage of total civilian employment



SOURCE: U.S. Bureau of the Census, Public Use Micro Data Sample (1980, 1990); Current Population Survey (2000).

Science & Engineering Indicators – 2002

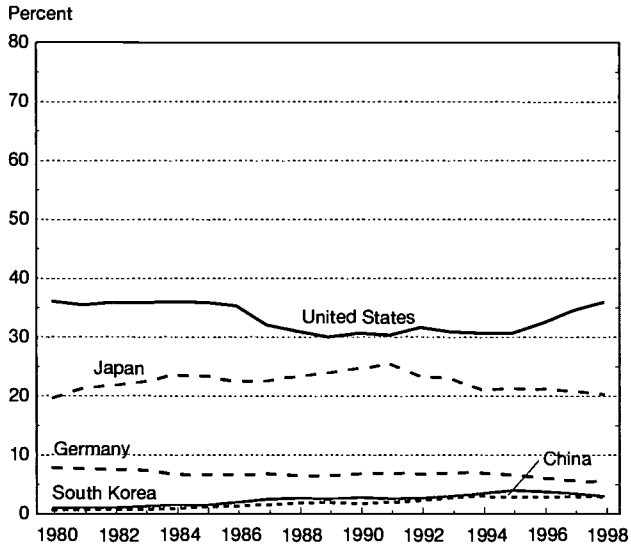
Overview Figure 9.
Employment of foreign-born scientists and engineers with U.S. Ph.Ds: 1999



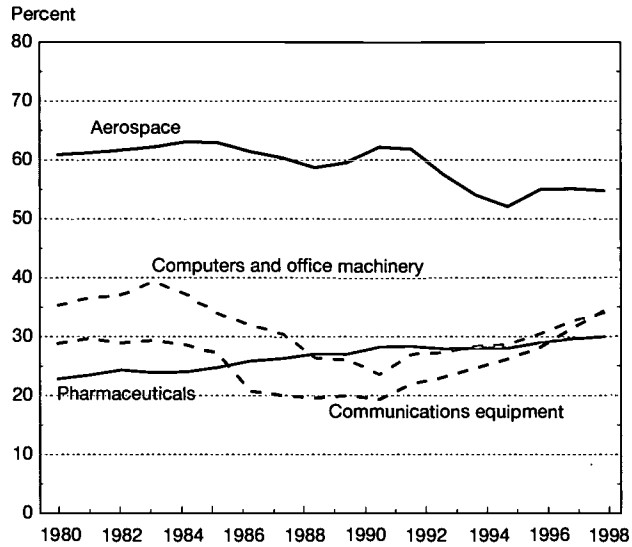
SOURCE: NSF/SRS, Survey of Doctorate Recipients.

Science & Engineering Indicators – 2002

Overview Figure 10.
Country share of global high-tech market: 1980–98



U.S. global market share, by high-tech industry: 1980–98



See appendix table 6-1.

Science & Engineering Indicators – 2002

Increases in the share of foreign-born Ph.D.-holders in academia have been less rapid but have generally occurred in the same fields as in industry. Among full-time faculty, foreign-born individuals with U.S. degrees since the 1970s have increased from 36 to nearly 40 percent in computer sciences, 21 to 35 percent in engineering, and 16 to 28 percent in mathematics. In the Federal Government in 1999, 16 percent of Ph.D.-holders were born abroad; the share of those in state and local government employment was 19 percent.

Census data show similar trends for bachelor's degree holders. In 1980, 11 percent of all baccalaureate recipients in the United States were born abroad. This percentage had risen to 13 percent in 1990 and to 19 percent in 2000. Field information is not available for the 2000 data, but analysis of a sample based on the 1990 census shows patterns of field concentration among bachelor's degree recipients similar to those of Ph.D.-holders, although at lower levels.

Indicators of U.S. Competitiveness

High-technology industries are important to national economies because they produce a large share of innovations, including new products, processes, and services that help gain market share, create entirely new markets, or lead to more productive use of resources. High-technology industries are also associated with high value-added production, success in foreign markets, and high compensation levels. Results of their activities diffuse to other economic sectors, leading to increased productivity and business expansion. The international competitiveness of their products and processes thus provides a useful market-based measure of the performance of a nation's S&T system.

Many decades of support for basic research have provided the basis for past and current innovations that generate economic benefits. During the 1990s, the United States maintained and improved its position in the exploitation of new knowledge, techniques, and technologies for economic advantage. By the end of the century, the United States remained the leading producer of high-technology[4] products, providing more than one-third of the world's output. (See figure O-10.) U.S.-based pharmaceuticals, computer, and communications equipment industries gained in world market share over the decade; only the aerospace industry lost market share. The nation's high-technology trade balance was positive throughout the decade, increasing during the second half.

The world's total manufacturing output has been rising during the past two decades, and the share of high-technology industry products in that output has increased. Worldwide, high-technology manufacturing rose from 7.6 percent of total manufacturing output in 1980 to 12.7 percent by 1998. The high-technology share of U.S. manufacturing output increased from 9.6 to 16.6 percent during the period, and the United Kingdom experienced similar growth. The high-technology output shares of other European Union members also increased but stayed at lower levels: 11.0 percent for France and 9.0 percent for Germany. In Asia, the high-technology sectors in the Taiwanese and South Korean economies grew especially rapidly, to 25.6 and 15.0 percent, respectively, of their 1998 manufacturing output.

These changes in the 1990s led to shifts in countries' world market shares for high-technology products. The U.S. share increase from about 30 to 36 percent, contrasted with declines

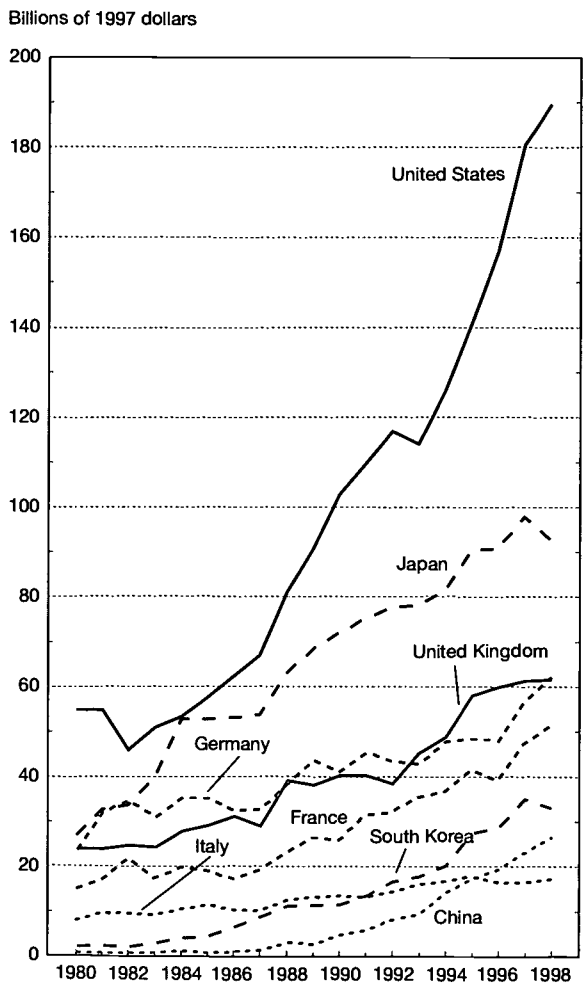
[4]Identified by OECD based on their high R&D intensities in 10 OECD member countries; the high-technology industries include aerospace, computers and office machinery, electronics and communication, and pharmaceuticals.

for the other large economies. Japan's share declined from nearly 25 to 20 percent, and Germany's declined from 6.4 to 5.4 percent; that of the United Kingdom declined from 6.0 to 5.4 percent, and France's declined from 5.3 to 3.9 percent. Some Asian countries increased their market share; South Korea and Taiwan had the largest gains at more than 3 percent each in 1998.[5] (See figure O-11.)

The U.S. world export share in high-technology products, 20 percent in 1998, was nearly twice its world share for all manufacturing exports. It compared with 10 percent for Japan and 7 percent for Germany. World export shares have risen for some Asian economies. For example, Taiwan and Singapore held 5 and 6 percent of high-technology export markets in 1998, up from about 4 percent a decade earlier. Although the United States remains the export leader in three of the four high-technology industries (it is second in drugs and medicines), its lead has been shrinking in all but communications equipment.

[5]Chinese data appear to indicate rapid growth as well but are not sufficiently comparable to permit a quantitative comparison.

Overview Figure 11.
High-tech exports: 1980–98



See appendix table 6-1. *Science & Engineering Indicators – 2002*

Another indicator of competitiveness in a world of increasingly open markets is the ability to succeed in the home market. The U.S. supply of its own high-technology markets had dropped to around two-thirds by the mid-1990s but reached three-quarters by the decade's end.

The United States has also been successful in exploiting its edge in knowledge-intensive services, namely in communication, financial, business, education, and health services. These industry segments have grown even faster than the already fast-growing U.S. high-technology manufacturing sector.

Patenting as an Indicator of Inventive Activity

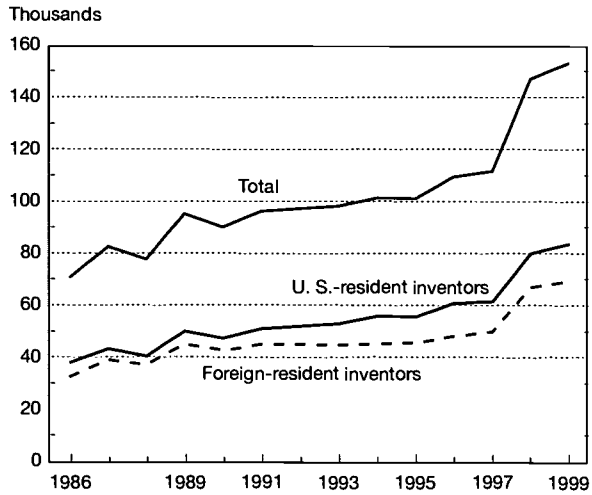
Technical inventions have important economic benefits to a nation because they often lead to innovations—new products, processes, services, and even entirely new industries. To foster inventiveness, governments assign property rights to inventors in the form of patents. Patent data thus provide useful indicators of inventive output over time.

Patent grants in the United States rose strongly during the 1990s, reaching 154,000 in 1999. More than half of these patents have been issued to U.S. inventors, 55 percent in 1999. Areas of U.S. technological strength, as reflected in these patents, include medical and surgical devices, electronics, telecommunications, advanced materials, and biotechnology. U.S. inventors are also successful in patenting abroad. They lead foreign inventors in most other major countries, where foreign patenting is generally much more prevalent than in the United States.

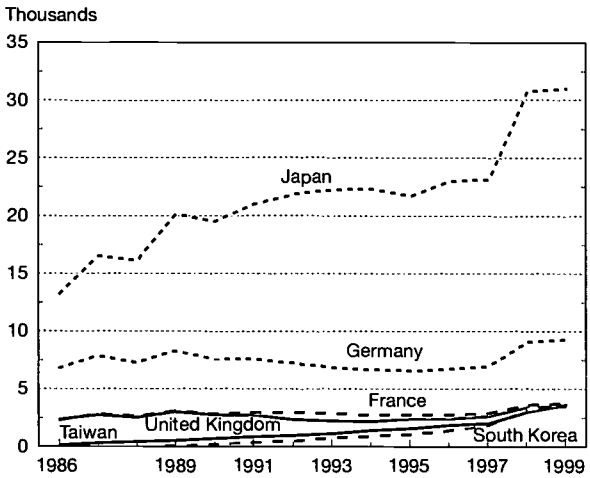
Foreign patenting in the United States is highly concentrated by country and field of application. (See figure O-12.) German and Japanese inventors received almost 60 percent of all foreign-owned U.S. patents in 1999; together with France and the United Kingdom, they accounted for 70 percent. Canada, historically among the top five foreign countries patenting in the United States, was displaced in 1998 by South Korea and Taiwan, whose U.S. patenting has increased dramatically. Before 1986, Taiwan received 742 U.S. patents, and South Korea received 213. Since then, they have received nearly 19,000 and more than 14,000 patents, respectively, indicating their growing capacity to produce technological innovations.

The distribution of foreign patent activity in the United States by technical area is an indicator of countries' technical strengths, which may signal a future competitive advantage. Relatively few technologies form the focus of other countries' patenting in the United States. Japanese inventors emphasize consumer electronics, photography, photocopying, and, more recently, computer technologies. German inventors tend to focus on heavy-manufacturing industries. British inventors focus on manufacturing applications, biotechnology, and chemistry. French-owned patents emphasize manufacturing applications, biotechnology, aeronautics, and communications technologies. South Korean patent activities focus on communications and computer technologies, which were also a focus of Taiwan during the 1990s. Both nations

Overview Figure 12.
U.S. patents granted, by nationality of inventor: 1986–99



U.S. patents granted to foreign inventors, by nationality of inventor: 1986–99



NOTE: Selected economies are the top six recipients of U.S. patents during 1998.

See appendix table 6-12. *Science & Engineering Indicators – 2002*

are major suppliers of U.S. computers and peripherals, and their patenting activity suggests further growth in their international competitive position in these and related areas.

The United States derives major benefits from intellectual property, including licensing fees from patents, a $23 billion surplus in 1999. (See figure O-13.) Firms trade intellectual property when they license or franchise proprietary technologies, trademarks, and entertainment to firms in other countries. Royalties and licensing fees generated by these transactions from abroad in recent years have averaged nearly three times the amount paid out by American firms for the use of foreign intellectual property.

By far, the largest purchaser of United States intellectual property was Japan, followed by South Korea; together they accounted for 44 percent of total U.S. receipts in 1999. U.S. firms purchase intellectual property chiefly from Europe, which accounted for about 44 percent of U.S. payments in 1999. However, Japan, the largest single supplier, accounted for one-third of the total.

The flows of intellectual property, traced here by funds flows, are indicative of the growing interdependency of countries' scientific and technical activities. Far from being simple supplier-customer relations, these flows indicate mutual benefits accruing from these exchanges. The participants also derive large indirect benefits that are not captured in these financial transactions.

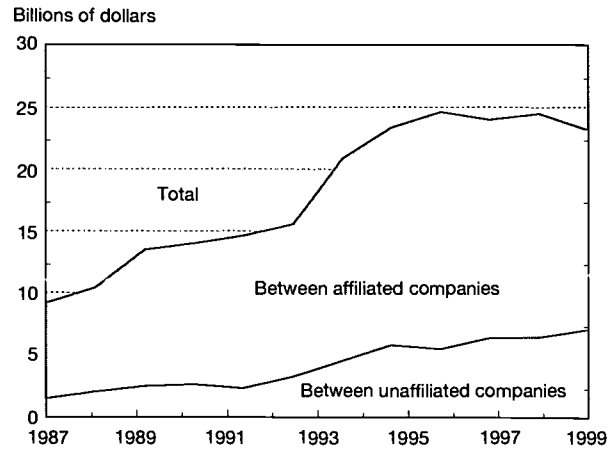
Venture Capital Funding and Seed Money

Small firms are widely viewed as important contributors to the nation's innovative activity and technological prowess. They benefit from the availability of capital from venture groups that often also supply technological and management know-how in exchange for an equity share. Venture capital flows serve as a useful indicator of the market's assessment of concrete entrepreneurial activity, even though they do not capture other forms of financing available to nascent firms, such as direct funding by larger firms, creation of spinoffs, and "angel" money.

The total pool of U.S. venture capital grew dramatically over the past two decades, reaching $234 billion in 2000, more than six times the amount managed just five years earlier. New venture funds committed in 2000 reached $93 billion, nearly 10 times the 1995 amount[6]. (See figure O-14.) Three-quarters of the new funds went to three types of firms: Internet firms (nearly 50 percent), telecommunications companies (about 17 percent), and software or software services companies (14 percent).

[6]Preliminary data indicate a drastic decline in new venture capital disbursements in 2001.

Overview Figure 13.
U.S. trade balance of royalties and fees: 1987–99



See appendix table 6-6. *Science & Engineering Indicators – 2002*

Little venture capital is disbursed as "seed" money (high-risk funds to underwrite proof-of-concept activities or early product development). Seed funding never exceeded 6 percent of total venture capital disbursements in the past two decades and, more typically, ranged from 2 to 4 percent. In 2000, seed money accounted for less than 2 percent of new commitments, and money for company expansion, a much less risky stage, accounted for more than 60 percent. Still, nearly $1.3 billion was disbursed as seed money in 2000, up from $313 million in 1995. Internet companies received 44 percent of the new seed funds in 2000, communications firms received 26 percent, and software companies received 11 percent. The share of seed funds that went to biotechnology firms dropped precipitously, from 12 percent in 1998 to less than 1 percent in 2000, and that of other medical- and health-related companies dropped from 20 to 3 percent.

U.S. Industrial R&D: Manufacturing and Service Sectors

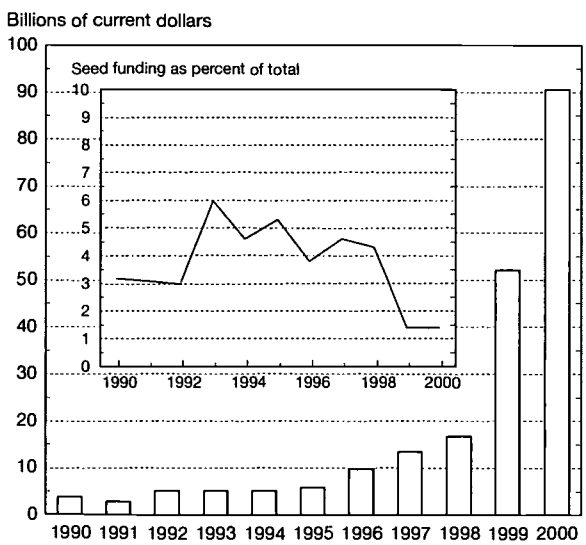
Since the early 1980s, R&D spending in the United States has consistently accounted for 2.3–2.8 percent of the gross domestic product (GDP). In the latter half of the 1990s, R&D growth has been particularly strong, rising faster than total economic output and reaching a 2.7 percent share of GDP, pushed upward primarily by a rise in industry-funded R&D. Several major trends have affected funders, performers, and the nature of R&D in the United States over the past two decades, indicating major changes in the structure of the nation's S&T enterprise.

The Federal Government has supplied a continually shrinking share of national R&D funds, just above one-quarter in 2000. (See figure O-15.) This trend began in the early 1960s, with the Federal share falling below 50 percent in 1979 and declining more steeply during the 1990s. After adjusting for inflation, Federal R&D funding has actually declined since the second half of the 1980s and was essentially flat during the past decade.

Federal defense-related R&D declined sharply in current and constant dollars, starting in 1987. By 2000, it had fallen to a 50-year low of 13.6 percent of total national R&D. Because defense-related R&D is mostly development, the basic research share of overall Federal R&D funding rose from 25 to about 35 percent, and development fell from 55 to 46 percent. However, at the total national level, shifts have been less pronounced, with the basic research share rising from 14 to 18 percent from 1980 to 2000 and development falling from 64 to 61 percent.

Partly as a result of the changes in Federal R&D support, the distribution of Federal funds across research fields shifted during the 1990s toward the life sciences and away from the physical sciences and engineering. The share of Federal funds for basic and applied research in the physical sciences and engineering dropped from 38 to 32 percent, whereas the life sciences share, reflecting growth in medical sciences R&D, rose from 40 to 45 percent. Computer science funding registered more modest gains and obtained 4–5 percent of Federal funds in 2000. These changes have prompted scientific organizations, Federal agency heads, and members of Congress to express concern about the potential adverse consequences of a perceived lack of balance in Federal research support.

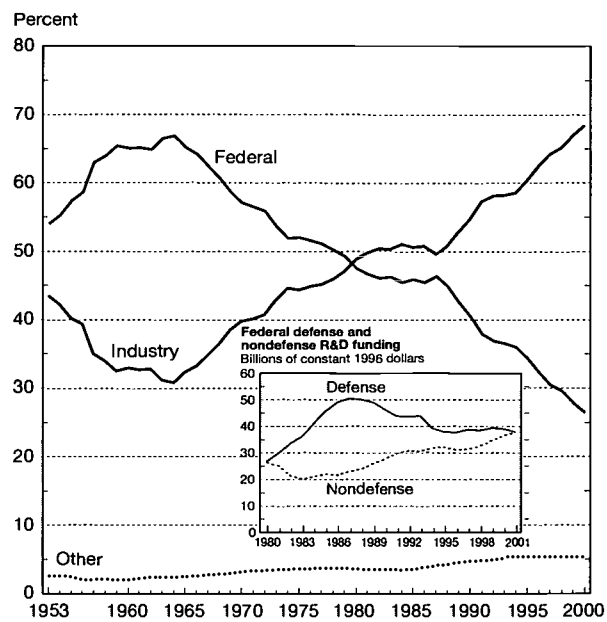
Overview Figure 14.
U.S. venture capital disbursement: 1990–2000



See appendix table 6-20.

Science & Engineering Indicators – 2002

Overview Figure 15.
National R&D expenditures, by source of funds: 1953–2000



See appendix tables 4-5 and 4-26.

Science & Engineering Indicators – 2002

Federal Government funds for industrial R&D contracted sharply between 1987 and 1993, a further consequence of the defense R&D cuts. In constant-dollar terms, Federal support for industrial R&D has fallen by about half since the late 1980s. The aerospace sector, traditionally the largest industry recipient of Federal R&D funds, still received about 40 percent of the shrinking Federal industrial R&D funds in 1999. However, the effects on the aerospace sector of the Federal shift away from defense-related R&D were clearly visible, because its share of total national R&D declined from about one-quarter in the late 1980s to 8 percent in 1999.

Industry funding of its own R&D has risen steeply since the mid-1990s and, by 2000, constituted nearly 70 percent of the national total. The expansion of industry funding for R&D in the manufacturing sector was driven especially by increases in sectors such as communications and electronic equipment,[7] motor vehicles, and chemicals (including pharmaceuticals and medicines); these were joined by the rapidly growing R&D investments of the nonmanufacturing sector.

A major development in the conduct of U.S. industrial R&D has been a two-decade-long rise in the importance of R&D in the nonmanufacturing sector, from less than 5 percent of the industrial R&D total in 1982 to 36 percent by the late 1990s. Three major segments[8] accounted for nearly 30 percent of the total industrial R&D performance: trade (10.7 percent); professional, scientific, and technical services (10.4 percent); and information (8.4 percent). Similar increases in service sector R&D are seen in many of the European Union economies, especially the United Kingdom, Italy, and France. Japan's industrial R&D performance remains largely confined to the manufacturing sector.

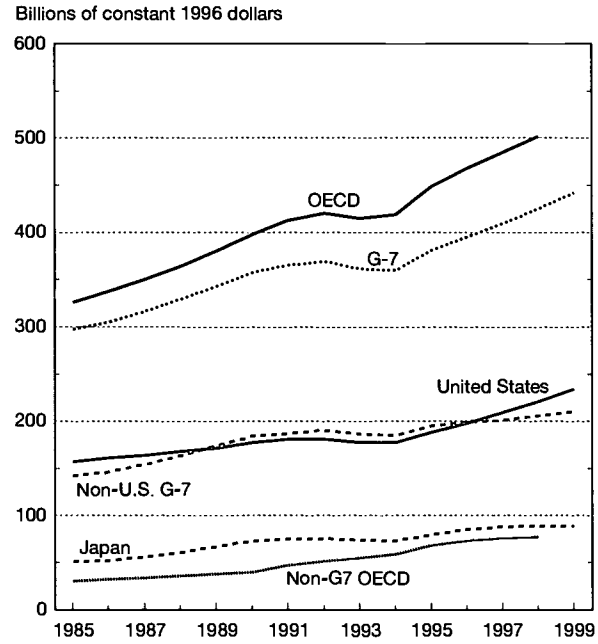
As measured by the ratio of R&D to net sales, scientific R&D services was the most research-intensive sector (32 percent), followed by software (17 percent), communications equipment (12 percent), and computer systems design and related services (11 percent).

Expanding R&D Activities Around the World

Heightened international attention to the economic advantages bestowed by the exploitation of new knowledge, processes, and products has led to increases in R&D spending around the world. This broad international expansion is reflected in a gradual decline of the U.S. share of total R&D performed by member countries of the Organisation for Economic Co-operation and Development (OECD).

Nevertheless, at 44 percent of the estimated $518 billion 1998 OECD total, the United States remains by far the largest single performer of R&D. (See figure O-16.) Its R&D expenditures equaled the combined total for Canada, France, Germany, United Kingdom, Italy, and Japan. By itself, Japan accounted for 20 percent, and the European Union accounted for 30 percent of the OECD total.

Overview Figure 16.
U.S., G-7, and OECD countries' R&D expenditures: 1985–99



OECD = Organisation for Economic Cooperation and Development

NOTE: Non-U.S. G-7 countries are Canada, France, Germany, Italy, Japan, and the United Kingdom.

See appendix table 4-40. *Science & Engineering Indicators – 2002*

The decline in the share of government funds for R&D is a key trend common to all major industrial nations and many other OECD countries.[9] In the mid-1980s, these nations derived an average of 45 percent of their R&D funds from government sources; by 1998, this figure had fallen to less than one-third. The relative retrenchment reflects the broad growth of industrial R&D, reductions in defense R&D in some key nations, and broader economic and spending constraints on governments. As a consequence, government funding for industrial R&D performance also fell, averaging 23 percent in 1983 but only 10 percent in 1998 for OECD as a whole.

Most OECD countries support their R&D activities with indirect assistance as well as direct funding. Tax credits for R&D expenditures are broadly granted and are often supplemented with specific additional incentives. Some countries use targeted approaches, such as favoring basic research. Some countries use tax provisions to stimulate R&D in small and medium-size firms. Increasingly, tax incentives are used to stimulate regional R&D.

OECD countries have some differences in sources of their R&D funds. Industry funded 67–70 percent of total R&D in Japan and the United States but less than 50 percent in the United Kingdom, Italy, and Canada. Government support ranged from 19 percent in Japan to 37 percent in France.

[7]The comparison is between 1988 and 1998 using the Standard Industrial Classification (SIC). Later data use the new National Industrial Classification System (NAICS) and are not comparable.

[8]Using the NAICS classification.

[9]OECD currently has 30 member countries.

Unlike the differences in funding sources, strong similarity in industry performance marks the largest OECD nations. In these countries, industry performed between 62 and 70 percent of total national R&D, with the exception of Italy, where industry performed 54 percent. The academic sector was the second largest performer in all countries except France, where government performance (including national laboratories) exceeded its volume.

OECD nations vary in the emphasis they put on research in various fields. The distributions of both R&D funds and articles in the world's leading research journals indicate that long-established differences exist in the relative field emphasis of these nations' scientific efforts. (See figure O-17.) Many countries appear to place relatively greater emphasis on the physical sciences and engineering than the United States; which has long put more weight on the life sciences, including medical research.

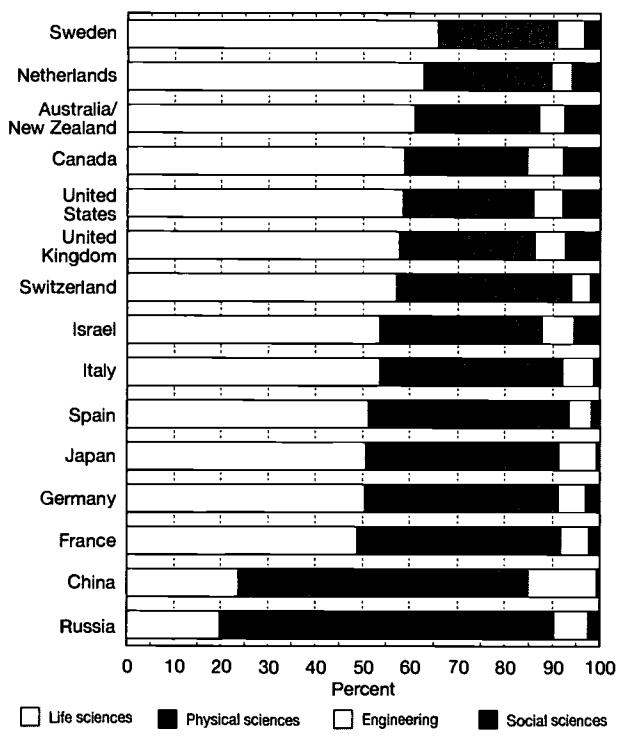
Growing International Conduct of Research

The expansion of R&D efforts in many countries is taking place against the backdrop of growing international collaboration in the conduct of R&D. The decline of global political blocs, expansion of convenient and inexpensive air travel, and advent of the Internet have facilitated scientific communication, contact, and collaboration. More R&D collaborations can be expected to develop with Internet-facilitated innovations such as virtual research laboratories and the simultaneous use of distributed virtual data banks by investigators around the globe.

Indications of this growing international activity can be drawn from the behavior of researchers, firms, and inventors. A rising share of the world's scientific and technical publications have coauthors who are located in different countries. U.S. investigators play a major part in these collaborations, and their coauthorship ties extend to a wider range of countries than those of scientists and engineers in any other nation. (See figure O-18.) Regional research collaborations are also growing stronger among European and Asian countries.

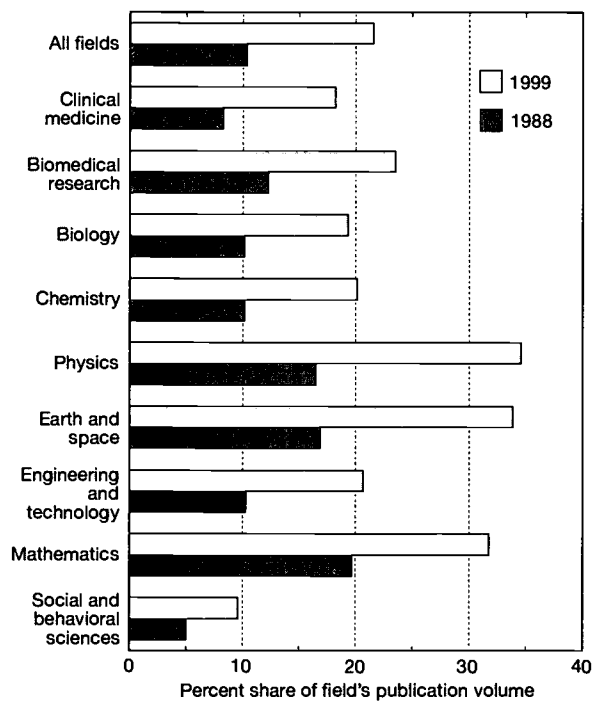
Greater global collaboration is not limited to the conduct of scientific research. In many countries, foreign sources of R&D funds have been increasing, underlining the growing internationalization of industry R&D efforts. In Canada and the United Kingdom, foreign funding has reached nearly 20 percent of total industrial R&D; it stands at nearly 10 percent for France, Italy, and the European Union as a whole. Foreign R&D funding remains low in Germany, however, and it is negligible in Japan.

Overview Figure 17.
Distribution of scientific and technical articles by field, by selected countries: 1999



See appendix table 5-43. *Science & Engineering Indicators – 2002*

Overview Figure 18.
U.S. international collaboration, by field



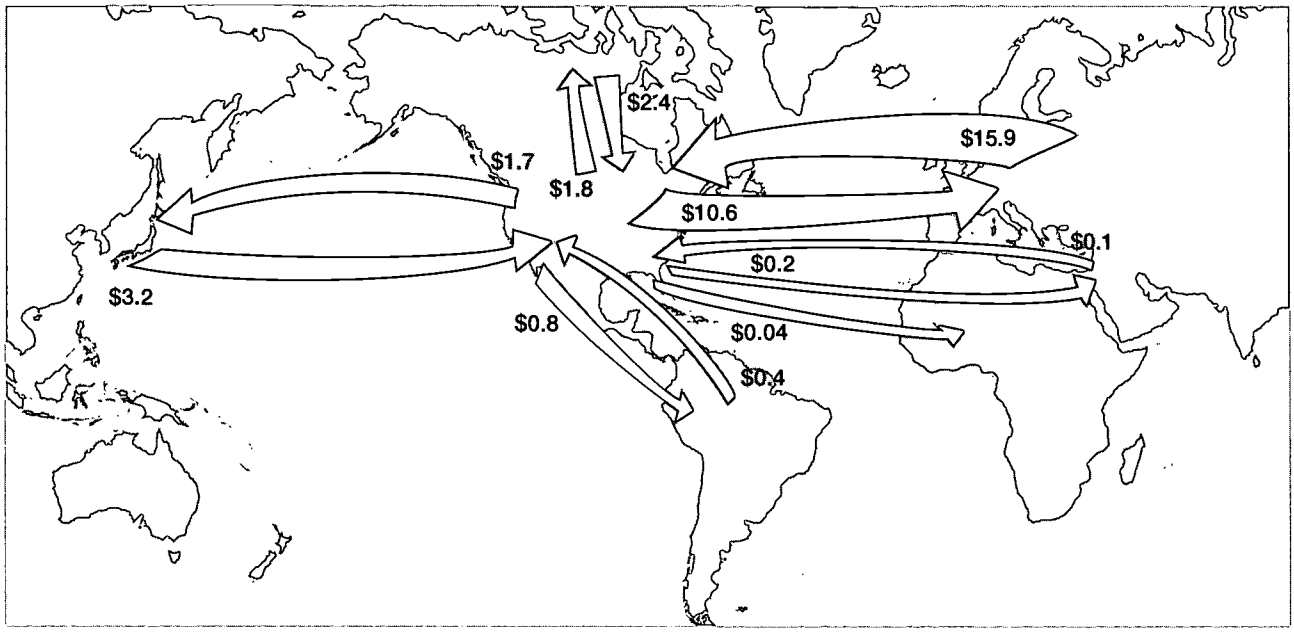
NOTES: Social and behavioral includes social sciences, psychology, health, and professional sciences. For coauthored papers, each collaborating institutional author is assigned an entire count.

SOURCES: Institute of Scientific Information; CHI Reseach, Inc., and NSF/SRS, special tabulations.

Science & Engineering Indicators – 2002

Overview Figure 19.
Industrial R&D spending flows of U.S. and foreign affiliates, by world region: 1998

Billions of dollars



See appendix tables 4-48 and 4-50.

Science & Engineering Indicators – 2002

The United States is attractive to foreign firms because of its technological sophistication and size of the market. R&D spending in the United States by foreign affiliates rose to a record $22 billion or 15 percent of company-funded R&D in 1998. U.S. affiliates of European companies (including Daimler-Chrysler) accounted for 72 percent of this total, the Asian/Pacific region for 14 percent (four-fifths Japan), and Canada for 11 percent. Foreign-owned subsidiaries of firms in particular countries tend to be concentrated in particular industries (e.g., computer and electronic products for Japan). Also in 1998, 715 R&D facilities were operated in the United States by 375 foreign-owned firms. Japan owned 35 percent of them; Germany and the United Kingdom each owned 14 percent.

U.S. firms are also investing in R&D conducted in other locations. R&D spending by U.S. companies abroad reached $17 billion in 1999, rising by 28 percent over a brief three-year span. (See figure O-19.) More than half this spending was in the areas of transportation equipment, chemicals (including pharmaceuticals), and computer and electronics products. Both inflows and outflows of foreign funds are dominated by manufacturing sector R&D. Relatively low levels of service sector R&D spending suggest a greater difficulty in exploiting nondomestic locations.

Globalization is also indicated by the strong growth of international patent families, which are patents filed in multiple countries covering the same invention. Their number has grown from 249 in 1990 to 1,379 in 1998. This development indicates the globalization of both markets and intellectual property. It also suggests increasing access to knowledge and know-how flows on a global scale.

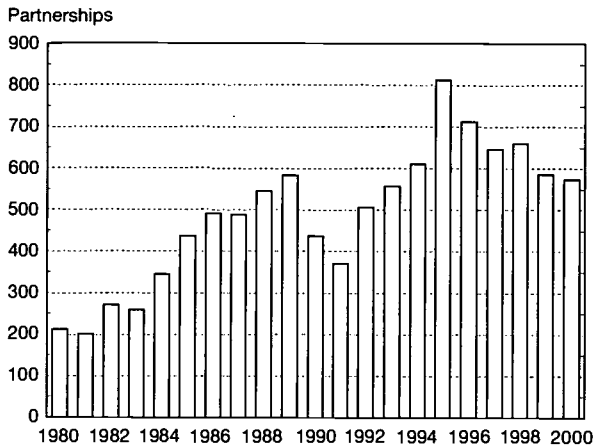
National and International Research Alliances

Changes in the financing, organization, and performance of R&D and technological innovation have affected the actions of industry, research performers, and governments in the United States and elsewhere. Key economic sectors have learned to exploit R&D advances rapidly, which has shortened product cycle times and increased market risk. The underlying research is increasingly multidisciplinary, requiring specialized knowledge from a broad range of fields. The development of new products, processes, and services often entails gaining access to firm-specific intellectual property and capabilities.

Firms and research performers have responded to these developments by outsourcing R&D and by forming collaborations and alliances to share R&D costs, spread market risk, and obtain access to needed information and know-how. Alliances, cross-licensing of intellectual property, mergers and acquisitions, and other tools have transformed industrial R&D and innovation. Universities have moved to increase funding links, technology transfer, and collaborative research activities with industry and government agencies. Government policies have supported these developments through changes in antitrust regulations, intellectual property regimens, and initiatives in support of technology transfer and joint activities.

The idea that efficient exploitation of new knowledge is fundamental to economic performance has become widely accepted, leading to policy and market changes in other in-

Overview Figure 20.
International strategic technology alliances: 1980–2000



NOTE: Data are annual counts of new international strategic technology alliances.

See appendix table 4-39.

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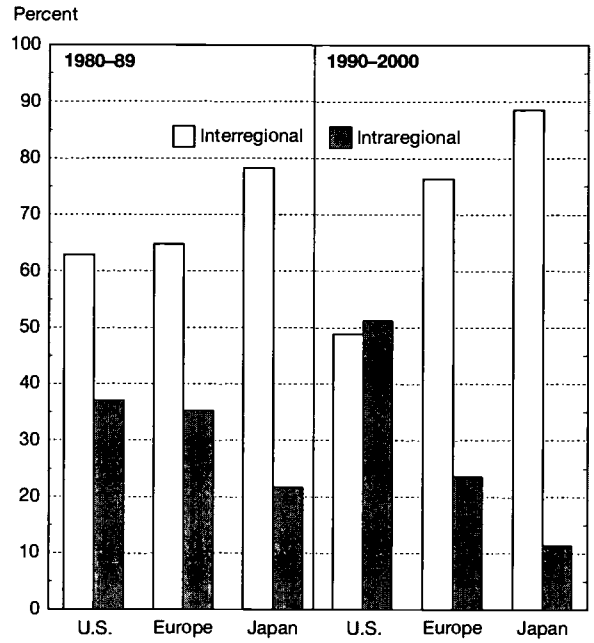
Overview Figure 21.
Shares of international strategic technology alliances: 1980–89 and 1990–2000



NOTE: Total alliances: 1980–89: U.S. = 2,445; Europe = 1,904; Japan = 1,073. 1990–2000: U.S. = 5,187; Europe = 2,784; Japan = 910.

See appendix table 4-39.

Science & Engineering Indicators – 2002

dustrial nations. In response, numerous strategic research and technology alliances have been created over the past two decades, many involving international partners.[10] During the 1980s, at least 3,800 such alliances were created; from 1990 to 2000, the number rose to nearly 6,500. (See figure O-20.) Alliances between U.S. and foreign firms increased by about 1,000 between the two decades. In 2000, about one-third each were in IT, biotechnology, and other technology sectors.

In the United States, about 800 formal research joint ventures were formally registered[11] between 1985 and 1999. They involved about 4,200 organizations, nearly 90 percent of them industrial firms. Thirty percent were foreign-owned participants, indicating broad interest in this form of activity.

Universities were important partners in these research joint ventures. During the 1985–99 period, they participated in 16 percent of them. Nearly one-third in the electronic and other electrical equipment sector involved academic partners, as did one in five industrial machinery and computer manufacturing ventures.

During the past decade, U.S. firms' alliances split about evenly between arrangements involving only domestic partners and those involving at least one foreign organization. (See figure O-21.) This is a shift from the earlier decade, when nearly two-thirds of U.S. alliances involved foreign partners. This development largely reflects the increasing intracountry alliance structure in the IT sector. European and Japanese alliances in the 1990s were focused to a larger extent on partners outside their immediate region but showed the same tendency as the United States toward domestic and regional collaboration in the IT field.

Risks that may be associated with these new forms of collaboration include the unintended transfer of technology; cultural differences among industrial, academic, and government partners or international participants; and the potential for anticompetitive behavior. Questions have been raised about the effects of industry-university relations on the funding balance of S&E fields, the nature of academic research, the open availability of research results, and especially research tools. However, the increasing number of collaborations suggests that, at least to the participants, the benefits outweigh the risks.

Conclusion

The performance of the U.S. S&T system has drawn the attention of other countries, which widely regard U.S. system performance as a de facto international benchmark in assessing their own performance.[12] The United States has a strong infrastructure of knowledge and trained personnel, thanks to long-term Federal Government investments in R&D. The nation's universities and colleges educate large proportions of young people, many of whom graduate with degrees in science, mathematics, and engineering. Moreover, its aca-

[10]The Maastricht Economic Institute on Innovation and Technology compiles the database from published sources; the database includes alliances in IT, biotechnology, aerospace and defense, automotive, and nonbiotechnology chemicals.

[11]Pursuant to provisions of the National Cooperative Research Act, these research joint ventures were formally registered with the Department of Justice to protect participants from antitrust litigation.

[12]See European Commission, 2001. *Towards a European Research Area: Key Figures 2001.*

demic institutions conduct nearly half of the nation's basic research, provide world-class advanced training to young researchers, and have become key partners in knowledge transfer to industry.

Rising U.S. industrial R&D has produced a steady stream of innovations, including new products, processes, and services, that have spurred economic growth, contributed to increased productivity, and raised per capita income. New forms of R&D and technology alliances connect firms with universities, nonprofit organizations, and government. The very conduct of R&D has changed in response to market pressures and the capabilities created by the IT revolution.

Governments in many countries have responded to these developments. Convinced that strength in S&T translates into concrete economic advantage, they have invested in education, R&D, and technical development. Private firms, responding to market pressures, have also increased their R&D activities. These moves have resulted in the creation of new centers of scientific and technical activity in many parts of the world. As industry, governments, and universities have started exploiting the new opportunities created by these developments, R&D and knowledge transfers have increasingly acquired global dimensions. U.S. research scientists and U.S. firms have been active participants in these international R&D activities.

The net effect of these trends for economic development and open international knowledge flows is undoubtedly positive both for the United States and for other countries. Yet these developments also pose challenges. As new centers of technological excellence arise, firms and universities in the United States may find it increasingly difficult to recruit scientists and engineers from abroad, currently an important source of supply. Foreign students may increasingly return home after their training, and U.S. firms may find it advantageous to locate technically sophisticated functions overseas. These potential developments bear watching, because they would affect U.S. policies that support S&T and the education and training of the domestic S&E workforce.

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Chapter 1
Elementary and Secondary Education

Nationally representative data on teacher quality, professional development, and working conditions have been collected by the National Center for Education Statistics' (NCES) 1999-2000 Schools and Staffing Survey. They were not available in time for the preparation of this chapter. Following release of the dataset by NCES, analyses of these topics will be available at the following National Science Foundation website: <http://www.nsf.gov/sbe/srs/seind02/update.htm>.

Highlights

Mathematics and Science Achievement

♦ **Although mathematics and science achievement, as measured by the National Assessment of Educational Progress (NAEP), have improved since the 1970s, few students are attaining levels deemed Proficient or Advanced by a national panel of experts.** For example, only 17 percent of 12th-grade students scored at the proficient level on the NAEP mathematics assessment in 2000.

♦ **At each grade level, white and Asian/Pacific Islander students are far more likely than their black, Hispanic, and American Indian/Alaskan Native counterparts to score at or above the Basic, Proficient, and Advanced levels set by the National Assessment Governing Board (NAGB).** For example, although 33 percent of Asian/Pacific Islander and 20 percent of white 12th graders scored at the Proficient level in 2000, only 4 percent of Hispanic, 3 percent of black, and 10 percent of American Indian/Alaskan Native 12th graders scored at that level. Furthermore, there was no evidence in the 2000 assessment of any narrowing of the racial/ethnic group score gaps since 1990.

♦ **There is a wide gap between the NAEP mathematics scores of high-and low-income students, as measured by eligibility for the National School Lunch Program.** For example, low-income 12th-grade students (those who were eligible for the Free/Reduced Price Lunch Program) had scale scores similar to high-income 8th-grade students (those who were not eligible for this program). Furthermore, at each grade level, low-income students were twice as likely or more to score below the Basic level of achievement than were high-income students.

♦ **Internationally, U.S. student relative performance becomes increasingly weaker at higher grade levels.** On the Third International Mathematics and Science Study (TIMSS), 9-year-olds tended to score above the international average, 13-year-olds near the average, and 17-year-olds below it. Even the most advanced students performed poorly compared with students in other countries taking advanced mathematics and science courses. On advanced mathematics and science assessments, U.S. students who had taken advanced coursework in these subjects performed poorly compared with their counterparts in other countries.

Coursetaking

♦ **Since the publication of *A Nation At Risk* nearly 20 years ago, most states have increased the number of mathematics and science courses required for high school graduation.** As of 2000, 25 states required at least 2.5 years of math and 20 states required 2.5 years of science; in 1987, only 12 states required that many courses in math and only 6 required that many courses in science. Opinions differ, however, on the quality of the added courses, especially those taken by students who are low achievers.

♦ **In 1998, more graduating students had taken advanced mathematics and science courses than did their counterparts in the early 1980s.** For example, almost all graduating seniors (93 percent) in the class of 1998 had taken biology, more than one-half (60 percent) had taken chemistry, and more than one-quarter (29 percent) had completed physics. Participation rates in advanced placement or honors science courses are considerably lower: 16 percent for biology, 5 percent for chemistry, and 4 percent for physics.

♦ **Female and male students have broadly similar coursetaking patterns, although there are some differences.** In high school, girls are as likely as boys to take advanced mathematics classes and are more likely to take biology and chemistry; they remain less likely to take physics.

♦ **Students in all racial and ethnic groups are taking more advanced mathematics and science courses, although black, Hispanic, and American Indian/Alaskan Native graduates still lag behind their Asian/Pacific Islander and white counterparts in advanced mathematics and science coursetaking.** For example, graduates in the class of 1998 who had taken algebra II ranged from 47 percent of American Indians/Alaskan Natives to 70 percent of Asians/Pacific Islanders. Percentages for white, black, and Hispanic graduates were 65, 56, and 48, respectively. Furthermore, Asians/Pacific Islanders were a third more likely than whites to take calculus (18 versus 12 percent) and three times more likely than blacks, Hispanics, and American Indians/Alaskan Natives (about 6 percent each).

Content Standards and Statewide Assessments

♦ **In the 1980s, most states approved policies aimed at improving the quality of K–12 education by implementing statewide curriculum guidelines and frameworks as well as assessments.** By 2000, 49 states had established content standards in mathematics and 46 states had established science standards. Teachers remain concerned, however, that standards do not always provide clear guidance regarding the goals of instruction and that schools do not yet have access to top-quality curriculum materials aligned with the standards.

♦ **Although some states have recently delayed the introduction of high-stakes tests (i.e., tests that students must pass to either graduate or advance a grade), public support for standards-based reform appears to be strong.** For example, in a 2000 survey, relatively few parents said that their child's school requires them to take too many standardized tests to the detriment of other important learning (11 percent), that teachers in their child's school "focus so much on preparing for standardized tests that real learning is neglected" (18 percent), or that their child receives too much homework (10 percent).

- **Employers and professors are far more disapproving than parents or teachers of how well young people are prepared for college and work, and very large majorities continue to voice significant dissatisfaction about students' basic skills.** For example, in a 2000 survey, about two-thirds of professors found the basic math skills of recent freshmen and sophomores to be only "fair" or "poor." More than 80 percent stated that student ability to write clearly was only "fair" or "poor." These results point to the continuing gap between student skill level and preparation for college and college professors' views of the adequacy of that preparation. Results were similar for employers regarding recent job applicants.

- **Public school teachers generally support the movement to raise standards, but they are less supportive than the general public.** The vast majority of public school teachers feel that the curriculum is becoming more demanding of students, although they also feel that new statewide standards have led to teaching that focuses too much on state tests and that a significant amount of "teaching to the test" occurs.

Curriculum and Instruction

- **Students in the United States receive at least as much classroom time in mathematics and science instruction as students in other nations:** for 8th graders, close to 140 hours per year in mathematics and 140 hours per year in science. Students in Germany, Japan, and the United States spent about the same amount of time on a typical homework assignment, although American students were assigned homework more often.

- **According to a curriculum analysis conducted as a part of TIMSS, curriculums and textbooks used in U.S. schools are highly repetitive, contain too many topics, and provide inadequate coverage of important topics.** Independent judges determined that only 6 of the 13 U.S. mathematics texts and none of the 9 U.S. science texts that were evaluated were satisfactory based on 24 instructional criteria. These findings are supported by math and science textbook analyses undertaken by the American Association for the Advancement of Science.

- **Instruction in U.S. 8th-grade classrooms focuses on development of low-level skills rather than on understanding and provides few opportunities for students to engage in high-level mathematical thinking.** A team of mathematicians found that 13 percent of Japanese lessons in 1995 were judged to be of low quality, whereas 87 percent of lessons from U.S. classrooms were judged to be of low quality.

Teacher Quality

- **Research suggests that the following factors are associated with teacher quality: having a high level of academic skills, teaching in the field in which the teacher was trained, having more than a few years of experience (to be most effective), and participating in high-quality induction and professional development programs.**

Teacher Working Conditions

- **The difference between the annual median salaries of all bachelor's degree recipients and teachers has declined over the past 20 years, mainly due to increases in the relative size of the older teaching workforce and in salaries of older teachers.** The average annual median salary of full-time teachers grew slowly during the 1990s, reaching $35,099 in 1998.

- **Teacher pay scales in the United States tend to be lower than those in a number of other countries, including Germany, Japan, South Korea, and the Netherlands.** In addition, teaching hours tend to be longer in American schools. The gaps are particularly wide at the upper secondary (high school) level because a number of countries require higher educational qualifications and pay teachers significantly more at this level than at the primary (elementary) level.

Information Technology in Schools

- **Computers and Internet access are becoming increasingly available in schools, although the distribution of these resources is not uniform.** In 2000, the ratio of students to instructional computers in public schools was 5:1, down from 6:1 in 1999 and a dramatic change from 125:1 in 1983. The ratio of students per instructional computer with Internet access in public schools declined from 12:1 in 1998 to 9:1 in 1999 and then to 7:1 in 2000.

- **Although gaps in access to computers and the Internet have narrowed between high-and low-poverty schools, differences remain.** For high-poverty schools (those with 75 percent or more students eligible for free or reduced-price lunch), 60 percent of all instructional rooms had Internet access in 2000, up from 5 percent in 1996. Schools with less poverty tended to have a larger percentage of rooms with Internet access—77 percent or higher in 2000, up from 11–17 percent in 1996.

- **In 1999, approximately half of the public school teachers who had computers or the Internet available in their schools used them for classroom instruction.** Teachers assigned students to use these technologies for word processing or creating spreadsheets most frequently (61 percent), followed by Internet research (51 percent), problem solving and data analysis (50 percent), and drills (50 percent).

- **Many teachers feel unprepared to integrate technology into the subjects they teach, and relatively few teachers find the current training activities in information technology very useful.** In 1999, only one-third of teachers reported feeling well prepared or very well prepared to use computers and the Internet for classroom instruction, with less experienced teachers indicating they felt better prepared to use technology than their more experienced colleagues. For many instructional activities, teachers who reported feeling better prepared to use technology were generally more likely to use it than were teachers who indicated that they felt unprepared.

Transition to Higher Education

- **Expectations for college attendance have increased dramatically over the past 20 years, even among low-performing students.** Overall, immediate college enrollment rates for high school completers increased from 49 to 63 percent between 1972 and 1999. Much of the growth in these rates between 1984 and 1999 was due to increases in the immediate enrollment rates for females at four-year institutions.

- **Since 1984, college transition rates for black graduates have increased faster than those for whites, thus closing much of the gap between the two groups. The enrollment rates for Hispanic graduates are lower and have been relatively stable over the past 20 years.** In 1994, white graduates were twice as likely to enroll in a four-year college as a two-year college after high school, black graduates were about 1.5 times as likely, and Hispanic graduates were equally likely to enroll in a four-year college as a two-year college.

- **High school graduates from low-income families enter four-year institutions at lower rates than those from high-income families.** Although financial barriers to college attendance exist for many low-income students, another reason for their lower enrollment rate is that they are less qualified academically.

- **Remedial work is widespread at the college level, particularly in two-year colleges.** In 1995, the latest year for which data are available, all public two-year and 81 percent of public four-year institutions offered remedial reading, writing, or mathematics courses. Moreover, freshmen at public two-year institutions were almost twice as likely as their peers at public four-year institutions to enroll in remedial courses in these subjects (41 percent versus 22 percent).

Introduction

This chapter focuses on several key issues at the heart of the current debate over the quality of our elementary and secondary mathematics and science education system. Trends in math and science achievement and coursetaking are examined first, both as system outputs and as the context for current reform efforts. Next, the chapter examines several quantifiable aspects of current reform efforts. Maintaining the science and engineering (S&E) pipeline and preparing all young people for an increasingly technological society are two goals driving reforms targeted to raise the academic bar for students and improve the quality of teaching. The desire to raise the academic expectations for all students has led states to both adopt standards specifying what students should know and be able to do and to implement new testing mechanisms to measure what students actually know.

Although it is widely recognized that education reforms cannot be successful without actively engaging teachers, comprehensive, valid measures of change in teacher quality are difficult to come by, leaving us to rely on currently available data. Indicators of teacher credentials, experience, and participation in professional development activities are presented, as well as data on how new teachers are being inducted into the profession. As access to computers and the Internet becomes more widespread in schools, the focus of the chapter turns toward understanding how IT is being implemented and how students are benefiting from its use. In conclusion, the adequacy of student preparation for higher education is examined as a lead into the discussion of college-level S&E in chapter 2.

This chapter emphasizes variation in both access to education resources (by school poverty level and minority concentration) and performance (by sex, race/ethnicity, and family background) as data availability allows. A distinction is also made between mathematics and science when the policy implications of data are different or the data tell different stories.

How Well Do Our Students Perform in Mathematics and Science?

U.S. and internationally comparable achievement data result in a mixed report card for the United States. Although performance on assessments of mathematics and science achievement by the National Assessment of Educational Progress (NAEP) has improved since the 1970s, few students are attaining levels deemed Proficient or Advanced by a national panel of experts, and the performance of U.S. students continues to rank substantially below that of students in a number of other, mostly Asian, countries. This cross-national achievement gap appears to widen as students progress through school. This section describes progress in student performance, both long-term trends based on NAEP curricular frameworks developed in the late 1960s and more recent trends that track performance across items aligned with more current standards. International comparisons are then used to benchmark U.S. performance in these subjects.

Long-Term Trends in Math and Science Performance

Generally, mathematics and science performance on the NAEP long-term trend assessment declined in the 1970s, increased during the 1980s and early 1990s, and has remained mostly stable since that time. (See sidebar, "The NAEP Trends Study.") NAEP mathematics achievement increased among 9-, 13-, and 17-year-old students since the early 1980s, although most of these gains occurred before 1992. (See figure 1-1.) Although the average scale scores of 17-year-olds declined by 6 points between 1973 and 1982, scores increased by 9 points between 1982 and 1992 and remained at about the same level through 1999 (National Center for Education Statistics (NCES) 2000e). These gains since 1982 were substantial, equating to about a quarter of the difference between the mathematics scores of 13- and 17-year-olds (an 8-point difference is roughly equivalent to a year of schooling between these ages). Substantial gains were also made by 9- and 13-year-olds between 1982 and 1999: 8 and 13 points, respectively.

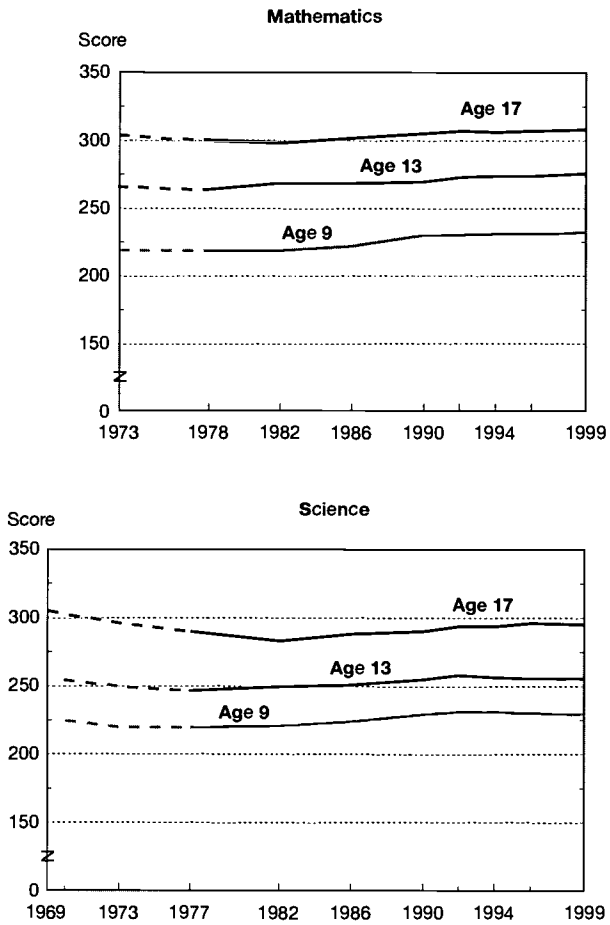
NAEP science performance over the past three decades has generally mirrored that of math: scores declined during the 1970s but increased in the 1980s and early 1990s. Because the first science assessments occurred before the first math assessments (1969 for 17-year-olds and 1970 for 13- and 9-year-olds), science achievement can be tracked over a longer period. Results for 17-year-olds show an initial 22-point decline between 1969 and 1982. In the decade between 1982 and 1992, an increase in the average score erased about half of that decline; since 1992, scores have been stable. (See figure 1-1.) Although 17-year-olds had higher science scores in 1999 than their counterparts in 1982, the average 1999 score remained 10 points below the average score in 1969. Gains since the early 1980s for 13- and 9-year-olds in science have essentially returned the average scores of these cohorts to levels similar to (for 13-year-olds) or higher than (for 9-year-olds) those posted in 1970.

A persistently wide gap in NAEP scores between low- and high-performing students remains. For example, the gap between the average mathematics scores of the highest and lowest performing quartiles for 17-year-old students was 73 points in 1999, a gap similar in size to the difference between the average scale scores for 17- and 9-year-olds in 1999 (roughly equivalent to eight years of schooling). Similar gaps have persisted for 9- and 13-year-olds as well. Efforts to apply uniformly high standards to all children need to confront the large variation in performance that currently exists in our schools.

Trends in Performance by Sex

Differences in the academic performance of female and male students on the NAEP long-term trend assessment appear as early as age 9 and persist through age 17. Although girls have consistently outperformed boys in reading and writing, gaps between the sexes in mathematics and science performance in the early grades have been much narrower and have varied over time. In 1999, 9-year-old girls had higher

Figure 1-1.
Trends in average scale scores in mathematics and science: 1969–1999



NOTE: Dashed lines represent extrapolated data.

SOURCE: National Center for Education Statistics, *NAEP 1999 Trends in Academic Progress: Three Decades of Student Performance*, NCES 2000-469. Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement, 2000e.

Science & Engineering Indicators – 2002

average reading scores than boys, although this gap has narrowed since 1971 (NCES 2000e). In mathematics, higher scores earned by girls in the 1970s shifted to higher scores earned by boys in the 1990s. In 1999, however, the difference between the scores of boys and girls was not statistically significant. In science, boys have tended to perform better than girls at age 9, although, as observed in mathematics, the difference in 1999 was not statistically significant.

Female and male achievement differences at age 9 remain nearly unchanged at age 13. For example, in 1999, the average reading proficiency score for a 13-year-old female was 12 scale points higher than for a 13-year-old male, and females scored at about the same level in math and 6 scale points lower than males in science (NCES 2000e). When 17-year-olds are assessed, female and male differences in reading persist. For example, in 1999, average reading proficiency for 17-year-old females was 13 scale points higher than for males of the same age. This corresponds to about 45 percent of the difference between the average scores of 13- and 17-year-olds in 1999. In other words, the gap in reading proficiency between females and males at age 17 is roughly equivalent to between 1.5 and 2 years of schooling.

The NAEP Trends Study

The National Assessment of Educational Progress's (NAEP's) long-term trend assessments have been the primary means for tracking the achievement trends of 9-, 13-, and 17-year-olds in science since 1969 and in mathematics since 1973. These primarily multiple-choice tests have remained substantially the same since first given, allowing the measurement of student progress over the past three decades. The content of these assessments is "traditional" by today's standards. For example, the mathematics assessment measures student knowledge of basic facts, ability to carry out numerical algorithms using paper and pencil, knowledge of basic measurement formulas as they are applied to geometry problems, and ability to apply mathematics to daily living skills (such as those related to time and money). Calculators are permitted only on a few questions. The computational focus of the long-term trend assessment provides the opportunity to determine how our students are measuring up to traditional procedural skills, even as the calculator plays an increasingly greater role in today's mathematics curriculum. Both the content (see the section, "Benchmarking of Mathematics Performance Against Standards") and the populations assessed, which are age groups rather than grades, distinguish these assessments from the "National" NAEP, which is discussed in the next section.

Student performance on the long-term trend assessments is summarized on a 0- to 500-point scale for each subject area. Item response theory (IRT) was used to estimate average proficiency for the nation and various subgroups of interest within the nation. IRT models the probability of answering a question correctly as a mathematical function of proficiency or skill. The main purpose of IRT analysis is to provide a common scale by which performance can be compared across groups, such as those defined by age, assessment year, or subpopulations (e.g., race/ethnicity or sex). Although the use of IRT scaling in the NAEP Trends Study puts the scores of 9-, 13-, and 17-year-olds on the same scale, which facilitates comparisons across ages, the scores of students on the Third International Mathematics and Science Study (TIMSS) are scaled separately for each grade. Therefore, the scores are not comparable across grades.

SOURCE: NCES 2000e and <http://www.nces.ed.gov/naep3/mathematics/trends.asp>.

In mathematics and science, boys have tended to score higher than girls, although the gap is narrower. A gap favoring 17-year-old males in mathematics narrowed from 8 points in 1973 to one that was statistically insignificant in 1999. (See figure 1-2.) The gap in science at this age narrowed from 16 points in 1973 to 10 points in 1999 (about a year's worth of science).

Trends in Performance by Race/Ethnicity

NAEP trend data on science and mathematics achievement of 17-year-olds between 1973 and 1999 suggest that the gap between whites and their black and Hispanic peers has narrowed but remains large.[1] Differences in percentile scores by race/ethnicity, that is, the score at which different percentages of a particular group (5, 25, 50, 75, or 95 percent) score at or below, provide an indication of the size of these gaps. (See figure 1-3.) For example, in 1999, 75 percent of white 17-year-olds scored 282 or above on the NAEP science test (the 25th percentile score), while only 25 percent of black 17-year-olds and fewer than 50 percent of Hispanic 17-year-olds scored at that level. In mathematics, the gap between blacks and whites appears to be somewhat narrower and the gap between whites and Hispanics somewhat wider. Gains by both high- and low-performing black and Hispanic students have narrowed the wide gaps that were in evidence since 1973, although there is little evidence that the gaps have continued to narrow in the 1990s, and some evidence that the gap between whites and blacks in mathematics has widened (NCES 2000e).

Gaps in mathematics achievement between whites and other racial/ethnic groups exist before entering high school, but evidence shows that these gaps widen for some groups during high school. In mathematics, the overall differences in 8th- to 12th-grade achievement gains show that blacks learn less than whites during high school, Hispanics and whites do not differ significantly, and Asians learn more than whites on average. However, when one compares blacks and whites completing the same number of math courses, the achievement gains during high school are not measurably (statistically) different. The Asian and white achievement gain differences are also generally reduced among students completing the same number of mathematics courses (NCES 1995). These data do not suggest, however, that coursetaking patterns alone lead to similar outcomes. The level of achievement that students from different backgrounds have attained before entering particular courses makes a difference, because parallel gains among students taking the same courses cannot close the gap. For example, NAEP data show that racial/ethnic differences in mathematics persist even among students who have completed similar courses at the time of assessment. The gap in average scores was 21 points between white and black 17-year-olds whose highest math course taken as of the 1996 assessment was algebra II; this gap is similar to the difference in scores observed between all 17-year-olds whose highest math course was algebra II and those whose highest course was geometry (NCES 2000b).

Benchmarking of Mathematics Performance Against Standards

In addition to the long-term trend data described above, NAEP periodically assesses the mathematics and science performance of students against more current frameworks of what students are expected to know in the 4th, 8th, and 12th grades (hereafter, referred to as the "National" NAEP).[2] Since 1990, the mathematics assessments have been based on a framework influenced by the National Council of Teachers of Mathematics (NCTM) Curriculum and Evaluation Standards for School Mathematics (NCTM 1989). The assessment framework contains five content strands (number sense, properties, and operations; measurement; geometry and spatial sense; data analysis, statistics, and probability; and algebra and functions). In addition to the five content strands, the assessments examine mathematical abilities (conceptual understanding, procedural knowledge, and problem solving) and mathematical power (reasoning, connections, and communication). Student mathematics performance is summarized on the NAEP mathematics scale, which ranges from 0 to 500. In addition, results for each grade are reported according to three achievement levels developed by NAGB: Basic, Proficient, and Advanced. These achievement levels are based on collective judgments by NAGB about what students should know and be able to do in mathematics.[3] The levels were defined by a broadly representative panel of teachers, education specialists, business and government leaders, and members of the general public. The Basic level denotes partial mastery of prerequisite knowledge and skills that are fundamental for proficient work at each grade. The Proficient level represents solid academic performance as determined by NAGB, and the Advanced level signifies superior performance. Although NCES still considers these proficiency levels developmental, they are used in this section to benchmark student math achievement.

Mathematics Performance by Achievement Level

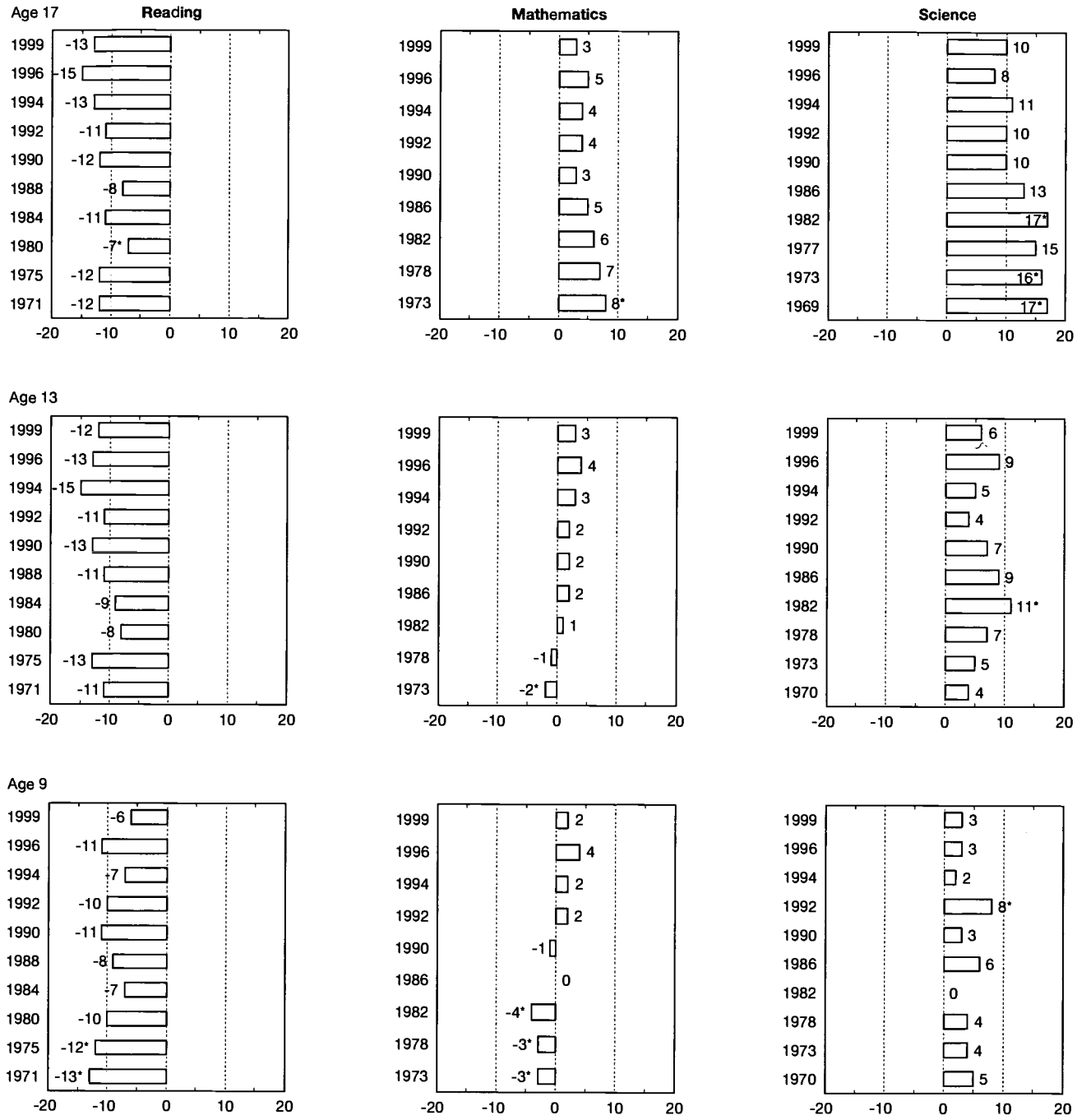
Although mathematics trends in the NAEP long-term trend study were relatively flat during the 1990s, mathematics per-

[1]Hispanics are a diverse group with considerable differences in country of origin, social class, race, educational status, and level of assimilation (Valdivieso and Nicolau 1992). What does characterize all the major groups except Cubans, albeit in varying intensities, are high levels of poverty and low levels of educational achievement. Although sample sizes in the data presented in this chapter do not allow the separate reporting of Hispanics by background characteristics, it should be acknowledged that there is a wide range of variability within this broad category. Sample sizes for Asians/Pacific Islanders and American Indians/Alaskan Natives are too small in the NAEP trends study to produce reliable estimates for these groups.

[2]Data from the 2000 NAEP Science Assessment were not available in time for inclusion in this chapter. The main findings were that 4th- and 8th-graders' scores remained stable between 1996 and 2000, while scores for high school seniors declined. See < http://nces.ed.gov/nationsreportcard/science/results/>. Accessed 11/26/01.

[3]A recent National Academy of Sciences-commissioned report found the current process of setting NAEP achievement levels to be "fundamentally flawed" (National Research Council 1998, 162). NAGB continues to use the mathematics achievement levels developed for the 1990 assessment, and they are used here because they so clearly highlight the widespread concern about the level of student performance in this subject.

Figure 1-2.
Trends in differences between male and female student average scale scores, by age, various years: 1969–1999
(Male minus female score)



*Significantly different from 1999. Small differences between male and female scores are often not statistically significant. For example the male-female differences were not statistically significant in 1999 for mathematics at all three ages and for 9-year-olds in science.

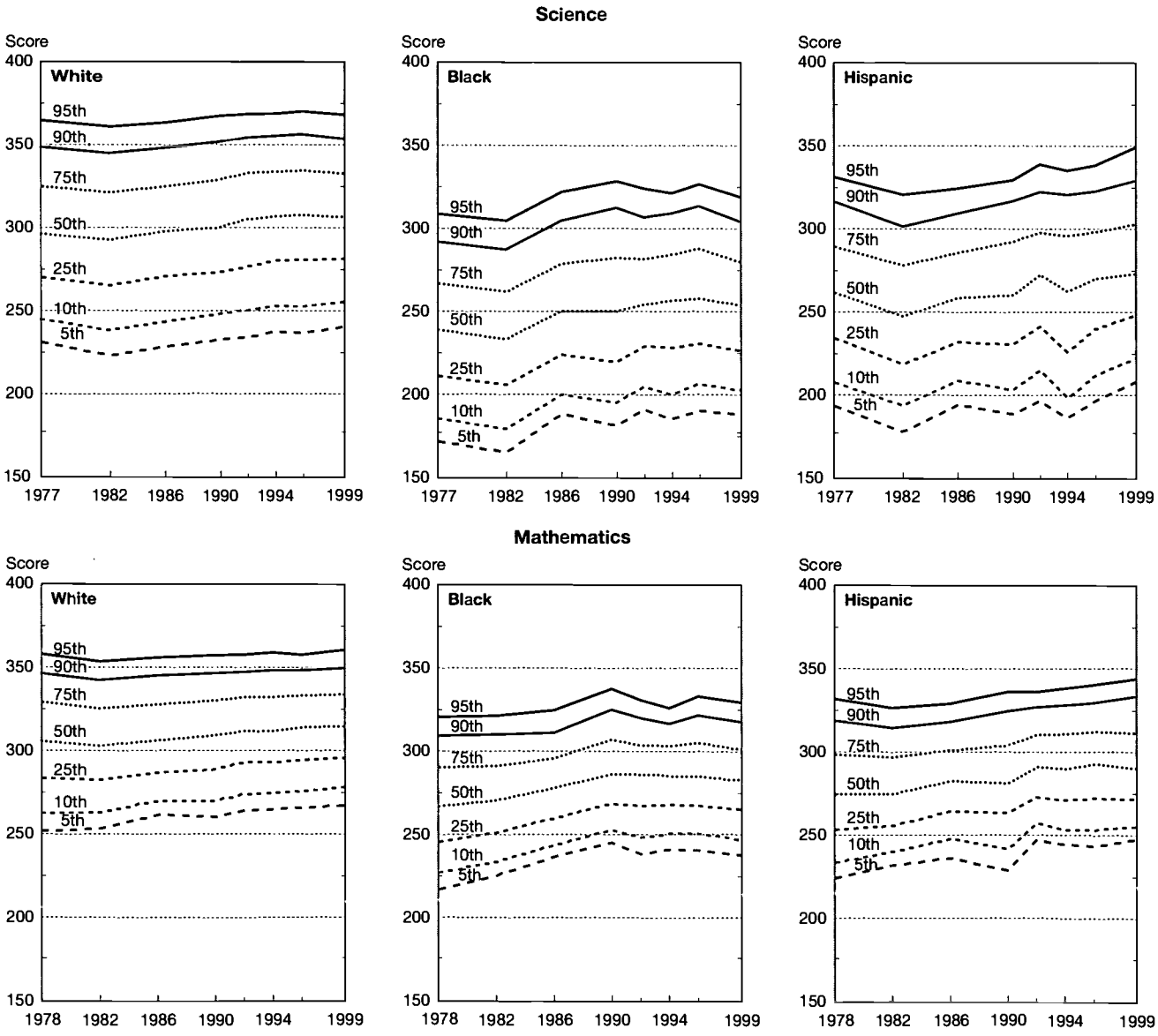
SOURCE: National Center for Education Statistics, *NAEP 1999 Trends in Academic Progress: Three Decades of Student Performance*, NCES 2000-469. Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement, 2000e.

Science & Engineering Indicators – 2002

formance on the National NAEP increased in the 4th, 8th, and 12th grades between 1990 and 2000. While the average scores of 4th and 8th graders made progress throughout the decade, the scores of 12th graders declined between 1996 and 2000, reducing some of the gain made between 1990 and 1996. The national average scale score for 4th graders in 2000 was 228, an increase of 15 points over the national average for 1990; the average scale score for 8th graders in 2000 was 275, an increase of 12 points; and the average scale score for 12th graders was 301, an increase of 7 points since 1990, but a decrease in 3 points since 1996 (NCES 2001f). The cross-decade increases of 4th and 8th graders are between a third and almost half of a standard deviation in test scores for these grades, roughly equivalent to a gain of between 1.5 and 2 grade levels. While smaller, the 12th-grade gain was still substantial, between 0.5 and 1 grade level.

Although these increases suggest that some progress is being made across areas emphasized in the NCTM mathematics standards, relatively few students scored at the Proficient or Advanced levels set by NAGB for each grade, and more than 30 percent scored below the Basic level. (See figure 1-4.) For 4th-grade students, the percentage performing at or above the Basic level was 69 percent in 2000 compared with 50 percent in 1990; for 8th-grade students, 66 percent compared with 52

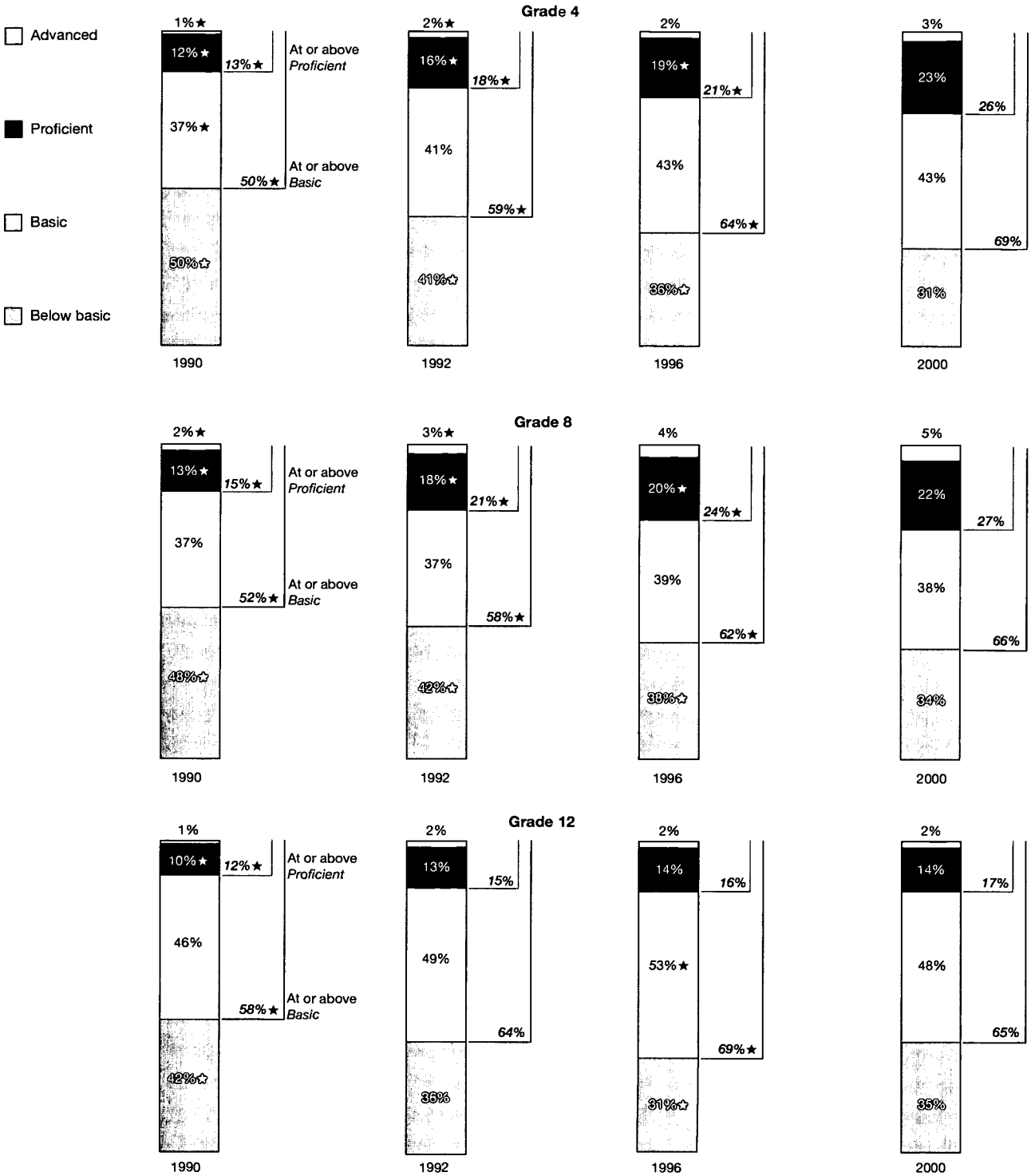
Figure 1-3.
Percentile distribution of science and mathematics proficiency for 17-year-olds, by race/ethnicity: selected years 1977–99



SOURCE: U.S. Department of Education, National Center for Education Statistics, National Assessment of Educational Progress, summary data tables http://nces.ed.gov/nationsreportcard/tables/.

Science & Engineering Indicators – 2002

Figure 1-4.
Percentage of students within each mathematics achievement level range and at or above achievement levels, grades 4, 8, and 12: 1990–2000



How to read these figures:
The italicized percentages to the right of the shaded bars represent the percent of students at or above *Basic* and *Proficient*.
The percentages in the shaded bars represent the percentages of students within each achievement level.
★ Significantly different from 2000.

NOTE: Percentages within each mathematics achievement level range may not add to 100, or to the exact percentages at or above achievement levels, due to rounding.

SOURCE: National Center for Education Statistics, *The Nation's Report Card: Mathematics 2000,* NCES 2001-517, Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement, 2001f.

percent; and for 12th-grade students, 65 percent compared with 58 percent. The percentages of students scoring at the Proficient and Advanced levels were much lower: 26 percent of 4th graders, 27 percent of 8th graders, and 17 percent of 12th graders scored at the Proficient level in 2000, and the percentage of students in these grades in 2000 scoring at the Advanced level were 3 percent, 5 percent, and 2 percent, respectively. From NAGB's perspective, then, as many as one-third of students continue to score below a Basic level of mathematics achievement, and few score at levels considered to be Advanced.

Proficiency levels provide an additional metric to gauge how wide the gaps in scores are between different subgroups. The NAEP sample shows differences in the achievement of boys and girls, students from different racial and ethnic groups, students from different states and jurisdictions, and students receiving and not receiving Title I services.

Proficiency by Sex

Although similar proportions of boys and girls scored at the Basic level or above on the 2000 NAEP mathematics assessment, boys were more likely to score at the Proficient or Advanced levels than girls at the 4th, 8th, and 12th grades. For example, 20 percent of 12th-grade males scored at the Proficient level compared with 14 percent of girls, and the percentage of each group scoring at the Advanced level was 3 and 1 percent, respectively. (See text table 1-1.)

Proficiency by Race/Ethnicity

At each grade level, a larger percentage of white and Asian/Pacific Islander students scored at the Basic, Proficient, and Advanced levels in 2000 than their black, Hispanic, and American Indian/Alaskan Native counterparts.[4] For example, while 34 percent of Asian/Pacific Islander and 20 percent of white 12th graders scored at or above the Proficient level in 2000, only 4 percent of Hispanic, 3 percent of black, and 10 percent of American Indian/Alaskan Native 12th graders scored at that level. Furthermore, there was no evidence in the 2000 assessment of any narrowing of the racial/ethnic group score gaps since 1990. These differences, combined with higher dropout rates for Hispanic, black, and American Indian/Alaskan Native youth, point to considerable disparities in achievement across racial/ethnic groups. However, there is substantial variation for ethnic groups by country of origin (see sidebar, "Variation in Educational Achievement and College Attendance Rates of Asian and Hispanic 1988 8th Graders by Country of Origin") and time since immigration. (The sidebar, "Generational Status and Educational Outcomes Among Asian and Hispanic 1988 8th Graders" compares ethnic groups by timing of immigration.)

[4]Sample sizes in the NAEP study are too small to report Asians by country of origin. Reporting a single category of all Asians/Pacific Islanders, however, "conceals complexities and differences in the lives of distinct Asian groups" (Carter and Wilson 1997).

Text table 1-1.
Percentage of 12th-grade students at each NAEP mathematics achievement level: 1990 and 2000

Year and characteristic	Advanced	Proficient	Basic	Below basic
Total				
2000	2	17[a]	65[a]	35[a]
1990	1	12	58	42
Male				
2000	3	20	66[a]	34[a]
1990	2	15	60	40
Female				
2000	1	14[a]	64[a]	36[a]
1990	1	9	56	44
Race/ethnicity				
White				
2000	3	20[a]	74[a]	26[a]
1990	2	14	66	34
Black				
2000	—	3	31	69
1990	0	2	27	73
Hispanic				
2000	—	4	44[a]	56[a]
1990	—	4	36	64
Asian/Pacific Islander				
2000	7	34	80	20
1990	5	23	75	25
American Indian/ Alaskan Native[b]				
2000	—	10	57	43
Location (2000)				
Central city	2	16	60	40
Urban fringe/large town	3	19	68	32
Rural/small town	1	13	65	35

— = Percentage is between 0.0 and 0.5.

[a]Significantly different from 1990 at 0.5 level.

[b]Sample size is insufficient to permit a reliable estimate of 1990 values.

SOURCE: National Center for Education Statistics, *The Nation's Report Card: Mathematics 2000,* NCES 2001-517, Washington DC: U.S. Department of Education, Office of Educational Research and Improvement 2001e.

Science & Engineering Indicators – 2002

Proficiency by Type of Location

At the 4th, 8th, and 12th grades, students in the urban fringe/large town locations had higher scale scores on the NAEP national mathematics assessment than students in central city locations (NCES 2001f). At grades 4 and 8, students in rural/small town locations also outperformed their counterparts in the central city locations. These differences were also reflected in proficiency scores. (See text table 1-1.) For example, at grade 12, there were higher percentages of students at or above the Proficient level and at or above the Advanced level attending schools in urban fringe/large town locations (19 and 3 percent, respectively) than in rural school locations (12 and 1 percent, respectively). While 16 percent of 12th graders in central city

Variation in Educational Achievement and College Attendance Rates of Asian and Hispanic 1988 8th Graders by Country of Origin

Sample sizes in the National Assessment of Educational Progress (NAEP) trends study and the National NAEP are too small to report scores for Asians/Pacific Islanders and Hispanics by country of origin. Collapsing all Asians/Pacific Islanders and all Hispanics into homogeneous ethnic categories can conceal wide variation in outcomes by country of origin. Data collected in the National Educational Longitudinal Study of 1988 show mathematics and science achievement differences between Asian and Hispanic 8th graders from different countries of origin when tested in 1992. This study also compares college attendance rates between Asian/Pacific Islander and Hispanic subgroups. (See text table 1-2.) Data show the following.

Asians/Pacific Islanders

Although the aggregate group of Asians/Pacific Islanders scored as well as or higher than their white counterparts on assessments of mathematics and science in 1992, considerable variation was seen within this group by country of origin. For example, students with ancestry in China, Korea, and South Asia tended to have higher scores than Asians/Pacific Islanders as a whole, and Pacific Islanders had lower scores.

College attendance rates among Asians/Pacific Islanders also varied by country of origin. For example, nearly 9 out of 10 Chinese, Filipino, Korean, and South Asian students in the 8th-grade class of 1988 had enrolled in postsecondary education by 1992, compared with enrollment rates of only 50 percent for those from Pacific Islands.

Hispanics

Hispanic 8th graders with Cuban ancestry tended to have higher mathematics and science test scores than their Mexican American counterparts. Mexican American students also tended to have lower rates of postsecondary attendance than Hispanics with Cuban, Puerto Rican, or other ancestry.

SOURCE: NCES 2001e.

Text table 1-2.
Percentile scores on mathematics and science tests in 1992 and postsecondary enrollment rates by 1994 of 1988 8th-grade class, by race/ethnicity and country of origin

Race/ethnicity and country of origin	1992 Percentile score		Postsecondary enrollment rate by 1994
	Mathematics	Science	
All students	51	51	65
White	56	56	68
Black	33	29	57
American Indian/ Alaskan Native	29	29	35
Asian/Pacific Islander	60	54	83
China	76	65	94
Philippines	62	57	89
Japan	69	67	65
Korea	75	69	95
Southeast Asia	61	52	79
Pacific Islands	39	35	50
South Asia	71	66	91
Hispanic	39	37	54
Mexico	37	37	51
Cuba	53	46	66
Puerto Rico	42	41	65
Other	46	43	67

SOURCE: National Center for Education Statistics, National Education Longitudinal Study: 1988–94, Data Analysis System 2001d.

Science & Engineering Indicators – 2002

locations scored at or above the Proficient level, only 60 scored at or above the basic level, lower than the 68 percent in urban fringe/large town locations.

Because of slight changes by the Census Bureau in the definitions of these categories, schools were not classified in exactly the same way in 2000 in terms of location type as in previous NAEP assessments. Therefore, comparisons to previous years are not possible (NCES 2001f).

Proficiency by Free/Reduced-Price Lunch Eligibility

There is a wide gap between the NAEP mathematics scores of high- and low- income students, as measured by eligibility for the National School Lunch Program. At the 4th, 8th, and 12th grades, the scale scores for students who are not eligible for the Free/Reduced Price Lunch Program (i.e., those above the poverty guidelines) are significantly higher than the scores for the students who are eligible for the program. For example, low-income 12th-grade students (those who were eligible for the Free/Reduced Price Lunch Program) had scale scores similar to high-income 8th-grade students (those who were not eligible for this program). The size of these gaps can also be seen by comparing the percentage of students in each group at or above the Proficient level. While 35 percent of high-income students scored at or above the Proficient level, only 10 percent of their low-income counterparts did so. Furthermore, at each grade level, low-income students were twice as likely or more to score below the Basic level of achievement than were high-income students (NCES 2001f).

Proficiency by State

Wide variability exists across states in the proportion of public 8th-grade students performing above the Proficient level, and growth seen at the national level between 1996 and 2000 was not uniform across states. At grade 8, between 8

Generational Status and Educational Outcomes Among Asian and Hispanic 1988 8th Graders

Past research has consistently shown that, compared with Hispanics, Asian students perform better in school, have higher expectations for educational attainment, are more likely to graduate from high school, and are more likely to continue their education past high school (Sanderson et al. 1996, Green et al. 1995). Most of these studies, however, report statistics and findings without regard to differences within these groups, such as immigrant status (whether or not the student is foreign or U.S. born) and generational status (the number of generations the student's family has lived in the United States). A recent study from the National Center for Education Statistics (NCES) examined the relationship between the immigration and "generational" status of Asian and Hispanic students and various educational indicators and outcomes. Students were classified as:

- first-generation immigrant (born outside the United States);
- second-generation immigrant (U.S.-born students with one or both parents born outside the United States); or
- third-generation or higher immigrant (both parents and the student born in the United States). Students born in Puerto Rico who moved to one of the 50 states or the District of Columbia were classified as immigrants.

The analysis looked at how the generational status of Asian and Hispanic students from the 1988 8th-grade cohort of the National Education Longitudinal Study of 1988 (NCES 1999d) was associated with various educational outcomes as this cohort entered and progressed through high school and began postsecondary education. The analysis makes comparisons both *within* race/ethnicity and *between* generations on student background (family and language characteristics); 8th-grade experiences (8th-grade school characteristics, achievement test scores, and plans for high school); high school experiences (type of high school and graduation rates); postsecondary expectations (student and parental); and postsecondary enrollment. The results of this study are summarized below.

Student Background Characteristics

Nearly half of 8th-grade Asians in 1988 were born outside the United States, compared with about 18 percent of their Hispanic peers. Families of first-generation Asian 8th graders were more likely to be from Southeast Asia (23 percent), the Philippines (19 percent), China (19 percent), and Korea (11 percent) than from Japan (1.7 percent) or the Pacific Islands (1.6 percent). The families of third-generation (or greater) Asian 8th graders were more likely than their first-generation counterparts to be from other Asian countries, including India (50 percent), the Pacific Islands (21 percent), and Japan (12 percent). Hispanic immigrants tended to be more consistently spread across Hispanic groups: Mexican Americans, who made up a large proportion of each generation, ranged between 62 and 70 percent; Cuban Americans between 2 and 6 percent; Puerto Ricans between 5 and 17 percent; and Hispanics from other countries between 16 and 23 percent. Conclusions were as follows:

Family Background

- Asian students were more likely than Hispanic students to come from two-parent families and to have at least one parent with a college degree.
- First-generation students in each racial/ethnic group were more likely to come from families that lived at or below the poverty level than their second- and third-generation counterparts.

Language Characteristics

- Similar proportions of all 1988 8th-grade Asians and Hispanics were categorized as being limited-English proficient (LEP) (6 and 8 percent, respectively). However, Hispanics from this cohort were more likely than their Asian peers to come from homes where a language other than English was spoken (66 versus 55 percent).
- Similar proportions of first-generation Asians and Hispanics were LEP students (12 and 15 percent, respectively), but second- and third-generation Hispanics were more likely to be LEP students than were their Asian counterparts (10 and 5 percent versus 2 and 1 percent, respectively).
- The likelihood that a student's family spoke a foreign language in the home decreased for each racial/ethnic group when a family had been in the United States for three or more generations. Nonetheless, the rate at which Hispanics from different generations spoke only English in the home was consistently lower than that of their Asian counterparts.

Mathematics, Reading, and Science Proficiency

- Among all 8th graders, Hispanics were more likely than Asians to be below the proficiency level on the NELS mathematics and science assessment (25 versus 9 percent in mathematics and 41 versus 25 percent in science). Students at the proficiency level in mathematics understand simple arithmetic operations on whole numbers—essentially single-step operations that rely on rote

memory. Students at the proficiency level in science have an understanding of everyday science concepts, e.g., "common knowledge" that can be acquired in everyday life.

- The proportions of Asians and Hispanics who tested below the proficiency level on the NELS reading assessment, however, did not differ significantly (14 and 19 percent, respectively).
- The gap between the percentages of 1988 Asian and Hispanic 8th graders scoring below the proficiency level on the NELS mathematics assessment appeared within each of the three generations.

Parental Education Expectations

- Overall, the parents of 1988 Asian 8th graders were more likely to expect their children to earn at least a college degree than were the parents of Hispanic 8th graders (76 versus 47 percent).
- The parents of third-generation Asian students were less likely than the parents of first- and second-generation Asian students to expect their children to earn at least a bachelor's degree (54 percent versus 81 and 86 percent, respectively). The parental expectations of Hispanic students did not differ significantly by generational status.

Postsecondary Enrollment

- As of 1994, among 1988 8th graders, Asian students were far more likely to have enrolled in postsecondary education in general and in a four-year institution in particular than their Hispanic counterparts.

First- and second-generation Asians in the 8th-grade class of 1988 were more likely than their third-generation counterparts to enroll in a postsecondary institution by 1994 (82, 91, and 63 percent, respectively). Enrollment rates for Hispanic students did not differ significantly by generation.

SOURCE: NCES 1999d.

and 40 percent of students in the 39 states participating in State NAEP were at or above the Proficient level in 2000. As shown in text table 1-3, thirty percent or more of public 8th-grade students scored at or above the Proficient level in Connecticut, Indiana, Kansas, Maine, Massachusetts, Minnesota, Montana, Nebraska, North Carolina, North Dakota, Ohio, Oregon, and Vermont, and 20 percent or less scored at that level in Alabama, Arkansas, California, Georgia, Hawaii, Louisiana, Mississippi, New Mexico, Oklahoma, South Carolina, Tennessee, and West Virginia. Between 1990 and 2000, the percentage of 8th graders performing at or above the Proficient level increased for 30 out of 31 jurisdictions participating in both years. Some states made more progress than others, however. For example, the percentage of public 8th-grade students scoring at the Proficient level tripled in North Carolina over this 10- year period (from 9 to 30 percent), while the percentage scoring at that level or higher in North Dakota remained stable (at about 30 percent).

Summary of NAEP Performance

Although science and mathematics achievement has improved since the late 1960s and early 1970s, the percentage of students scoring in mathematics at a level considered proficient is still only about a quarter at the 4th and 8th grades and one in six in 12th grade. The gap in math and science proficiency between whites and Asians/Pacific Islanders and their black, Hispanic, and American Indian/Alaskan Native counterparts is particularly wide, as is the gap between students from low- and high-income backgrounds (as measured by eligibility for the National School Lunch Program). Although the gap between the scores of white and black students narrowed through the 1980s, there is evidence that the gap is now widening. The range between high- and low-performing students within a particular grade is particularly wide, pointing to a challenge for programs designed to hold all students accountable to high standards.

International Comparisons of Mathematics and Science Achievement

Internationally, U.S. student relative performance becomes increasingly weaker at higher grade levels. On the Third International Mathematics and Science Study (TIMSS), 9-year-olds tended to score above the international average, 13-year-olds near the average, and 17-year-olds below it. Even the most advanced students at the end of secondary school performed poorly compared with students in other countries taking similar advanced mathematics and science courses. This section reviews the mathematics and science performance of U.S. students, drawing primarily on the 1995 TIMSS and the 1999 repeat of this study at the 8th-grade level (TIMSS-R).

The 1995 TIMSS included assessments of 4th- and 8th-grade students as well as students in their final year of secondary school. The study included several components: the assessments, analyses of curriculums for various countries, and an observational video study of mathematics instruction in 8th-grade classes in Germany, Japan, and the United States. In addition to updating the comparison of U.S. math and science achievement in the 8th grade, the design of TIMSS-R made it possible to track changes in achievement and certain background factors from the earlier TIMSS study between the 4th and 8th grades. TIMSS-R also indicates the pace of educational change across nations, informing expectations about what can be achieved (NCES 2000f).

Text table 1-3.
Percentage of students at or above the proficient level in NAEP mathematics by state for grade 8 public schools: 1990–2000

State	1990	1992	1996	2000
National	15[a]	20[a]	23[a]	26
Alabama[c]	9[b]	10[b]	12	16
Arizona[c]	13[b]	15[b]	18	21
Arkansas	9[b]	10[b]	13	14
California[c]	12[b]	16	17	18
Connecticut	22[b]	26[b]	31	34
Georgia	14[b]	13[b]	16	19
Hawaii	12[b]	14	16	16
Idaho[c]	18[b]	22[b]	—	27
Illinois[c]	15[b]	—	—	27
Indiana[c]	17[b]	20[b]	24[a]	31
Kansas[c]	—	—	—	34
Kentucky	10[b]	14[b]	16[a]	21
Louisiana	5[b]	7[b]	7[a]	12
Maine[c]	—	25[b]	31	32
Maryland	17[b]	20[b]	24	29
Massachusetts	—	23[b]	28[a]	32
Michigan[c]	16[b]	19[b]	28	28
Minnesota[c]	23[b]	31[b]	34[a]	40
Mississippi	—	6	7	8
Missouri	—	20	22	22
Montana[c]	27[b]	—	32	37
Nebraska	24[b]	26[a]	31	31
Nevada	—	—	—	20
New Mexico	10[b]	11	14	13
New York	15[b]	20[b]	22	26
North Carolina	9[b]	12[b]	20	30
North Dakota	27	29	33	31
Ohio	15[b]	18[b]	—	31
Oklahoma	13[b]	17	—	19
Oregon[c]	21[b]	—	26[a]	32
Rhode Island	15[b]	16[b]	20[a]	24
South Carolina	—	15	14[a]	18
Tennessee	—	12[b]	15	17
Texas	13[b]	18[b]	21	24
Utah	—	22[a]	24	26
Vermont[c]	—	—	27[a]	32
Virginia	17[b]	19[b]	21[a]	26
West Virginia	9[b]	10[b]	14[b]	18
Wyoming	19[b]	21[b]	22[a]	25

— = Jurisdiction did not participate.

[a]Significantly different from 2000 if only one jurisdiction or the nation is being examined.

[b]Significantly different from 2000 when examining only one jurisdiction and when using a multiple-comparison procedure based on all jurisdictions that participated both years.

[c]Indicates that the jurisdiction did not meet one or more of the guidelines for school participation.

NOTE: National results are based on the national sample, not on aggregated state assessment samples. Comparative performance results may be affected by changes in exclusion rates for students with disabilities and limited-English-proficient students in the National Assessment of Educational Progress samples.

SOURCE: National Center for Education Statistics, *The Nation's Report Card: Mathematics 2000*, NCES 2001-517 (Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement, 2001e).

Science & Engineering Indicators – 2002

Achievement of 4th- and 8th-Grade American Students in 1995

U.S. 4th-grade students performed at competitive levels in 1995 in both science and mathematics.[5] In science, they scored well above the 26-country international overall average as well as the average in all content areas assessed: earth sciences, life sciences, physical sciences, and environmental issues/nature of science. Only students in South Korea scored at a higher level overall. The 4th-grade assessment in mathematics covered topics in whole numbers; fractions, and proportionality; measurement, estimation, and number sense; data representation, analysis, and probability; geometry; and patterns, functions, and relations. U.S. 4th-grade students scored above the international average on this assessment and performed comparatively well in all content areas except measurement (NCES 1997c).

As with 4th-grade students, the TIMSS science assessment taken by 8th-grade students covered earth and life sciences and environmental issues, but it also included content in physics and chemistry. With a mean score of 534 in science, 8th-grade U.S. students scored above the 41-country international average of 516. U.S. students performed at about the international average in chemistry and physics and above average in life sciences, earth sciences, and environmental issues (NCES 1996c).

Mathematics was the weaker area of 8th-grade achievement relative to the performance of students in other countries. The assessment covered fractions and number sense; geometry; algebra; data representation, analysis, and probability; measurement; and proportionality. Overall, 8th-grade U.S. students performed below the 41-country international overall average and at about the international average in algebra, data representation, and fractions and number sense. Performance in geometry, measurement, and proportionality was below the international average.

Change in Relative Performance Between 4th and 8th Grades

Change in the relative performance of U.S. students can be examined by comparing the average mathematics and science scores of U.S. 4th graders in 1995 and 8th graders in 1999 relative to the international average of the 17 nations that participated in 4th-grade TIMSS and 8th-grade TIMSS-R. (See sidebar, "How Comparisons Between 4th Graders in 1995 and 8th Graders in 1999 Are Made.") Figure 1-5 compares the average scores of the 17 nations between 4th-grade TIMSS and 8th-grade TIMSS-R with the international averages at both grades for each subject. The numbers shown in the figure are differences from the international average for the 17 nations. Nations are sorted into three groups: above the international average, similar to the international average, and below the international average.

[5]TIMSS results for 4th-, 8th-, and 12th-grade students have been widely reported, including in the previous volume of *S&E Indicators* (National Science Board 2000). TIMSS findings are outlined here in only general terms.

Figure 1-5.
Mathematics and science achievement for TIMSS-R 1999 countries/economies that participated in 1995 at both the 4th and 8th grades relative to the average across these locations

Mathematics

Country/economy	Fourth grade, 1995	Difference[a]
Singapore		73
South Korea		63
Japan		50
Hong Kong		40
Netherlands		32
Czech Republic		23
Slovenia		8
Hungary		4
United States		0
Australia		0
Italy		–7
Canada		–12
Latvia[b]		–18
England		–33
Cyprus		–42
New Zealand		–48
Iran		–130
Average		517

Country/economy	Eighth grade, 1999	Difference[a]
Singapore		80
South Korea		63
Hong Kong		58
Japan		55
Netherlands		16
Hungary		8
Canada		7
Slovenia		6
Australia		1
Czech Republic		–4
Latvia[b]		–19
United States		–22
England		–28
New Zealand		–33
Italy		–39
Cyprus		–48
Iran		–102
Average		524

Science

Country/economy	Fourth grade, 1995	Difference[a]
South Korea		62
Japan		39
United States		28
Australia		28
Czech Republic		18
Netherlands		17
England		14
Canada		12
Italy		10
Singapore		10
Slovenia		8
Hong Kong		–6
Hungary		–6
New Zealand		–9
Latvia[b]		–27
Cyprus		–64
Iran		–134
Average		514

Country/economy	Eighth grade, 1999	Difference[a]
Singapore		44
Hungary		28
Japan		25
South Korea		24
Netherlands		21
Australia		16
Czech Republic		15
England		14
Slovenia		9
Canada[c]		9
Hong Kong		5
United States		-9
New Zealand		–15
Latvia[b]		–21
Italy		–26
Cyprus		–64
Iran		–76
Average		524

Significantly higher than international average.
Does not differ significantly from international average.
Significantly lower than international average.

TIMSS = Third International Mathematics and Science study.

[a]Difference is calculated by subtracting international average of 17 locations from national average of each one.

[b]Only Latvian-speaking schools were tested.

[c]Shading may appear incorrect, but is statistically correct.

SOURCE: National Center for Education Statistics, *Pursuing Excellence: Comparisons of International Eighth-Grade Mathematics and Science Achievement from a U.S. Perspective, 1995 and 1999*, NCES 2001-028, Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement: 2000f.

Science & Engineering Indicators – 2002

The available evidence appears to confirm what had been suggested four years ago: the relative performance of U.S. students in mathematics and science is lower in 8th grade than in 4th grade among this group of nations. In mathematics, the U.S. 4th-grade score in 1995 was similar to the international average of the 17 nations in-common between the 4th-grade TIMSS and 8th-grade TIMSS-R. At the 8th-grade level in 1999, the U.S. average in mathematics was below the international average of the 17 nations. Because U.S. 4th graders performed at the international average in 1995 and U.S. 8th graders performed below the international average in 1999

How Comparisons Between 4th Graders in 1995 and 8th Graders in 1999 Are Made

The Third International Mathematics and Science Study (TIMSS) and other studies before it have suggested that the international performance of the United States relative to other nations appears lower at grade 8 in both mathematics and science than at grade 4. These statements were based on comparisons of the relative standing of 4th- and 8th-grade students in the same year, as opposed to a comparison of the growth in scores of cohorts of 4th graders over time. TIMSS-R provides the opportunity to examine how the relative achievement of U.S. 4th-grade students in 1995 compares with the achievement of 8th-grade students four years later in 1999. Direct comparisons between the 1995 4th-grade assessment and the 1999 8th-grade assessment are complicated by several factors, however. First, the 4th-grade and 8th-grade assessments include different test questions. By necessity, the type of mathematics and science items that can be asked of an 8th grader may be inappropriate for a 4th grader. Second, because mathematics and science differ in the two grades, the content areas assessed also differ. For example, geometry and physics at grade 4 are different from geometry and physics at grade 8. Without a sufficient set of in-common test items between the grade 4 and grade 8 assessments (which is the way that assessments are equated across ages and grades in the National Assessment of Educational Progress), it can be difficult to construct a reliable and meaningful scale on which to compare 1995 4th graders to 1999 8th graders. Thus, comparisons in this section between 4th and 8th grade are based on the performance relative to the international average of the 17 nations that participated in 4th-grade TIMSS and 8th-grade TIMSS-R.

SOURCE: NCES 2000f.

in mathematics, this suggests that the relative performance of the cohort of 1995 U.S. 4th graders in mathematics was lower relative to this group of nations four years later.

In science, the U.S. 4th-grade score in 1995 was above the international average of the 17 nations in-common between the 4th-grade TIMSS and 8th-grade TIMSS-R. At the 8th-grade level in 1999, the U.S. average in science was similar to the international average of the 17 nations. Thus, U.S. 4th graders performed above the international average in 1995 and U.S. 8th graders performed at a level similar to the international average in 1999 in science. As in mathematics, this suggests that the relative performance of the cohort of U.S. 4th graders in science was lower relative to this group of nations four years later. The data also suggest that, in science, the relative performance of the cohort of 1995 4th graders in Singapore and Hungary was higher relative to this group of nations in 1999; the relative performance of the cohort of 1995 4th graders in Italy and New Zealand was lower relative to this group of nations four years later; and the relative performance of the cohort of 1995 4th graders in the 12 other nations was unchanged relative to this group of nations four years later.

Mathematics and Science Achievement of 8th Graders in 1999

For most of the 23 nations that participated in 8th grade in both TIMSS and TIMSS-R, including the United States, there was little change in the mathematics and science average scores over the four-year period. There was no change in 8th-grade mathematics achievement between 1995 and 1999 in the United States and in 18 other nations. (See text table 1-4.) Three nations, Canada, Cyprus, and Latvia, showed an increase in overall mathematics achievement between 1995 and 1999. One nation, the Czech Republic, experienced a decrease in overall math achievement over the same period. In the United States and 17 other nations, there was no change in the science achievement score of 8th graders between 1995 and 1999; while it increased in four countries and decreased in one.

Students' Achievement in the Final Year of Secondary School

Students' performance in the final year of secondary school can be considered a measure of what students have learned over the course of their years in school. Assessments were conducted in 21 countries in 1995 to examine performance on the general knowledge of mathematics and science expected of all students and on more specialized content taught only in advanced courses.

Achievement on General Knowledge Assessments. The TIMSS general knowledge assessments were taken by all students in their last year of upper secondary education (12th grade in the United States), including those not taking advanced mathematics and science courses. The science assessment covered earth sciences/life sciences and physical sciences, topics covered in grade 9 in many other countries but not until grade 11 in U.S. schools. On the general science knowledge assessment, U.S. students scored 20 points below the 21-country international average, comparable to the performance of 7 other nations but below the performance of 11 nations participating in the assessment. Only 2 of the 21 countries, Cyprus and South Africa, performed at a significantly lower level than the United States. Countries performing similarly to the United States were Germany, the Russian Federation, France, the Czech Republic, Italy, and Hungary.

A curriculum analysis showed that the general mathematics assessment given to students in their last year of secondary education covered topics comparable to 7th-grade material internationally and 9th-grade material in the United States. Again, U.S. students scored below the international average, outperformed by 14 countries but scoring similarly to Italy,

Text table 1-4.
Comparison of 8th-grade mathematics and science achievement, by country or economy: 1995 and 1999

Country/economy	1995	1999	Difference[a]
Mathematics			
(Latvia)[b]	488	505	17*
Hong Kong	569	582	13
(Netherlands)	529	540	11
Canada	521	531	10*
(Lithuania)[c]	472	482	10
United States	**492**	**502**	**9**
Cyprus	468	476	9*
Belgium	550	558	8
South Korea	581	587	6
(Australia)	519	525	6
Hungary	527	532	5
Iran	418	422	4
Russian Federation	524	526	2
Slovak Republic	534	534	0
(Slovenia)	531	530	–1
(Romania)	474	472	–1
(England)	498	496	–1
Japan	581	579	–2
Singapore	609	604	–4
Italy	491	485	–6
New Zealand	501	491	–10
(Bulgaria)	527	511	–16
Czech Republic	546	520	–26*
International average	519	521	2
Science			
(Latvia)[b]	476	503	27*
(Lithuania)[c]	464	488	25*
Hong Kong	510	530	20
Canada	514	533	19*
Hungary	537	552	16*
(Australia)	527	540	14
Cyprus	452	460	8
Russian Federation	523	529	7
(England)	533	538	5
(Netherlands)	541	545	3
Slovak Republic	532	535	3
South Korea	546	549	3
United States	**513**	**515**	**2**
Belgium	533	535	2
(Romania)	471	472	1
Italy	497	498	1
New Zealand	511	510	–1
Japan	554	550	–5
(Slovenia)	541	533	–8
Singapore	580	568	–12
Iran	463	448	–15
Czech Republic	555	539	–16
(Bulgaria)	545	518	–27*
International average	518	521	3

*1999 average is significantly different from the 1995 average.

[a]Difference is calculated by subtracting 1995 score from 1999 score. Detail may not add to totals because of rounding.

[b]Only Latvian-speaking schools were tested.

[c]Lithuania tested the same cohorts of students as other locations, but later in 1999, at the beginning of the next school year.

NOTES: Parentheses indicate countries not meeting international sampling and/or other guidelines in 1995, 1999, or both years. The international average is derived from the national averages of 23 locations.Tests for significance take into account the standard error for the reported differences. Thus, a small difference between the 1995 and 1999 averages for one location may be significant, whereas a large difference for another location may not be significant. The 1995 scores are based on rescaled data.

SOURCE: National Center for Education Statistics, *Pursuing Excellence: Comparisons of International Eighth-Grade Mathematics and Science Achievement From a U.S. Perspective, 1995 and 1999*, NCES 2001-028 (Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement, 2000f).

Science & Engineering Indicators – 2002

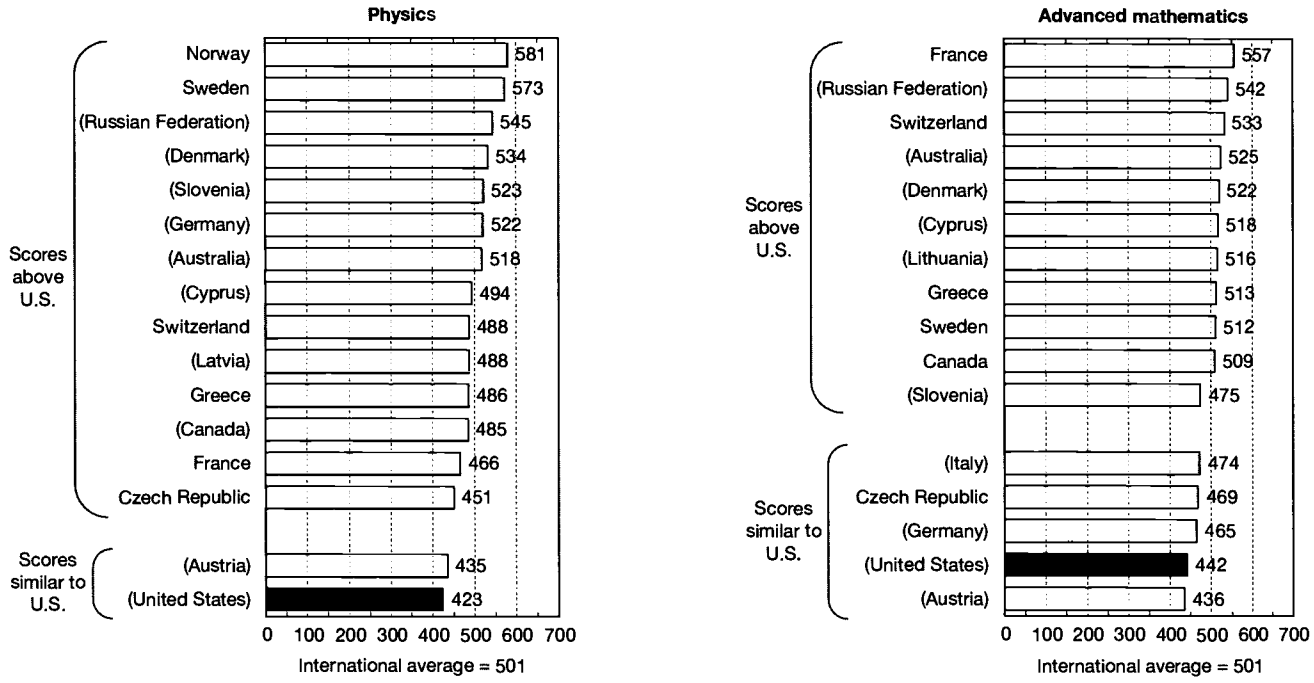
the Russian Federation, Lithuania, and the Czech Republic. As on the general science assessment, only Cyprus and South Africa performed at a lower level. These results suggest that students in the United States appear to be losing ground in mathematics and science to students in many other countries as they progress from elementary to middle to secondary school.

Achievement of Advanced Students. On advanced mathematics and science assessments, U.S. 12th grade students who had taken advanced coursework in these subjects performed poorly compared with their counterparts in other countries, even though U.S. students are less likely to have taken advanced courses than students at the end of secondary school in other countries. The TIMSS physics assessment was administered to students in other countries who were taking advanced science courses and to U.S. students who were taking or had taken physics I and II, advanced physics, or advanced placement (AP) physics (about 14 percent of the entire age cohort). The assessment covered mechanics and electricity/magnetism as well as particle, quantum, and other areas of modern physics. Compared with their counterparts in other countries, U.S. students performed below the international average of 16 countries on the physics assessment. (See figure 1-6.) The mean achievement scores of the United States (423) and Austria (435) were at the bottom of the international comparison (average = 501). Students in 14 other countries scored significantly higher than the United States. The subset of U.S. students taking or having taken AP physics scored 474 on the assessment, similar to scores of all advanced science students in nine other countries, and six countries scored higher (scores ranged from 518 to 581). Only Austria performed at a significantly lower level, with an average score of 435 (NCES 1998b). However, U.S. AP physics students represented a much smaller proportion of the age cohort in the United States (about 1 percent of the relevant age cohort) than did the students taking the advanced physics assessment in most of the other countries. For example, the physics assessment was taken by about 14 percent of the relevant age cohort in Canada, 20 percent in France, 8 percent in Germany, and 14 percent in Switzerland (NCES 1998b).

The advanced mathematics assessment was administered to students in other countries who were taking advanced mathematics courses and to U.S. students who were taking or had taken calculus, precalculus, or AP calculus (about 14 percent of the relevant cohort). One-quarter of the items tested calculus knowledge. Other topics included numbers, equations and functions, validation and structure, probability and statistics, and geometry.

The international average on the advanced mathematics assessment was 501. U.S. students, scoring 442, were outperformed by students in 11 nations, whose average scores ranged from 475 to 557. No nation performed significantly below the United States; Italy, the Czech Republic, Germany, and Austria performed at about the same level. (See figure 1-6.) U.S. students who had taken AP calculus had an average score of 513 and were exceeded only by students in France. Five nations scored significantly lower than the AP calculus students in the United States. Thus, the most advanced mathematics students in the United States (about 5 percent of the

Figure 1-6.
Average scale score on TIMSS physics and advanced mathematics assessment for students in final year of secondary school: 1994–95



TIMSS = Third International Mathematics and Science Study.

NOTE: Countries not meeting international guidelines are shown in parentheses.

SOURCE: I. Mullis, M. Martin, A. Beaton, E. Gonzalez, D. Kelly, and T. Smith. *Mathematics and Science Achievement in the Final Year of Secondary School: IEA's Third International Mathematics Study (TIMSS)* (Chestnut Hill, MA: Boston College, TIMSS International Study Center: 1998).

Science & Engineering Indicators – 2002

relevant age cohort) performed similarly to 10 to 20 percent of the age cohort in most of the other countries. In other words, U.S. calculus students performed at a level similar to a number of other countries, although the percentage of the relevant age cohort (e.g., 17-year-olds) taking the test was significantly lower than in other countries.

Summary of International Assessment Results

Data from TIMSS and TIMSS-R show that U.S. students generally perform comparatively better in science than in mathematics; that students in the primary grades demonstrate the strongest performance, especially in science; that students in grade 8 show weaker performance; and that those in grade 12 show weaker performance still, relative to their counterparts in other countries. Furthermore, while the United States tends to have fewer young people taking advanced math and science courses, students that do take them score lower on assessments of advanced mathematics and physics than do students who take advanced courses in other countries.

Science and Mathematics Coursework

Concerns about both the content and lack of focus of the U.S. mathematics and science curriculum, both as it is stated in state-level curricular frameworks and how it is implemented in the classroom, have appeared in major studies since the early 1980s (NCES 2000d). In 1983, the National Commission on Excellence in Education concluded that the curricular "smorgasbord" then offered in American schools combined with extensive student choice explained a great deal of the low performance of U.S. students (National Commission on Excellence in Education 1983).

Since the publication of *A Nation At Risk* nearly 20 years ago, most states have increased the number of mathematics and science courses required for high school graduation as a way to address this concern. A number of states and districts have also implemented "systemic" or "standards-based" reform efforts in order to align curricular content with student testing and teacher professional development. (See sidebar, "The NGA Perspective on Systemic, Standards-Based Reform"). This section examines state-level changes in curricular requirements, as well as changes in student course-taking patterns. While the impact of these changes on student performance is uncertain, it is clear that more students are taking advanced mathematics and science courses than they were two decades ago.

Changes in State-Level Graduation Requirements

As of 2000, 25 states required at least 2.5 years of math and 20 states required 2.5 years of science; in 1987, only 12 states required that many courses in math and only 6 states required that many courses in science. A survey of states conducted by the Council of Chief State School Officers (CCSSO) in 2000 showed the following state totals for required credits in mathematics and science (CCSSO 2000a):

- Twenty-one states required between 2.5 and 3.5 credits of mathematics and four states required four credits.
- Sixteen states required between 2.5 and 3.5 credits of science and four states required four credits.
- Five states left graduation requirements to local districts.

The National Education Commission on Time and Learning (NECTL) cites research indicating positive effects of strengthened graduation requirements. As schools offered more academic courses, particularly in mathematics and science, more students, including minority and at-risk students, actually enrolled in the courses (National Education Commission on Time and Learning 1994). Data from high school transcripts collected by NCES support this finding. Students took more advanced science and mathematics courses in 1998 than did students who graduated in the early 1980s (NCES 2001c). In 1998, almost all graduating seniors (93 percent) had taken biology, and more than one-half (60 percent) had taken chemistry. (See figure 1-7 and text table 1-5.) In comparison, 77 percent of 1982 seniors had completed biology and 32 percent had completed chemistry. In the class of 1998, more than one-quarter (29 percent) of graduates had completed physics compared with 15 percent of 1982 graduates. Participation rates in AP or honors science courses are considerably lower: 16 percent for biology, 5 percent for chemistry, and 3 percent for physics (NCES 2001c).

In 1998, more graduating students had taken advanced mathematics courses than did their counterparts in the early 1980s (see figure 1-7). In 1998, 62 percent of students had taken algebra II compared with 40 percent in 1982. The 1998 participation rates for geometry and calculus were 75 percent and 11 percent, respectively. Corresponding figures for 1982 were 47 percent in geometry and 5 percent in calculus. The percentage of graduates taking AP calculus rose from 1.6 to 6.7 percent over the same period (NCES 2001c).

From 1982 to 1998, there was a corresponding decrease in the percentage of graduates who took lower level mathematics courses. For example, the average number of Carnegie units in mathematics earned by graduates increased from 2.6 to 3.4 between 1982 and 1998, but the average number of units earned in courses at a lower level than algebra declined from 0.90 to 0.67 (NCES 2001c).[6]

Differences in Course Participation by Sex

Given the established association between courses taken in high school and later educational outcomes (J. Smith 1996; Sells 1978), the lower representation of females throughout the science, mathematics, and engineering pipeline has been

The NGA Perspective on Systemic, Standards-Based Reform

According to the National Governors Association (NGA), systemic, standards-based education reform centers on the premise that all students can achieve at high levels and is based on rigorous academic standards for student learning. This is a comprehensive approach that aligns numerous educational policies, practices, and strategies, including:

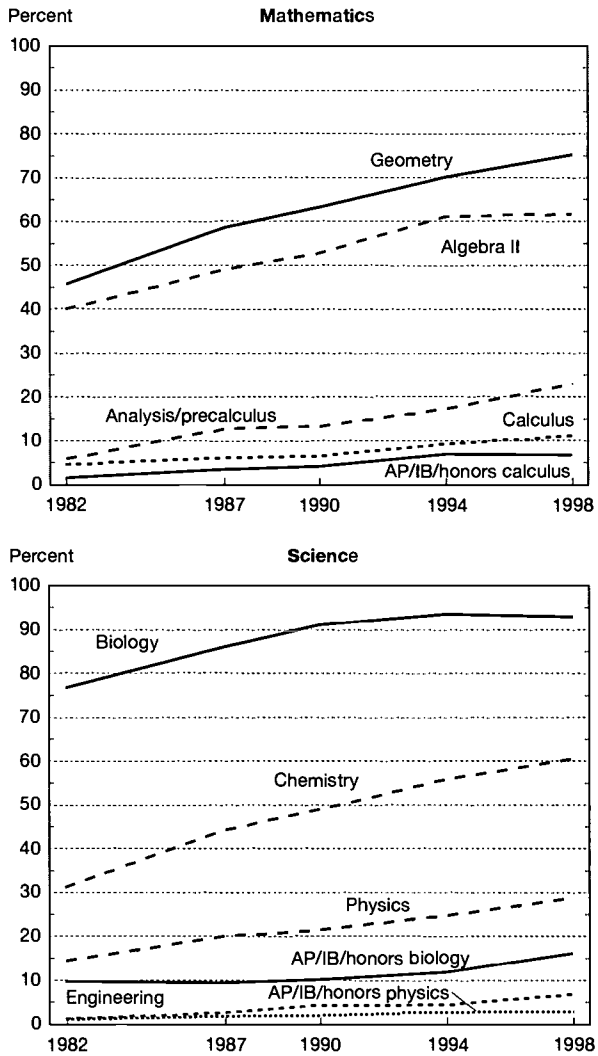
- **Content standards**—standards that reflect subject-matter benchmarks;
- **Performance standards**—standards that clarify the benchmarks to be obtained;
- **Student assessments**—tests that measure student performance against content and performance standards;
- **An accountability system**—a system that monitors student and school performance;
- **Teacher preparation**—licensure requirements that permit someone to teach;
- **Professional teacher development**—activities that provide continued learning opportunities;
- **A governance structure**—a structure that defines how decisions are made; and
- **Public support**—tools that help the public understand the education reforms.

The premise underlying systemic, standards-based reform is that rigorous academic standards make achievement expectations clear. In principle, standards detail what students should know and be able to do in various subjects at each grade level or at specified benchmark grade levels. High-quality assessments can then measure student progress toward meeting the standards and provide parents, teachers, and policymakers with information about student progress. A strong accountability system is one that holds schools, educators, and students accountable for making sure students achieve the established standards. A solid system also recognizes high-performing or improving students and schools for their success and provides assistance and guidance to struggling students and schools.

SOURCE: National Governor's Association Center for Best Practices, n.d.

[6] The Carnegie unit is a standard of measurement that represents one unit of credit for the completion of a one-year course.

Figure 1-7.
Percentage of high school graduates who took selected mathematics and science courses: 1982, 1987, 1990, 1994, and 1998



AP = Advanced Placement; IB = International Baccalaureate

SOURCE: National Center for Education Statistics, *The 1998 High School Transcript Study Tabulations: Comparative Data on Credits Earned and Demographics for 1998, 1994, 1990, 1987, and 1982 High School Graduates*, NCES 2001-498, Washington DC: U.S. Department of Education, Office of Educational Research and Improvement: 2001a.

Science & Engineering Indicators – 2002

a cause for concern. Therefore, there has long been an interest in tracking sex differences in the patterns of advanced mathematics and science courses taken in high school.

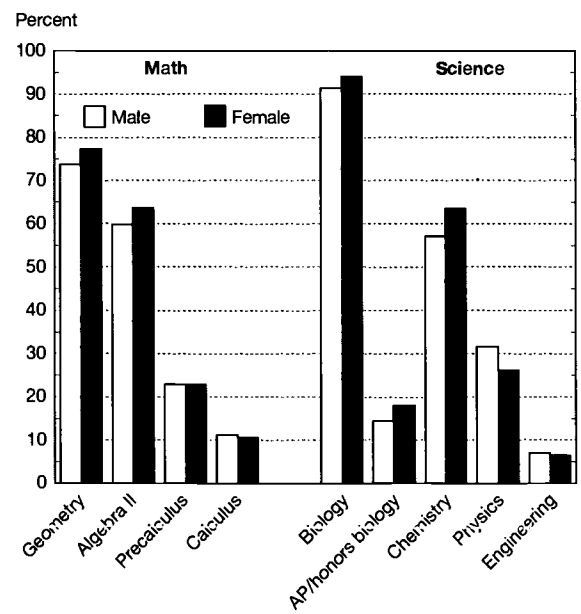
Both female and male students are following a more rigorous curriculum than they were two decades ago, and female graduates in 1998 were more likely than males (58 versus 53 percent) to have completed the "New Basics" curriculum, composed of four units of English and three units each of science, social studies, and mathematics, as recommended in *A Nation At Risk* (NCES 2000b). Comparison of the transcripts of high school graduates indicates that female and male students have broadly similar coursetaking patterns, although there are some differences. Female students are as likely as males to take advanced math and science courses but are more likely to study a foreign language. Between 1982 and 1992, the percentage of both female and male graduates who took advanced mathematics and science courses in high school increased, although for many subjects parity between the sexes had been attained by 1982 (NCES 2000b). In the class of 1998, females were less likely than males to take remedial mathematics in high school but at least as likely as their male peers to take upper level mathematics courses such as algebra II, trigonometry, precalculus, and calculus. (See figure 1-8 and text table 1-5.) With respect to science, females were more likely than males to take biology and chemistry. Females have continued, however, to be less likely than males to take physics (NCES 2000b).

Research has shown that once females begin science courses, they are taught similar amounts of science and receive grades similar to (or better than) those of their male counterparts (Hanson, Schaub, and Baker 1996; Baker and Jones 1993; DeBoer 1984).

Differences in Course Participation by Race/Ethnicity

Students from racial/ethnic groups that are typically underrepresented in science have made substantial gains in both the total number of academic courses taken in high school and in the number of advanced mathematics and science

Figure 1-8.
Percentage of 1998 high school graduates who took selected mathematics and science courses in high school, by sex



SOURCE: National Center for Education Statistics, *Trends in Educational Equity of Girls and Women*, NCES 2000-030 (Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement: 2000h).

Science & Engineering Indicators – 2002

Text table 1-5.
High school graduates who completed selected mathematics and science courses in high school, by sex and race/ethnicity
(percentages)

					1998							
								Race/ethnicity				
Courses (Carnegie units)	1982	1987	1990	1994	Total	Male	Female	White	Black	Hispanic	Asian/ Pacific Islander	American Indian/Alaskan Native
Mathematics[a]												
Any mathematics (1.0)	98.5	99.0	99.9	99.8	99.8	99.8	99.8	99.8	99.9	99.8	100.0	99.7
Algebra I (1.0)[b]	55.2	58.8	63.7	65.8	62.8	62.0	63.6	63.5	62.3	61.4	56.8	63.3
Geometry (1.0)	47.1	58.6	63.2	70.0	75.1	73.7	77.3	77.7	72.5	62.3	75.9	57.2
Algebra II (0.5)[c]	39.9	49.0	52.8	61.1	61.7	59.8	63.7	64.6	55.6	48.3	70.1	46.6
Trigonometry (0.5)	8.1	11.5	9.6	11.7	8.9	8.2	9.7	10.0	4.8	5.6	11.7	5.5
Analysis/precalculus (0.5)	6.2	12.8	13.3	17.3	23.1	23.1	22.8	25.0	13.8	15.3	41.3	16.4
Statistics/probability (0.5)	1.0	1.1	1.0	2.0	3.7	3.4	3.9	4.3	2.1	1.7	3.8	3.7
Calculus (1.0)	5.0	6.1	6.5	9.3	11.0	11.2	10.6	12.1	6.6	6.2	18.4	6.2
AP/IB calculus (1.0)	1.6	3.4	4.1	7.0	6.7	7.3	6.4	7.5	3.4	3.7	13.4	0.6
Science												
Any science (1.0)	96.4	97.8	99.3	99.5	99.5	99.5	99.6	99.5	99.3	99.3	99.4	99.4
Biology (1.0)	77.4	86.0	91.0	93.2	92.7	91.4	94.1	93.7	92.8	86.5	92.9	91.3
AP/IB honors biology (1.0)	10.0	9.4	10.1	11.9	16.2	14.5	18.0	16.7	15.4	12.6	22.2	6.0
Chemistry (1.0)	32.1	44.2	48.9	55.8	60.4	57.1	63.5	63.2	54.3	46.1	72.4	46.9
AP/IB honors chemistry (1.0)	3.0	3.5	3.5	3.9	4.7	4.9	4.7	4.8	3.5	4.0	10.9	0.9
Physics (1.0)	15.0	20.0	21.6	24.5	28.8	31.7	26.2	30.7	21.4	18.9	46.4	16.2
AP/IB honors physics (1.0)	1.2	1.8	2.0	2.7	3.0	4.0	2.1	3.0	2.1	2.1	7.6	0.9
Engineering (1.0)	1.2	2.6	4.2	4.5	6.7	7.1	6.5	7.9	4.8	2.3	5.2	9.6
Astronomy (0.5)	1.2	1.0	1.2	1.7	1.9	2.4	1.5	2.4	0.9	0.8	1.0	2.1
Geology/earth science (0.5)	13.6	13.4	24.7	22.9	20.7	21.5	20.1	21.5	24.2	15.9	9.5	21.7
Biology and chemistry (2.0)	29.3	41.4	47.5	53.7	59.0	55.4	62.3	62.0	53.0	43.7	69.5	43.2
Biology, chemistry, and physics (3.0)	11.2	16.6	18.8	21.4	25.4	27.4	23.7	27.6	17.4	15.9	40.2	14.2

AP = Advanced placement; IB = International Baccalaureate

[a]Data include only percentage of students who earned credit in each course while in high school and do not count those students who took these courses before entering high school. Many students now take algebra I in 8th grade.

[b]Excludes prealgebra.

[c]Includes algebra II/trigonometry and algebra II/geometry.

NOTE: A Carnegie unit is a standard of measurement that represents one unit of credit for the completion of a one-year course.

SOURCES: National Center for Education Statistics, *Digest of Education Statistics 2000*, table 140, NCES 2001-034, (Washington DC: U.S. Department of Education, Office of Educational Research and Improvement, 2001b).

Science & Engineering Indicators – 2002

courses taken, although the range in coursetaking patterns remains wide. The emphasis on academic coursetaking is reflected by the increase in the percentage of high school graduates in all racial/ethnic groups taking the "New Basics" curriculum. The proportion of 1998 high school graduates who took this core curriculum ranged from about 40 percent for Hispanics and American Indians/Alaskan Natives, to 56 percent for blacks and whites, to 66 percent for Asians/Pacific Islanders. This is a substantial increase from 1982, when only 14 percent of graduates took this stringent curriculum (NCES 2001c).

Students in all racial and ethnic groups are taking more advanced mathematics and science courses, although black, Hispanic, and American Indian/Alaskan Native graduates still lag behind their Asian/Pacific Islander and white counterparts in advanced mathematics and science coursetaking. For example, the percentage of graduates in the class of 1998 who had taken algebra II ranged from 47 percent of American Indians/ Alaskan Natives to 70 percent of Asians/Pacific Islanders. Percentages for white, black, and Hispanic graduates were 65, 56, and 48 percent, respectively. (See text table 1-5.) Furthermore, Asians/Pacific Islanders were a third more likely than whites to take calculus (18 versus 12 percent) and approximately three times more likely than blacks, Hispanics, and American Indians/Alaskan Natives (about 6 percent each). Also, although 46 percent of Asian/Pacific Islander graduates took physics in high school, blacks, Hispanics, and American Indians/Alaskan Natives were less than half as likely to do so (NCES 2001c). From a coursetaking perspective at least, it appears that all racial and ethnic groups are better prepared for college today than they were in the early 1980s, although blacks, Hispanics, and American Indians/Alaskan Natives are less prepared than their Asian/Pacific Islander and white peers.

Both prior achievement and peer choices appear to strongly influence coursetaking in high school. Although some researchers have found that minority and low socioeconomic

status (SES) students are more likely to be assigned to lower curriculum tracks in high school, even after ability is held constant (Oakes 1985; Rosenbaum 1980, 1976), others have found that verbal achievement scores and the expectations and guidance of others (parents, teachers, guidance counselors, and peers) are influenced by race and SES and that these mediating variables then influence track placement (Cicourel and Kituse 1963; Rosenbaum 1976; Erickson 1975; Heyns 1974). Fordham and Ogbu (1986) argue that one major reason black students do poorly in school is that they experience inordinate ambivalence and affective dissonance with regard to academic effort and success. They argue that because of these social pressures, many black students who are academically able do not muster the necessary perseverance in their schoolwork. (See sidebar, "Advanced Placement Test Results.")

Impact of Coursetaking on Student Learning

On balance, it appears to be too early to draw general conclusions about the quality of either the new courses required in state-level curriculums or the advanced mathematics and science courses that more and more students are taking. Studies of "dilution" of course content are mixed and not uniform across all students. Moreover, many of these studies were conducted in only a handful of states and school districts and for only a handful of courses, with the earlier studies having

Advanced Placement Test Results in Urban Schools

A recent study by the Council of the Great City Schools (GCS), titled *Advancing Excellence in Urban Schools: A Report on Advanced Placement Examinations in the Great City Schools,* examined advanced placement (AP) coursetaking patterns and subject test results in America's urban schools. The council conducted the analysis in collaboration with the College Board, which offers AP courses and exams in 33 subjects. Findings were based on approximately 38,000 AP test results from 58 GCS districts in the spring of 1999. Results showed that:

- Mean AP test scores for GCS students were more likely to be below the 3.0 needed to earn college credit than were the scores of students nationally, whose mean AP test scores were slightly above 3.0.
- African American GCS students were more likely to take AP exams in English language, biology, and English literature; they were least likely to take calculus BC and physics C (electricity and magnetism) exams.
- Hispanic GCS students were most likely to take English literature, calculus AB, and physics B exams; they were least likely to take calculus BC and computer science A exams.
- Asian American GCS students were most likely to take calculus BC and physics C (electricity and magnetism) exams; they were least likely to take AP exams in English language and English literature.
- GCS students posted their highest average AP scores in calculus (3.3) and lowest average scores in physics and chemistry (2.2).
- GCS students who had taken more core courses outscored those who had taken fewer core courses. For this study "core" academic preparation was defined as the courses in each content area that many college admissions officers use to determine proper academic preparation for an incoming first-year college student. For example, the core includes three years of mathematics, such as one year credit each for Algebra 1, Algebra 2, and Geometry and one-half year credit each for Trigonometry, Calculus (not Precalculus), other mathematics courses beyond Algebra 2, and Computer Mathematics/Computer Science. The core also includes three years of science reasoning, such as one year credit each for General/Physical/Earth Science, Biology, Chemistry, and Physics.
- Nationally, students with core or more academic preparation attained higher AP subject test scores than GCS students with similar academic preparation. African American test-takers in the GCS were less likely to have taken core courses in Biology and Chemistry than all other racial groups in the GCS. Hispanic test-takers in the GCS were more likely to have taken core courses in Chemistry than all other racial groups in the GCS.
- AP scores nationally and in GCS were strongly related to family income. Students nationally outscore their GCS counterparts at each household income bracket. The only GCS students who had average scores of 3.0 or above in any AP subject were those with household incomes greater than $80,000.
- White students were likely to outperform other students nationally and in GCS. White students in the national sample had higher AP subject test scores than their white counterparts in the GCS. African American students in the GCS scored lower than their counterparts in the national sample.

The Council of the Great City Schools consists of 57 urban school districts (out of 16,411 in the United States) and enrolls about 14 percent of the students attending U.S. public schools. These districts serve a larger proportion of minority students than the national average (73 percent of students were black or Hispanic in 1999), and the majority are poor (63 percent are free-lunch eligible compared with 35 percent of students nationally).

SOURCE: Council of the Great City Schools (CGCS) and the College Board. 2001. *Advancing Excellence in Urban Schools: A Report On Advanced Placement Examinations in the Great City Schools.* Washington, DC <http://www.cgcs.org/reports/home/ap_1999.htm> and Key Facts: 1997–98 Data About Council Member Districts <http://www.cgcs.org/reports/data/index.cfm>.

been conducted not long after the increased requirements were enforced. Thus, there may have been little opportunity for revisions and improvement.

Several studies point to possible negative effects of stronger coursetaking requirements. For example, minority and at-risk students failed more courses than they did before stronger mandates were put into practice (NECTL 1994). Opinions differ on the quality of the additional courses taken, especially those taken by low-achieving students. There has been particular concern about the quality of new mathematics courses designed for low achievers, who, under a traditional curriculum, would have taken general or basic mathematics. Research suggests that implementation of state-level mandates for stronger coursetaking requirements varies greatly across districts and schools. Studying 18 high schools in 12 districts in 6 states, Porter, Smithson, and Osthoff (1994) found some schools pushing students into demanding content in higher level course while others did not. Furthermore, Gamoran (1997) found that bridging courses, those designed to prepare lower achieving students for college-preparatory courses, achieved some success in improving student achievement. Research in this area is inadequate, however, for evaluating whether or not the increase in state-level curricular requirements have changed the level of difficulty or quality of mathematics and science courses offered to students.

Additional studies accessing the content of the mathematics curriculum, as well the quality of 8th grade mathematics instruction, are described in the section on Curriculum and Instruction. Strengthening course-taking requirements is only one component of most educational reform strategies, however. The next section examines states' attempts to implement state-wide curricular frameworks, as well as assessments of the underlying content.

Content Standards and Statewide Assessments

In the 1980s, most states approved policies aimed at improving the quality of K–12 education, implementing statewide curriculum guidelines and frameworks as well as assessments. At present, half of the states require students to pass some form of exit examination to graduate from high school, and others report developing such tests (CCSSO 2000a). Underlying this reform agenda is the assumption that these standards and assessments will lead to higher student achievement. However, assessments and standards are not always tightly linked, and the implied performance incentives for students, teachers, and administrators vary across states. Furthermore, there is concern that some state-level assessments focus too much on facts, even though the associated standards call for complex scientific inquiry. This section reviews the national data available concerning the implementation of standards and assessments across states. Particular attention is paid to the alignment of these new standards and assessments to student achievement by reviewing recent research in this area.

Adoption of Content Standards

State-level content standards are typically intended to provide the basis for state and local decisions on curriculum, texts, instructional materials, student assessments, teacher preparation and professional development, and other components of programs of instruction (CCSSO 2000a). CCSSO reported that, by 2000, 49 states had established content standards in mathematics and 46 states had established standards in science (CCSSO 2000a). Teachers remain concerned, however, that standards do not always provide clear guidance regarding the goals of instruction and that schools do not yet have access to top-quality curriculum materials aligned with the standards (Achieve 2000). The next section highlights some issues regarding the degree to which states require or facilitate the alignment between instructional materials and standards.

Statewide Policies on Textbooks and Standards

One way that states can influence the implementation of mathematics and science standards is to select or recommend textbooks and curriculum materials for schools that are aligned with their standards. Fewer than half of the states, however, mandate or recommend particular textbooks and curriculum materials. The Council of Chief State Officers reported that a total of 21 states had a state policy regarding textbooks and curriculum materials for classrooms, as of spring 2000 (CCSSO 2000a). Among the total, 11 have a state policy defining state selection of textbooks and materials to be used and another 10 recommend texts or materials to the local districts. In 2000, 20 of the 21 states with a textbook policy use their state content standards to select or recommend curriculum materials, the same as in 1998.

Some examples of state policies on textbooks include California, where content standards and frameworks are used to select the materials that will be adopted by the State Board of Education and recommended to school districts and Tennessee, where the state adopts an approved list of curricular materials from which local schools boards may then choose and receive state funds. These policies contrast with those of Alaska and New Jersey, where textbook selection decisions are left up to the local boards. As noted above, most states do not have a statewide policy on aligning textbooks and standards (CCSSO 2000a). (See sidebar, "States Band Together to Create a Market for Standards-Based Materials").

State Assessment Programs in Mathematics and Science

Nearly all states conduct statewide assessments in mathematics, although the grades assessed and the type of test vary widely. Results of the most recent CCSSO Annual Survey of State Student Assessment Programs (for the 1998/99 school year) show that 48 states have a statewide program in one or more subjects (CCSSO 2000a). Although many states have administered statewide assessments of student learning since the 1970s, additional states approved policies requiring

States Band Together to Create a Market for Standards-Based Materials

Although some states set statewide curriculums and approve textbooks for statewide use, the development and use of curricular materials is typically the responsibility of a local school district or a school. Because most of the materials used in schools come from commercial publishers, obtaining curricular materials that are well aligned to a school's curriculum is a challenge. One way in which states can influence the development of standards-based materials is by banding together to create a larger market. One example of this is the Mathematics Achievement Partnership (MAP), a consortium of 11 states brought together by Achieve, Inc., an independent, bipartisan, nonprofit organization created by governors and corporate leaders to help raise standards and performance in American schools. MAP is developing a common set of expectations for middle school mathematics, and participating states will administer an 8th-grade assessment based on these expectations. Although the partnership plans to develop materials, it may also create enough of a market to encourage publishers to align their materials with the expectations the states have jointly produced.

SOURCE: Achieve 2000.

statewide student testing throughout the 1980s and 1990s, and the number of subjects and grades to be assessed increased. Important factors in the growth of state policies are greater interest in accountability tied to student performance; needs for assessing learning growth related to policies and programs; and federally funded programs linked to state assessments of learning, such as Title I and the Individuals with Disabilities Education Act (CCSSO 2000a).

In academic year 1998/99, 48 states required statewide assessments in mathematics, up from 34 states in 1984 and 45 states in 1994; 23 states started at grade 3 or earlier and nearly all states assessed at least one grade near the end of high school. Thirty-one states administered norm-referenced tests and 40 administered criterion-referenced tests (CRT).[7] Twenty-five states administered both, depending on the grade and the purpose of the assessments. All states had multiple-choice items on their tests, although 26 states included short-answer questions and 27 included extended-response items as well. Only two states included individual performance assessments as part of their testing program, and another two included reviews of portfolios or learning records.

Fewer states have statewide assessment programs in science; there were 33 in 1998/99, up from 13 in 1983/84 and 30 in 1993/94. Among these states, 19 administer norm-referenced tests, 23 administer criterion-referenced tests, and 9 use some combination of both at different grades. As with mathematics, multiple-choice items are included on each state's tests, although 12 states include short-answer questions, 12 states include extended-response items, and 6 states included some means of performance assessment (CCSSO 2000a).

Public Support for Standards and Testing

Although some states have recently delayed the introduction of high-stakes tests (i.e., tests that students must pass to either graduate or advance a grade), public support for standards and testing remains strong. In September 2000, the nonprofit, nonpartisan research organization Public Agenda conducted a national survey of parents to gauge whether there had been backlash against standards. The study contained both a nationally representative sample of parents and a sample of parents in districts that are actually implementing higher academic standards (Public Agenda 2000).[8]

This study found that only 2 percent of parents who knew that their school district was implementing higher academic standards wanted to return to previous practice. Fifty-three percent wanted to continue with the effort as planned, and one in three (34 percent) wanted to continue with some adjustments. Additional interviews in Boston, Chicago, Cleveland, Los Angeles, and New York (five cities with highly visible efforts to raise standards) returned similar results. More than 8 in 10 (82 percent) parents who knew their school district was implementing higher standards believed their schools had, in fact, been "careful and reasonable" in putting the new standards in place.

Relatively few parents in the study said that their child's school requires them to take too many standardized tests to the detriment of other important learning (11 percent), that teachers in their child's school "focus so much on preparing for standardized tests that real learning is neglected" (18 percent), or that their child receives too much homework (10 percent). Furthermore, three out of four parents agreed that "students pay more attention and study harder if they know they must pass a test to get promoted or to graduate," and a similar proportion agreed that "requiring schools to publicize their standardized test scores is a wake-up call and a good way to hold schools accountable."

Parents did not feel, however, that promotion or graduation decisions should be based on a single test. Almost 8 in 10 (78 percent) agreed that "it's wrong to use the results of just one test to decide whether a student gets promoted or graduates." (See sidebar, "Employer and College Professor Perceptions of How Well Young People Are Prepared for Work and College.")

[7]Norm-referenced tests compare the scores of test takers with those of a representative, usually national, sample of students who have taken the test previously. Criterion-referenced tests (CRTs) are designed to indicate the degree of mastery of skills that have been taught. CRTs report how well students are doing relative to a predetermined performance level on a specified set of educational goals or outcomes included in the school, district, or state curriculum (Bond 1996).

[8]This survey was based on a national random sample telephone survey of 803 parents of public school students in grades K–12. The margin of error for the national sample is ±3 percentage points. Oversamples were conducted with at least 200 additional parents of students who attend public schools in Boston, Chicago, Cleveland, Los Angeles, and New York, where the margin of error for each oversample city is ±7 percentage points.

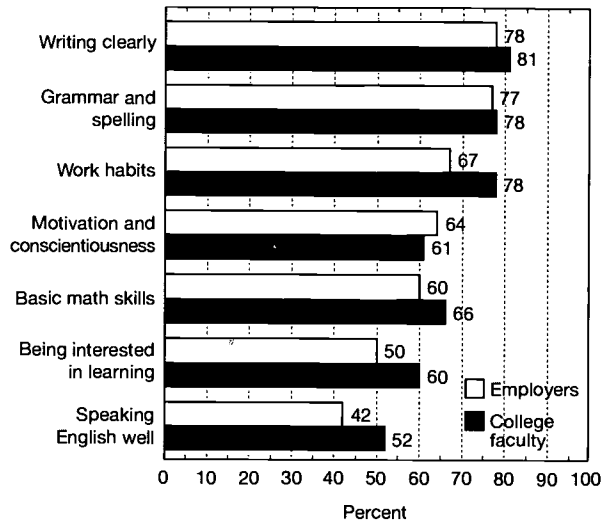
Employer and College Professor Perceptions of How Well Young People Are Prepared for Work and College

Employers and professors are far more disapproving than parents or teachers of how well young people are prepared for college and work, and very large majorities continue to voice significant dissatisfaction about students' basic skills. This finding comes from a recent "Reality Check" Survey by Public Agenda, a nonprofit, nonpartisan research group. (See figure 1-9.) This survey tracks whether efforts to set high education standards have made a difference by interviewing the students and teachers in public schools, the parents of those students, and the employers and college professors who deal with recent graduates. Employers and college professors were asked how they would rate recent job applicants/freshmen and sophomores across different topics, including clear writing, work habits, motivation and conscientiousness, and basic math skills. About two-thirds of professors found the basic math skills of recent freshmen and sophomores to be only "fair" or "poor." About 80 percent stated that student ability to write clearly was only "fair" or "poor." These results point to the continuing gap between student skill level and preparation for college and college professor views of the adequacy of that preparation. Results were similar for employers regarding recent job applicants. Both professors and employers support testing, with employers more likely to support testing of basic skills and professors more likely to support a test "showing that they (high school graduates) have learned at higher levels." Less than 10 percent of both groups reported thinking that "requiring kids to pass a test" before receiving a high school diploma is a "bad idea." (See figure 1-10.)

The responses above were derived from telephone interviews conducted in November and December 2000 with national random samples of 251 employers who make hiring decisions for employees recently out of high school or college and 254 professors at two- and four-year colleges who taught freshmen or sophomores in the last two years. The margin of error for employers and college professors is ±6 percentage points.

SOURCE: Public Agenda Online 2001.

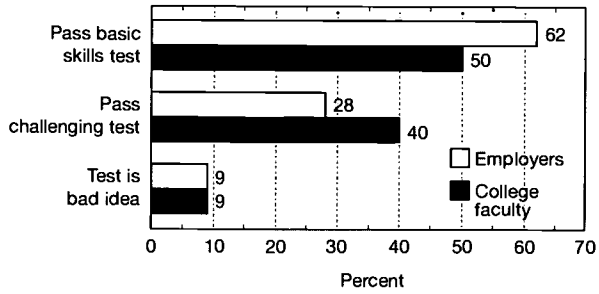
Figure 1-9.
Percentage of employers and college faculty who rated job applicants/freshman and sophomore students as "fair" or "poor" on various activities: 2000



SOURCE: Public Agenda, *Reality Check 2001*, http://www.publicagenda.org/specials/rc2001/reality6.htm. Accessed 8/20/2001.

Science & Engineering Indicators – 2002

Figure 1-10.
Employee/faculty support for high stakes testing: 2000[a]



[a]Data are based on responses to the following question:
Before students are awarded a high school diploma, would you want the school district where you work/teach to require students to pass a basic skills test in reading, writing, and math; pass a more challenging test showing they have learned at higher levels; or do you think requiring kids to pass a test is a bad idea?

SOURCE: Public Agenda, *Reality Check 2001*, http://www.publicagenda.org/specials/rc2001/reality6.htm. Accessed 8/20/2001.

Science & Engineering Indicators – 2002

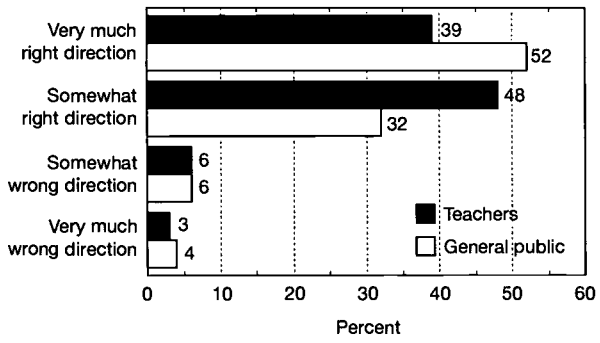
Attitudes of Teachers on Academic Standards and State Testing

The success of reforms based on state-wide standards and high-stakes testing rests to a large extent on the commitment of teachers to align their teaching to the standards. In September 2000, *Education Week* sponsored a survey of public school teachers to find out whether they thought that the academic standards being put into place are helping them teach children better. Specifically, teachers were asked whether they find the standards useful or a hindrance, whether they have enough time and resources to understand the standards and integrate them successfully into their lesson plans, and whether they feel the current tests are helping to assess student abilities or are taking up too much classroom time. Finally, teachers were asked whether they believe students are learning more (Belden, Russonello, and Stewart Research and Communications 2000). The findings of this survey are summarized below.

How Do Teachers View Academic Standards?

Public school teachers generally support the movement to raise standards, but they are less supportive than the general public. (See figure 1-11.) Nearly 9 out of 10 teachers said that raising academic standards for what students should learn each year and before they graduate is a move in the right direction, 39 percent said it is very much in the right direction, and 48 percent said it is somewhat in the right direction. Nearly three-quarters of teachers said that the academic standards for students in the state where they live are "about right," 5 percent said the standards are too high, and only 7 percent said that standards are too low. These findings were similar for mathematics and science teachers.

Figure 1-11.
Opinion of teachers and general public on move to raise academic standards: 2000



NOTE: Data are based on answers to the following:
Many states are adopting new standards for what students should learn each year before they graduate. In general, do you believe the emphasis on raising academic standards is a move in the right or in the wrong direction?

SOURCE: Belden, Russonello, and Stewart Research and Communications, *Making the Grade: Teachers' Attitudes Toward Academic Standards and State Testing: Findings of National Survey of Public School Teachers for Education Week* (Washington, DC: 2000).

Science & Engineering Indicators – 2002

A larger proportion of the general public supports the direction of the standards movement, and these supporters are more likely than teachers to say that the current standards are too low. On a national survey conducted in August 2000, 52 percent of Americans believed the movement to adopt new standards is very much in the right direction, and 32 percent believed that it is somewhat in the right direction (Public Agenda 2000). Only 42 percent of the general public said that the current standards are about right, 5 percent said they are too high, and 47 percent said they are too low.

Do Teachers Believe That Their Students Are Meeting Standards?

Nearly two-thirds of public school teachers said that all or most of their students are currently meeting the standards for their grade, and only 8 percent said that a few or none of their students are meeting standards. Suburban teachers, teachers in schools where fewer than 10 percent of students are receiving free lunch, and teachers in states with exit examinations were more likely to report that their students were meeting the standards. Teachers in schools with a high percentage of minority students were less likely to say that all or most of their students are meeting the standards.

Do Teachers Think That the Curriculum Has Become More Demanding of Students?

The vast majority of teachers feel that the curriculum is becoming more demanding of students. In the 2000 study cited above, 79 percent of teachers reported that the curriculum is more demanding of students than three years ago: 39 percent reporting a lot more and 40 percent reporting somewhat more. Only 17 percent reported that there has been no change, and 4 percent reported that the curriculum has become less demanding. Elementary school teachers were more likely to say the current curriculum is more demanding, and middle and high school teachers were more likely to say that there has been no change in the level of the curriculum. Teachers in states with exit exams, those teaching a high percentage of minority students, and those teaching where standards have been put in place more recently (since 1995) were more likely than other teachers to report that the curriculum has become more demanding over the three-year period.

Among teachers who reported that the curriculum is more demanding, nearly two-thirds said that this change is the result of new statewide academic standards. An additional 20 percent responded that a combination of other factors and the standards have resulted in the more demanding curriculum, and 16 percent said that it was due solely to other factors. Math teachers were more likely than English, science, or social studies teachers to report new standards as having made the curriculum more demanding, as were teachers in schools where more than 10 percent of the students received free lunch.

How Do Teachers View Testing?

Have the new statewide standards led to teaching that focuses too much on state tests? Two-thirds of teachers said that this is the case: a third stated that statewide standards

had led to far too much time focused on testing, and another third indicated that this was somewhat the case. Most of the remaining teachers said that the focus is just right. Similarly, two-thirds of the teachers surveyed agreed more with the statement, "State testing is forcing you to concentrate too much on information that will be on the test to the detriment of other important areas" as opposed to "State testing is helping you as a teacher to focus on teaching what children really need to know."

How Much Do Teachers Integrate Standards and Testing Into Their Teaching?

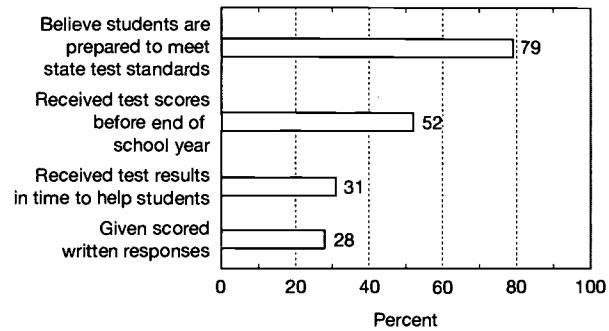
The 2000 *Education Week* survey of public school teachers cited above also indicates that teachers feel prepared to implement state standards in their classrooms, more so than in the previous year (Belden, Russonello, and Stewart Research and Communications 2000). Almost all of the public school teachers (94 percent) reported that they have a copy of the statewide academic standards, and 84 percent said that they have modified their curriculum to reflect the standards (36 percent a "great deal" and 48 percent "somewhat"). A similar proportion said that they have adopted or developed modules, units, or lesson plans linked to the state standards.

A significant amount of "teaching to the test" appears to occur, but using these tests as diagnostic tools is also quite widespread. Nearly 8 out of 10 teachers reported instructing their classes in the previous year in test-taking skills, such as pacing themselves and filling in bubbles clearly (45 percent "a great deal" and 34 percent "somewhat"); 7 out of 10 teachers reported using individual results to help diagnose what students need (36 percent "a great deal" and 34 percent "somewhat"); and 6 out of 10 teachers reported using results to diagnose what they need to be teaching in their classes (32 percent "a great deal" and 42 percent "somewhat"). Nearly two-thirds of teachers said that they had amended what they taught in the previous year to fit what is on the state tests (22 percent "a great deal" and 43 percent "somewhat"). (See sidebar, "High School Teachers Have a Generally Favorable Opinion of State Graduation Tests.") (See figure 1-12.)

While the data in this section have shown that the vast majority of states have adopted content standards in mathematics and science and that state-wide testing in these subjects is increasing, a number of studies raise concerns over the degree to which state tests align with state standards. For example a recent study from the American Federation of Teachers found that "no state or the District of Columbia has a fully developed standards-based system that links quality standards to tests, curriculum and accountability measures" (AFT 2001). This study found that:

- Almost a third of the states' tests are based on weak standards;
- Forty-four percent of those tests are not aligned to the standards;
- Fewer than one-third of the tests are supported by adequate curriculum; and

Figure 1-12.
Opinion on preparation for and utility of state test by public high school teachers whose state has graduation test: 2000



NOTE: Data are based on responses to the following questions:
Q51. Are students well prepared enough to meet the standards on the tests, or are they ill prepared?
Q52. Last year, did you receive your students' scores on the state exams before the end of the year?
Q53. Last year, did you receive your individual students' test results early enough in the year or too late to be helpful in working with those individuals?
Q55. Are you given copies of your students' scored written responses on the state exams?

SOURCE: Belden, Russonello, and Stewart Research and Communications, *Making the Grade: Teachers' Attitudes Toward Academic Standards and State Testing: Findings of National Survey of Public School Teachers for Education Week* (Washington, DC: 2000).

Science & Engineering Indicators – 2002

- One-third of the tests used in decisions regarding promotion or graduation are not aligned to the standards.

While other studies come up with different numbers, the problem of alignment between standards, testing, instruction and accountability remains a common theme (e.g., Achieve, Inc. 2001; CCSSO 2001; Finn and M.J. Petrilli 2000). (See sidebar, "A Survey of Curriculum Use in Classrooms.") Data presented in this section show that both teachers and the general public support standards and testing, although the latter more strongly than the former. The next section examines how the organization of the math and science curriculum in the United States differs from other countries and reviews current measures of the quality of mathematics instruction.

Curriculum and Instruction

Debate continues over the effectiveness of two distinct instructional approaches: (1) emphasis on drill and practice activities in which students work toward skill mastery and (2) emphasis on reasoning, conceptual understanding, and skill application. This debate is driven by differences in opinion regarding the nature of the curriculum as well as different theories about how people learn. Although whole-group instruction and worksheets are still commonly used , the majority of American teachers report using small-group instruction as well as using manipulatives or models to dem-

High School Teachers Have a Generally Favorable Opinion of State Graduation Tests

In the 2000 survey of public school teachers conducted for *Education Week,* a series of questions on testing was asked of public high school teachers who reported that they have a state graduation test. Generally, these high school teachers have favorable opinions of the graduation test.

- A majority (54 percent) believed that the graduation test in their state is appropriate. Only 1 in 10 (13 percent) believed it is too difficult, and 15 percent believed it is too easy. Twenty percent (2 in 10) were unable to offer an opinion of the test.
- A total of 8 in 10 (79 percent) reported that their students are well prepared to meet the standards on the tests. Only 1 in 10 (13 percent) believed that their students are ill prepared.

These high school teachers differed widely, however, on whether the tests are helpful as a diagnostic tool.

- Fifty-eight percent of the teachers reported that test results are helpful for improving their own teaching. Only 1 in 10 (11 percent) found the test results very helpful, and 47 percent said they are somewhat helpful. One-quarter of high school teachers said the results are not at all helpful.

One reason these high school teachers may not find the tests more useful is that the teachers are not receiving the results, or if they are, they are not receiving them in time to implement changes.

- Only half (52 percent) of these high school teachers received their students' scores on the state exams before the end of the year.
- Only 3 in 10 (31 percent) said they received the test results early enough to help individual students.
- Only 3 in 10 (31 percent) were given copies of their students' scored written responses on the state tests.

NOTE: Based on a sample of 173 high school teachers who said their state has a graduation test.

SOURCE: Belden, Russonello, and Stewart Research and Communications 2000.

onstrate a concept (Henke, Chen, and Goldman 1999).[9] Data from the TIMSS video study indicate, however, that teacher implementation of the kinds of instructional techniques for mathematics advocated in the NCTM standards are often superficial. National data that link these approaches to differences in learning outcomes are sparse. This section reviews the most recent data available on curriculum and instruction.

Data from the TIMSS video study show considerable cross-national variation in curricular approaches used in mathematics instruction. For example, American and German middle school mathematics lessons focus primarily on the acquisition and application of skills, but Japanese lessons stress problem solving and thinking. Furthermore, the quality of U.S. mathematics lesson plans was judged to be substantially below that in Germany and Japan in an evaluation by U.S. college mathematics teachers. International studies have also shown that U.S. math and science textbooks cover comparatively more topics with less depth of coverage and development. Recent studies by the American Association for the Advancement of Science (AAAS) have found the most widely used middle school mathematics textbooks and high school science (e.g., biology) textbooks to be less than satisfactory (AAAS 1999a,b and 2000a,b).

Both the new mathematics and the new science standards envision instruction that challenges students, but neither provides an exact blueprint for action. Measuring the extent to which this vision is becoming a reality is difficult because available methods cannot measure quality directly. Instead, educational researchers have relied most often on indicators of the amount of time students spend studying a subject (classwork and homework), the content of lessons, and the types of instructional resources used (e.g., textbooks). This section reviews instructional and curricular topics where recent data collection and research have been strongest: international comparisons of time spent studying mathematics and science, cross-national comparisons of curricular structure, and evaluations of the quality of mathematics and science textbooks. Although these lines of research have yielded valuable information for education policymakers, much remains to be learned about how to make mathematics and science instruction more effective.

Instructional Time

The question of whether U.S. students spend enough time in school or receiving instruction has persisted for many years, and research results on this issue are mixed. Research by Stigler and Stevenson (1991) showed that U.S. students spend fewer hours in school than Japanese students and that U.S. schools allocate less time to core instruction than do other industrialized nations. For example, core academic time in U.S. schools was estimated at 1,460 hours during the four years of high school compared with 3,170 hours in Japan. NECTL reported in 1994 that at the time of the Commission's study, only 10 states specified the number of hours to be spent in academic subjects at various grades. Only eight others provided recommendations regarding academic time. Based on these and other findings, the Commission concluded: "[T]ime is the missing element in the debate about the need for higher academic standards....We have been asking the impossible of our students—that they learn as much as their foreign peers while spending only half as much time in core academic studies" (NECTL 1994).

[9]Manipulatives are materials designed to provide concrete, hands-on experiences that can help students make the link between math concepts and the real world.

A Survey of Curriculum Use in Classrooms

States' movement toward standards-based reform in mathematics and science has produced strong interest in reliable data for evaluating the effects of reforms. A recent study by the Wisconsin Center for Education Research (WCER) and the Council of Chief State School Officers (CCSSO) applied research-based models and instruments for studying the curriculum to the broader purpose of reporting indicators of curriculum and instruction that could be used by policymakers and educators. States were asked to voluntarily participate in the study if they were interested in gaining information on effects of their reform efforts and gaining knowledge about the development and use of a survey approach to analyzing curriculum. In 1999, schools and teachers in 11 states participated in a study of the enacted curriculum in mathematics and science classrooms. Half the schools selected had high involvement in their state's initiative for improving math or science education ("Initiative" schools), and the other half were schools with less involvement but were similar to the first group based on student demographics ("Comparison" schools). More than 600 teachers across the states completed self-report surveys that covered the subject content they taught and the instructional practices they used in their classes. The enacted curriculum data were designed to give states, districts, and schools an objective method of analyzing current classroom practices in relation to content standards and the goals of systemic initiatives. This National Science Foundation-funded study was a collaborative effort involving state education leaders in science and mathematics, researchers from WCER, and project managers from CCSSO. Educators and researchers worked together to develop survey instruments that would gather reliable data from teachers and students and to develop formats for reporting survey results that would communicate key findings to educators. The goals of the study were to:

- measure differences in instructional practices and curriculum content among teachers and schools,
- determine whether state policy initiatives and state standards lead to differences in math and science teaching, and
- demonstrate the use of "surveys of enacted curriculum" to analyze classroom practices and to produce useful analyses and reports for educators.

The findings from the 1999 study listed below typify the types of issues and questions that can be explored with the survey data.

Active Learning in Science

Question: To what extent are students involved in active, hands-on learning approaches in science class?

- Sample survey data suggest one-fourth of science class time is spent on hands-on science or laboratory activities, but there is wide variation among schools.
- Survey data allow comparison of active science methods in schools that are involved in state initiatives and of science teaching in typical schools.

Problem Solving in Mathematics

Question: To what extent are students in math class learning problem-solving and reasoning skills and learning how to apply knowledge to novel problems?

- A majority of teachers report teaching problem solving in math, but teachers use a wide variety of instructional practices, such as small groups, writing, data analysis, and applying concepts to real-world problems.
- Differences are found in the types and depth of instruction of problem-solving activities between schools involved in state initiatives and comparison schools.

Mathematics and Science Content in Classrooms

Question: How does math and science content taught in classes compare to the goals outlined in state and national standards?

- In middle-grade math and science, most recommended standards are covered, but the level of expectation and depth of coverage vary widely among schools and classes.
- Data reveal differences in the extent of teaching science content across the standards and the extent of articulation between grades.
- Schools differ in their emphasis on algebra, geometry, and data and statistics in the elementary and middle grades.

Multiple Assessment Strategies in Math and Science

Question: What methods of student assessment are used in class, and are the strategies consistent with goals of learning in content standards?

- A majority of teachers use multiple assessment methods in math and science classes but infrequently use extended student responses that require student explanation and justification of answers.
- In science, the survey data allow analysis of differences in the use of performance tasks (hands-on activities) for assessment in class.

Use of Education Technology and Equipment

Question: How is education technology, e.g., calculators and computers, used in math and science instruction? Do teachers have science equipment available in their classes, and how often is it used?

- A majority of elementary- and middle-grade teachers use calculators in teaching math; graphing calculators are available in the typical grade 8 classroom but are rarely used.
- The average elementary school classroom has basic science equipment, but rate of use varies widely among teachers.

Influences on Curriculum and Practices

Question: What effect do state and national standards for science and math learning have on the curriculum taught in classrooms?

- State frameworks and standards and national standards are reported by most teachers to have strong positive influences on their curriculum.
- Survey data allow comparisons of degree of influence on curriculum of state and national standards, textbooks, state and district tests, and teacher preparation and knowledge.

Alignment of Content Taught With State Assessments

Question: Do state assessments reflect what is being taught in classes?

- Analysis of teacher reports and state assessment items shows that tests cover a narrower range of expectations for students than are reported for instruction: tests focus more on memorization, facts, and performing procedures and less on solving novel problems and applying skills and concepts.
- The data on alignment between teacher reports on instruction and content and state assessments allow teachers and assessment staff to examine the areas of weakness and strength of tests and classroom practices.

Teacher Preparation

Question: How well prepared are our teachers to teach science and mathematics?

- The survey data show how well prepared teachers are for using innovative teaching strategies and handling students with varied needs and capacities.
- Middle-grade teachers in math and science receive more professional development than elementary school teachers both in methods of teaching and subject content. Teachers report very positive reactions to professional development related to standards, curriculum, and assessment.

SOURCE: CCSSO 2000b.

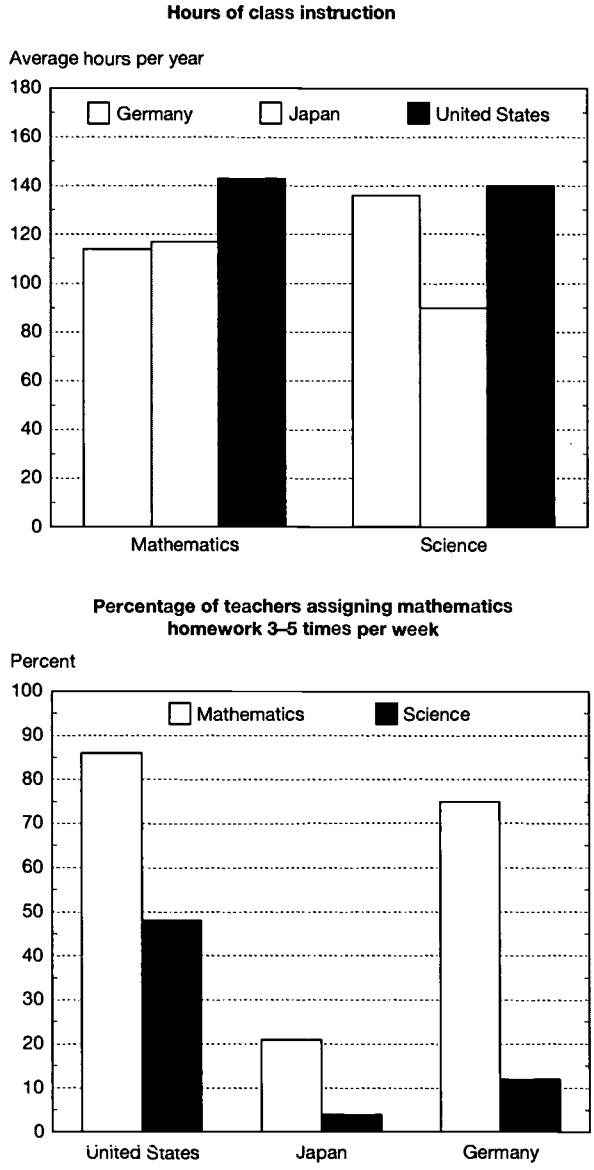
This may not be the case for mathematics and science, as 1995 and 1999 data for 8th graders from TIMSS and TIMSS-R suggest. Eighth-grade students in the United States receive at least as much classroom time in mathematics and science instruction as students in other nations: close to 140 hours per year in mathematics and 140 hours per year in science in 1994-95. (See figure 1-13.) Students in Germany, Japan, and the United States spent about the same amount of time on a typical homework assignment, but U.S. students were assigned homework more often, thus increasing total time spent studying in the two subjects (Beaton et al. 1996b; NCES 1997a,c and 1996c).

Certain caveats are necessary in interpreting results on instructional time. First, in other nations, particularly Japan, students participate in extracurricular mathematics and science activities in afterschool clubs or in formal tutoring activities. Second, disruptions for announcements, special events, and discipline problems in U.S. classrooms considerably reduce the amount of classroom time actually spent on instructional activities (Stigler et al. 1999).

Curriculum and Textbook Content

Analyses conducted in conjunction with TIMSS (Schmidt, McKnight, and Raizen 1997) documented that curriculum guides in the United States include more topics than is the international norm. Most other countries focus on a limited number of topics, and each topic is generally completed before a new one is introduced. In contrast, U.S. curriculums

Figure 1-13.
Selected characteristics of grade 8 mathematics and science instruction, Germany, Japan and United States: 1994–95



NOTE: Data are from the Third International Mathematics and Science Study.

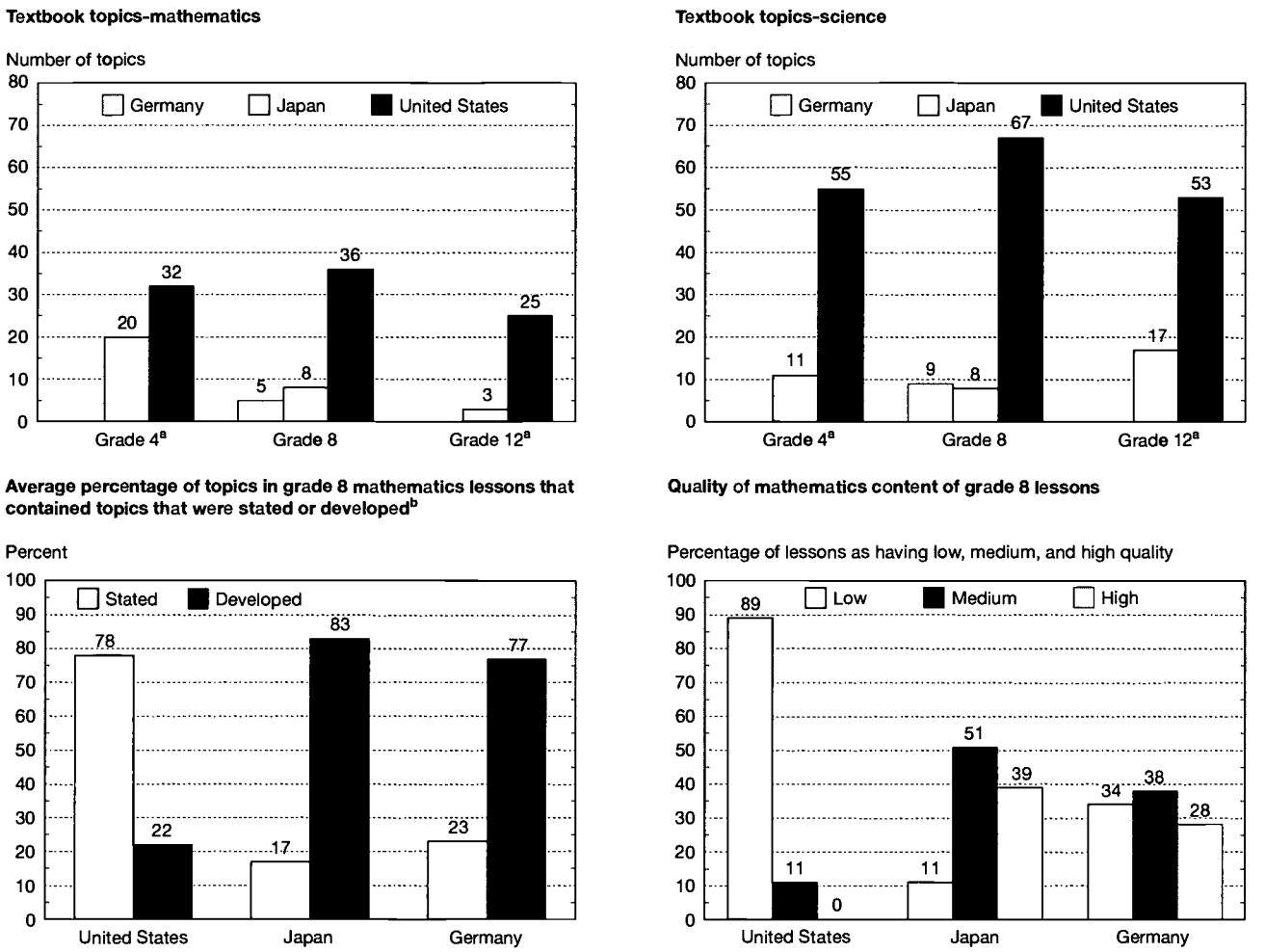
SOURCE: National Center for Education Statistics, *Pursuing Excellence: A Study of U.S. Eighth Grade Mathematics and Science Teaching, Learning, Curriculum, and Achievement in International Context*, NCES 97-198 (Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement: 1996c).

Science & Engineering Indicators – 2002

follow a "spiral" approach: topics are introduced in an elemental form in the early grades, then elaborated and extended in subsequent grades. One result of this is that U.S. curriculums are quite repetitive, because the same topic appears and reappears at several different grades. (See figure 1-14.) Another result is that topics are not presented in any great depth, giving the U.S. curriculum the appearance of being unfocused and shallow.

The Schmidt, McKnight, and Raizen (1997) study also suggests that U.S. curriculums, especially math, make fewer intellectual demands on students, delaying until later grades topics that are covered much earlier in other countries. U.S. mathematics curriculums also were judged to be less advanced, less challenging, and out of step with curriculums in other countries. The middle school curriculum in most TIMSS countries, for example, covers topics in algebra, geometry, physics, and chemistry. Meanwhile, the grade 8 curriculum in U.S. schools is closer to what is taught in grade 7 in other countries and includes a fair amount of arithmetic. Science curriculums, however, are closer to international norms in content and in the sequence of topics. Textbooks reflect the same inadequacies documented by curriculum analyses: insufficient

Figure 1-14.
Selected characteristics of grade 4, 8, and 12 mathematics and science instruction, Germany, Japan, and United States: 1994–95



[a]Data for Germany not available.

[b]A concept was coded as "stated" if it was simply provided by the teacher or students but was not explained or derived. A concept was coded as "developed" when it was derived and/or explained by the teacher or the teacher and students collaboratively in order to increase students' understanding of the concept.

NOTE: Data are from the Third International Mathematics and Science Study. Eighth-grade algebra texts are not included.

SOURCE: J.W. Stigler, P. Gonzales, T. Kanaka, S. Knoll, and A. Serrano, *The TIMSS Videotape Classroom Study: Methods and Findings From an Exploratory Research Project on Eighth-Grade Mathematics Instruction in Germany, Japan, and the United States*, NCES 1999-074 (Washington, DC: U.S. Department of Education, National Center for Education Statistics, Office of Educational Research and Improvement: 1999; W.H. Schmidt, C.C. McKnight, and S.A. Raizen, *A Splintered Vision: An Investigation of U.S. Science and Mathematics Education*. Boston, MA: Kluwer Academic Publishers: 1997).

Science & Engineering Indicators – 2002

coverage of many topics and insufficient development of topics. (See figure 1-14.) Compared to textbooks used in other countries, science and mathematics textbooks in the United States convey less challenging expectations, are repetitive, and provide little new information in most grades, a finding reported in earlier research by Flanders (1987) and by Eyelon and Linn (1988). Publishers have made some attempts to reflect the topics and demands conveyed by the educational standards; however, the TIMSS curriculum analyses suggest that when new "standards-referenced" topics are added, much of the old material is retained (Schmidt, McKnight, and Raizen 1997).

Recent studies by AAAS (1999a,b) have reinforced the findings of TIMSS and other studies about the inadequacies of mathematics and science textbooks. AAAS conducted a conceptual analysis of content based on 24 instructional criteria and applied them to the evaluation of 9 middle-school science texts and 13 mathematics texts. The samples included the most widely used texts in both subjects. Each text was evaluated by two independent teams of middle school teachers, curriculum specialists, and science and mathematics education professors. AAAS developed and tested the evaluation procedure over a three-year period in collaboration with more than 100 scientists, mathematicians, educators, and curriculum developers. On a 0- to 3-point scale (where 3 represents "satisfactory"), all nine science textbooks scored below 1.5. Six mathematics texts scored below 1.5, and only three scored above 2.5 points (AAAS 1999a,b).

Similar evaluations of high school biology and algebra texts were only slightly more supportive of their content. In a 2000 evaluation of 10 widely used and newly developed biology textbooks, none received high ratings (AAAS 2000b). Two independent teams of biology teachers, science curriculum specialists, and professors of science education evaluated each biology text, along with its teacher guide. The evaluation examined how well the texts are likely to help students learn the important ideas and skills in the widely accepted Benchmarks for Science Literacy (developed earlier by AAAS Project 2061) and in the National Science Education Standards (NRC 1996). Directors of this study reported, for example, that the textbooks ignore or obscure the most important biological concepts by focusing instead on technical terms and trivial details (which are easy to test) and that activities and questions included are inadequate to help students understand many of the more difficult concepts.

Among the 12 high school algebra textbooks evaluated by AAAS Project 2061, 7 were considered adequate; however, not one was rated highly (AAAS 2000a). Five textbooks, including three that are widely used in American classrooms, were rated so inadequate that they lack potential for student learning. Highlights of the evaluation included the following:

- All of the textbooks present algebra using a variety of contexts and give students appropriate firsthand experiences with the concepts and skills.
- Most of the textbooks do an acceptable job of developing student ideas about algebra by representing ideas, demonstrating content, and providing appropriate practice.
- No textbook does a satisfactory job of providing assessments to help teachers make instructional decisions based specifically on what their students have or have not learned.
- No textbook does a satisfactory job of building on students' existing ideas about algebra or helping them overcome their misconceptions or missing prerequisite knowledge.

Instructional Practice

Most information about instructional practice has come from surveys that asked teachers about specific aspects of their teaching. In a recent survey, 82 percent of full-time U.S. mathematics teachers and 74 percent of full-time science teachers gave themselves good grades on using practices consistent with educational standards in their fields (NCES 1999d). However, classroom observational studies, which have provided more depth and dimension to depictions of practice, often paint quite a different picture. These studies demonstrate that it is relatively easy for teachers to adopt the surface characteristics of standards-based teaching but much harder to implement the core features in everyday classroom practice (Spillane and Zeuli 1999; Stigler et al. 1999; and NCES 2000d).

The TIMSS video study of 8th-grade mathematics instruction is a case in point. Lessons in U.S., German, and Japanese classrooms were fully documented, including descriptions of the teachers' actions, students' actions, amount of time spent on each activity, content presented, and intellectual level of the tasks that students were given in the lesson (Stigler et al. 1999). These findings identified four key points:

- The content of U.S. mathematics classes requires less high-level thought than classes in Germany and Japan.
- The typical goal of U.S. mathematics teachers is to teach students how to do something, but the typical goal of Japanese teachers is to help them understand mathematical concepts.
- Japanese classes share many features called for by U.S. mathematics reforms, but U.S. classes are less likely to exhibit these features.
- Although most U.S. mathematics teachers report familiarity with reform recommendations, relatively few apply the key points in their classrooms.

Ratings by mathematicians of the quality of instruction in 8th-grade German, Japanese, and U.S. mathematics classrooms in 1994–95 suggest a lower level of quality in U.S. instruction. Approximately 30 percent of lessons in Japanese classrooms were rated as "high quality" and 13 percent were rated as "low quality." In German classrooms, 23 percent of lessons received high ratings and 40 percent received low ratings. In comparison, approximately 87 percent of U.S. lessons were considered "low quality" and none were considered "high quality." (See figure 1-14.) However, because of the small scale of the study, these results are suggestive rather than definitive. The studies are now being replicated on a larger scale in both mathematics and science.

Teacher Quality and Changes in Initial Teacher Training

Research suggests that school quality is tightly linked to teacher quality (NCES 2000d). According to Hanushek (1992), "The estimated difference in annual achievement growth between having a good and having a bad teacher can be more than one grade-level equivalent in test performance." Rivkin, Hanushek, and Kain (1998) recently concluded in one study that teacher quality is the most important determinant of school quality. Current research, however, has yet to definitively determine the specific, observable factors that distinguish a good teacher from a bad one. Research does suggest that the following factors are associated with teacher quality: having academic skills, teaching in the field in which the teacher received training, having more than a few years of experience (to be most effective), and participating in high-quality induction and professional development programs (NCES 2000d). Data relating to these issues were collected by the NCES during academic year 1999/2000 through the Schools and Staffing Survey (SASS). Data from sources other than the SASS have been included, to the extent possible.

Nationally representative data on teacher quality, professional development, and working conditions have been collected by the National Center for Education Statistics' (NCES) 1999–2000 Schools and Staffing Survey. They were not available in time for the preparation of this chapter. Following release of the dataset by NCES, analyses of these topics will be available at the following National Science Foundation website: <http://www.nsf.gov/sbe/srs/seind02/update.htm>.

Measuring Academic Skills of Teachers

Research shows that students tend to learn more from teachers with strong academic skills than they do from teachers with weak academic skills (Ballou 1996; Ferguson and Ladd 1996; Ehrenberg and Brewer 1995, 1994; Ferguson 1991; Mosteller and Moynihan 1972). Some researchers argue that teacher quality has less to do with how teachers perform on standardized tests than with how they perform in the classroom (Darling-Hammond 1998). Although traits not measured on standardized tests (such as interpersonal skills, public speaking skills, and enthusiasm for working with children) influence whether someone will be an effective teacher, these traits tend to be hard to quantify, and most studies examining the link between teacher skills and student learning limit their definitions of teacher skills to academic skills (NCES 2000d).

Several studies show that over the past three decades, teachers with low academic skills have been entering the profession in much higher numbers than teachers with high academic skills (Henke, Chen, and Geis 2000; Gitomer, Latham, and Ziomek 1999; Ballou 1996; Henke, Geis, and Giambattista 1996; Murnane et al. 1991; Vance and Schlechty 1982). However, a recent study by the Educational Testing Service (ETS) suggests that the pattern for potential mathematics and science teachers may be different. ETS found that the teaching profession tends to attract teachers with below-average skills, based on the Scholastic Aptitude Test (SAT) scores of prospective teachers taking the Praxis II between 1994 and 1997 (Gitomer, Latham, and Ziomek 1999).[10] Based on a comparison of SAT scores for teacher candidates passing the Praxis II exam with the average score for all college graduates, ETS concluded that elementary education candidates, the largest single group of prospective teachers, have much lower math and verbal scores than other college graduates. The pattern in other content areas for teacher candidates was less consistent, however. The average math SAT score for those passing the Praxis II exam and seeking licensure in physical education, special education, art and music, social studies, English, or foreign language was lower than the average math score for all college graduates. Those seeking to teach science and math, however, had higher average math scores than other college graduates. The average verbal SAT scores of those seeking to teach some subjects were more encouraging. The scores of mathematics, social studies, foreign language, science, and English candidates who passed the Praxis II exam were as high as or higher than the average verbal SAT score for all college graduates. Physical education, special education, and art and music teachers scored below the average.

A major disadvantage of the ETS study, however, is that it examines only candidates, not those who actually take teaching jobs. Ballou (1996) demonstrated that there are large drop-offs in the pipeline. For example, although 20 percent of students from average colleges became certified to teach, 17 percent applied for teaching jobs and 8 percent actually became employed as teachers. Given such large drop-offs, one should not assume that individuals taking the Praxis II examination have the same characteristics as those who actually become teachers (NCES 2000d).

Several recent studies using data from the 1993 NCES Baccalaureate and Beyond Longitudinal Study provide more comprehensive pictures of the teacher pipeline, that is, from preparation at the baccalaureate level to employment (Henke, Chen, and Geis 2000; Henke, Geis, and Giambattista 1996). These studies found that the college entrance examination scores of 1992/93 college graduates in the teaching pipeline (defined by NCES as students who had prepared to teach, who were teaching, or who were considering teaching) were lower than those students who were not in the pipeline. "At each step toward a long-term career in teaching, those who were more inclined to teach scored less well than those less inclined to teach" (Henke, Geis, and Giambattista 1996). For example, by 1997, the 1992/93 college graduates in this study with the highest college entrance examination scores were consistently less likely than their peers with lower scores to prepare to teach, and when they did teach, they were less likely to teach students from disadvantaged backgrounds:

[10]The Praxis II assessments are designed to measure teacher candidates' knowledge of the subjects they will teach and how much they know about teaching that subject.

- Graduates whose college entrance examination scores were in the top quartile were half as likely as those in the bottom quartile to prepare to teach (9 versus 18 percent).
- Teachers in the top quartile of college entrance examination scores were more than twice as likely as teachers in the bottom quartile to teach in private schools (26 versus 10 percent).
- Teachers in the top quartile of scores were about one-third as likely as teachers in the bottom quartile to teach in high-poverty schools (10 versus 31 percent).
- Graduates in the top quartile of scores who did teach were twice as likely as those in the bottom quartile to leave the profession within four years (32 versus 16 percent) (Henke, Chen, and Geis 2000).

Match Between Teacher Background and Courses Taught

Research shows that assigning teachers to teach courses that they are not trained to teach has a negative effect on student achievement (Darling-Hammond 2000; Goldhaber and Brewer 1997; Monk and King 1994). In the early 1990s, however, it was quite common for students to be taught mathematics and science by teachers without a major or minor in those subjects, especially in schools with large concentrations of poor and minority students or those in rural areas (Ingersoll 1999). This section examines the "mismatch" between those teaching mathematics and science and their educational backgrounds in those fields using data from a recently released national survey of teachers, the NCES SASS. Because it is common for an individual teacher to teach courses in multiple fields simultaneously, examining the match between a teacher's main assignment field and his or her educational background can overestimate or, as is more likely, underestimate the amount of out-of-field teaching that is occurring. For this reason, the indicators presented below are calculated at the student level, that is, the percentage of students taught mathematics or science by a teacher without a major or minor in the related field. Unlike previously reported measures, these indicators attempt to measure the degree to which someone is teaching out of field, including whether he or she (1) has a major in the field at either the undergraduate or graduate level, (2) has a minor in the field, (3) has a major or minor in a related field of science, (4) has an education degree with a specialization in the field taught, or (5) has no previous education in the field as laid out in the four previous categories (referred to as "severely" out of field).

> Nationally representative data on teacher quality, professional development, and working conditions have been collected by the National Center for Education Statistics' (NCES) 1999–2000 Schools and Staffing Survey. They were not available in time for the preparation of this chapter. Following release of the dataset by NCES, analyses of these topics will be available at the following National Science Foundation website: <http://www.nsf.gov/sbe/srs/seind02/update.htm>.

Teacher Experience

Research suggests that students learn more from experienced teachers (those with at least five years of experience) than they do from less experienced teachers (NCES 2000d; Rivkin, Hanushek, and Kain 1998; Murnane and Phillips 1981). These studies point primarily to the difference between teachers with fewer than five years of experience (new teachers) and teachers with five or more years of experience. The benefits of experience, however, appear to level off after 5 years, and studies suggest that there are no noticeable differences, for example, in the effectiveness of a teacher with 5 years of experience versus a teacher with 10 years of experience (Darling-Hammond 2000). This section examines the proportion of students in middle and high schools who are taught by new teachers, defined here as teachers in their first three years of teaching.

> Nationally representative data on teacher quality, professional development, and working conditions have been collected by the National Center for Education Statistics' (NCES) 1999–2000 Schools and Staffing Survey. They were not available in time for the preparation of this chapter. Following release of the dataset by NCES, analyses of these topics will be available at the following National Science Foundation website: <http://www.nsf.gov/sbe/srs/seind02/update.htm>.

Induction of Recently Hired Teachers

Teacher recruitment and retention will become increasingly important as the baby boom generation reaches retirement age and its echo in terms of increased student enrollment makes its way through schools. In the 1980s and 1990s, large numbers of teachers left the profession after teaching just a few years. For example, between the 1993/94 and 1994/95 academic years, the most recent years for which national attrition data exist, 17 percent of teachers with three or fewer years of experience left the profession (NCES 2000d). Nine percent left after teaching for less than one year. A disproportionately high share left high-poverty schools. In efforts to retain good teachers, schools are increasingly using mentorships with master teachers and formal "induction" programs. This section examines the characteristics of the initial training of mathematics and science teachers who entered the profession between 1994/95 and 1999/2000 and examines the degree to which these new teachers reported receiving different types of support in their first year of teaching.

> Nationally representative data on teacher quality, professional development, and working conditions have been collected by the National Center for Education Statistics' (NCES) 1999–2000 Schools and Staffing Survey. They were not available in time for the preparation of this chapter. Following release of the dataset by NCES, analyses of these topics will be available at the following National Science Foundation website: <http://www.nsf.gov/sbe/srs/seind02/update.htm>.

Teacher Professional Development

Many experts assert that high-quality professional development should enhance student learning, but data for undertaking the requisite analysis are sparse. Almost all teachers participate in some form of professional development over the course of a year, most for the equivalent of a day or less. Teachers who spend more time in professional development activities are more likely to self-report improvements in classroom teaching as the result of these activities than are those who spend less time. Although several reports have asserted that teachers will perform better if they are given opportunities to sharpen their skills and keep abreast of advances in their fields (Henke, Chen, and Geis 2000; National Commission on Teaching and America's Future 1996), there has been no comprehensive assessment of the availability of such learning opportunities and the effects of those opportunities on teachers and students (Mullens et al. 1996; Smylie 1996). This section reviews participation in three types of professional development activities by mathematics and science teachers in 1999/2000:

- activities focused on indepth study of their content areas,
- activities focused on methods of teaching, and
- activities focused on the use of computers for teaching.

The amount of time teachers spent in these activities and whether they found them useful are also reviewed.

> Nationally representative data on teacher quality, professional development, and working conditions have been collected by the National Center for Education Statistics' (NCES) 1999–2000 Schools and Staffing Survey. They were not available in time for the preparation of this chapter. Following release of the dataset by NCES, analyses of these topics will be available at the following National Science Foundation website: <http://www.nsf.gov/sbe/srs/seind02/update.htm>.

Observation of Other Teachers Teaching

Some research suggests that the experience of teachers observing other teachers can contribute to the sharing of good practices. TIMSS-R asked the mathematics and science teachers of U.S. 8th-grade students during the 1998/99 academic year about the number of class periods they observed other teachers during the past year and the number of periods other teachers observed them during the past year (NCES 2000f).[11] In general, the mathematics teachers of U.S. 8th-grade students rarely participated in observational activities. On average, U.S. 8th-grade students were taught by mathematics teachers who spent one class period during the 1998/99 academic year observing other teachers and who were observed by other teachers during two class periods. There were no differences in the average number of class periods that mathematics teachers observed other teachers or were observed by other teachers based on years of teaching experience.

The science teachers of U.S. 8th-grade students also rarely participated in observational activities. On average, U.S. 8th graders were taught by science teachers who observed other teachers for one class period during the 1998/99 academic year and who were observed by other teachers for one class period. However, the situation was different for U.S. 8th-grade students whose science teachers had the fewest years of experience (0–5 years): their teachers spent approximately three periods observing other teachers, a greater number of periods than science teachers with more years of experience (NCES 2000f).

Teacher Working Conditions

Salaries for math and science teachers remain well below those of bachelor's and master's degree scientists and engineers in industry. Given that teacher retirements are on the rise, increased salaries provide a means of retaining good teachers and attracting the number of quality teachers needed to replace retirees. The difference between the annual median salaries of all bachelor's degree recipients and teachers has declined over the past 20 years, mainly due to increases in the relative size of the older teaching workforce and in salaries of older teachers. This section reviews how average teacher salaries have changed over the past quarter century, how the earnings of math and science teachers vary in high- and low-poverty schools, and, finally, how the salaries and teaching time of U.S. teachers compare with those of their counterparts in other countries.

Salary and teaching time are only two components of teacher working conditions. The amount of professional development time supported by a school or district, student behavior, participation in school decisionmaking, class size, quality of facilities, and adequacy of resources are examples of conditions that could also influence a teacher's desire to teach or not teach at a particular school. Many of these conditions, however, are either difficult to measure or do not have a parallel in S&E occupations outside teaching.

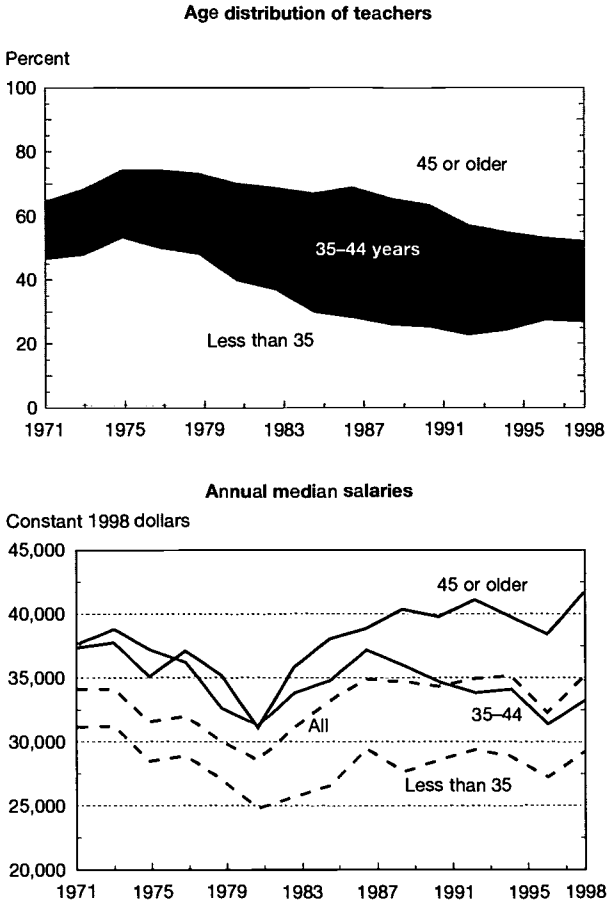
Trends in Teacher Salaries

As a wave of younger teachers hired in the mid-1970s has aged, a demographic shift in the age of teachers has occurred (NCES 1999a). For example, in 1975, 53 percent of all full-time teachers were younger than age 35; in 1993, the percentage of younger teachers fell to about 23 percent. By 1998, the percentage of younger teachers had risen only slightly, reaching 27 percent. Meanwhile, the percentage of full-time teachers age 45 years or older increased from about 26 percent in 1975 to 48 percent in 1998. (See figure 1-15.) Average teacher salaries have been affected by these demographic shifts, particularly over the past 20 years.

The annual median salaries (in constant 1998 dollars) of full-time teachers decreased between 1971 and 1981 by about

[11] Questions regarding the professional development of teachers, including whether or not they had observed other teachers teaching in the previous year, were only asked of U.S. mathematics and science teachers in TIMSS-R.

Figure 1-15.
Age distribution and annual median salaries by age of full-time elementary and secondary school teachers: 1971–98



NOTE: Median salaries refer to previous calendar year, for example, salaries reported in 1971 refer to salaries earned in 1970. Consumer Price Index (CPI) used to calculate constant dollars. Includes full-time public and private school teachers who taught grades 1–12.

SOURCE: National Center for Education Statistics, *The Condition of Education 1999*, NCES 1999-022 (Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement: 1999a).

Science & Engineering Indicators – 2002

$500 to $700 annually in each age group. Between 1981 and 1989, the salaries of teachers rose. The annual median salary of full-time teachers grew slowly during the 1990s, reaching $35,099 in 1998 (NCES 1999a). For the oldest group of teachers, salaries rose by about $1,100 per year on average, while for the middle-aged and youngest groups, salaries increased by smaller amounts. Since 1989, the salaries of the oldest and youngest groups of teachers have remained about the same, while the salaries of the middle-aged group (between ages 35 and 44) have declined by about $400 per year on average. (See figure 1-15.)

The difference between the annual median salaries of bachelor's degree recipients and all full-time teachers declined from about $5,000 in 1981 to $2,300 in 1998. This decline in the salary gap has been due mainly to increases in the relative size of the older teaching workforce and in the salaries of teachers age 45 or older (NCES 1999a).

Variation in the Salaries of Math and Science Teachers

Many believe that competitive salaries and benefits are key to attracting and retaining high-quality teachers (Murnane et al. 1991). Research has shown that levels of compensation and criteria for awarding salary increases affect who goes into teaching, who stays, and how teachers move from district to district and from school to school (Odden and Kelley 1997). When asked whether various factors were important to them in determining the type of work they planned to do in the future, 1992/93 bachelor's degree recipients responded affirmatively to "income potential over career" and "intellectually challenging work" (45 percent in each case) more often than to any of the other factors mentioned (Henke et al. 1997). This section examines variability in the compensation levels of mathematics and science teachers in 1999/2000 across high- and low-poverty districts by school location.

Nationally representative data on teacher quality, professional development, and working conditions have been collected by the National Center for Education Statistics' (NCES) 1999–2000 Schools and Staffing Survey. They were not available in time for the preparation of this chapter. Following release of the dataset by NCES, analyses of these topics will be available at the following National Science Foundation website: <http://www.nsf.gov/sbe/srs/seind02/update.htm>.

International Comparisons of Teacher Salaries

Internationally, teacher pay scales in the United States tend to be lower than those in a number of other countries, including Germany, Japan, South Korea, and the Netherlands, and teaching hours tend to be longer. The gaps are particularly wide at the upper secondary (high school) level because a number of countries, unlike the United States, require higher educational qualifications and pay teachers significantly more at this level than at the primary (elementary) level. For example, salaries for upper secondary teachers with 15 years of experience and the minimum level of education and training required to be certified exceeded $40,000 in 1998 in Denmark, Germany, Japan, and the Netherlands and exceeded $60,000 in Switzerland (Organisation for Economic Co-operation and Development (OECD) 2000). The comparable salary for the United States was $35,000. This section reviews cross-country variation in teacher salary, adjusting first for differences in country wealth or ability to spend on education, and second for differences in the amount of time that teachers are required to spend in instructional activities to earn their salaries.

Association Between Teacher Salaries and Per Capita Gross Domestic Product

Teacher salaries relative to per capita gross domestic product (GDP) are an indication of the extent to which a country invests in teaching resources relative to the financial ability to fund educational expenditures. A high salary relative to per capita GDP suggests that a country is making more of an effort to invest its financial resources in teachers. Relative to per capita GDP, teacher salaries are relatively low in the Czech Republic, Hungary, and Norway and relatively high in South Korea, Spain, and Switzerland.

Wealthier countries do not necessarily spend a greater share of their wealth on educational resources, however. (See figure 1-16.) Although the Czech Republic and Hungary have both relatively low GDP per capita and low teacher salaries, other countries with GDP per capita below the OECD average, including South Korea and Spain, have comparatively high teacher salaries. Norway and the United States, two countries with relatively high GDP per capita, spend a below-average share of their wealth on teacher salaries, and Switzerland spends an above-average share of its relatively high per capita GDP on teacher salaries.

Salaries Adjusted for Statutory Teaching Time

Another measure of the investment in teaching is the statutory teacher salary relative to the number of hours per year that a full-time classroom teacher is required to teach students. This measure reflects the fact that teaching time is organized differently across countries, influenced by both the number of instructional hours planned for students each year and the proportion of the working day that a full-time teacher is expected to be engaged in direct instruction. Although this measure does not adjust salaries for the amount of time that teachers spend in all teaching-related activities, it can nonetheless provide a rough estimate of the cost of an hour of instruction across countries.

The average statutory salary per teaching hour after 15 years of experience is $35 in primary education, $43 in lower secondary education, and $52 in upper secondary (general) education across OECD countries (OECD 2000). For primary education, the Czech Republic, Hungary, and Mexico have relatively low salary costs per hour of instruction ($13, $15, and $16, respectively); by contrast, costs are relatively high in Denmark ($48), Germany ($49), South Korea ($62), and Switzerland ($48). Salary costs per primary teaching hour in the United States are in the middle of this range at $35. In South Korea, high costs per teaching hour at the primary level are balanced by a relatively high student/teacher ratio (31.2) and a low proportion of current expenditure on nonteaching staff, resulting in below-average expenditure per student (OECD 2000). In contrast, Denmark's high costs per teaching hour at the primary level combine with a relatively low student/teacher ratio (11.2) and an above-average expenditure on nonteaching staff to create one of the highest expenditure-per-student figures in the OECD. There is more variability in salary cost per hour of teaching in upper secondary schools, ranging (among OECD countries) from $16 or below in the Czech Republic and Hungary to $90 or above in Denmark and South Korea. Comparable costs for the United States were $38.

IT in Schools

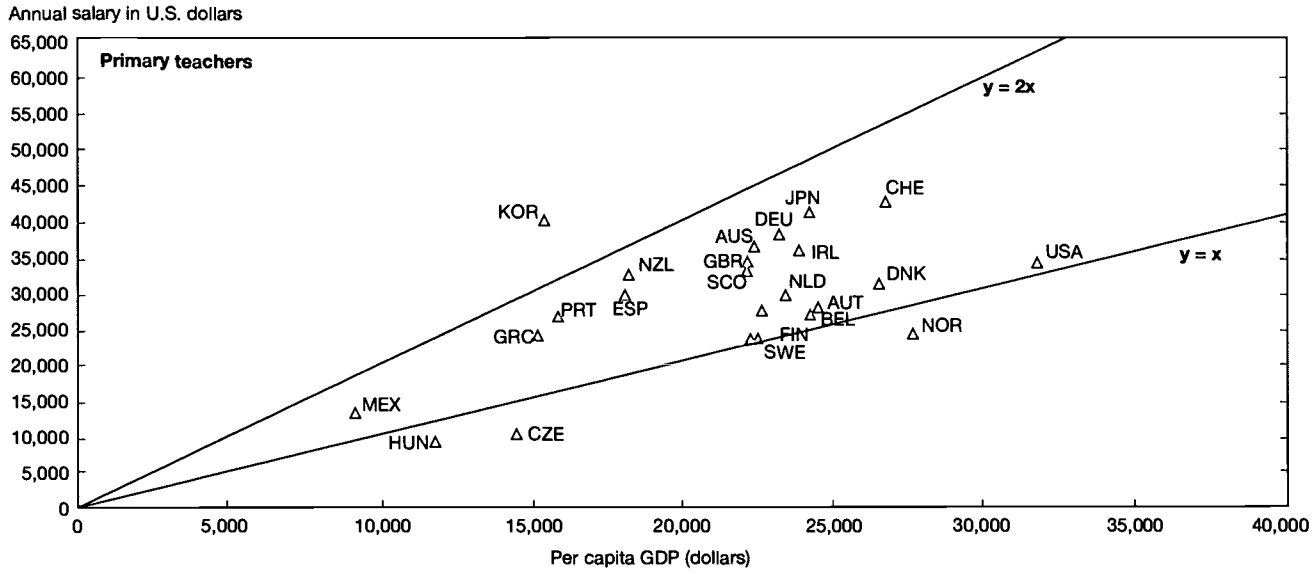
Although myriad approaches have been proposed for improving K–12 education in the United States, one common element of many such plans is more extensive and more effective utilization of computer, networking, and other information technologies (IT) to support a broad program of systemic and curricular reform (President's Committee of Advisors on Science and Technology 1997). IT has fundamentally transformed America's offices, factories, and retail establishments. Although the transformation in schools has been quite modest by comparison, technology and computers are rapidly appearing in schools and classrooms, and their integration into the curriculum is redefining the perception of a quality school (NCES 2000d).

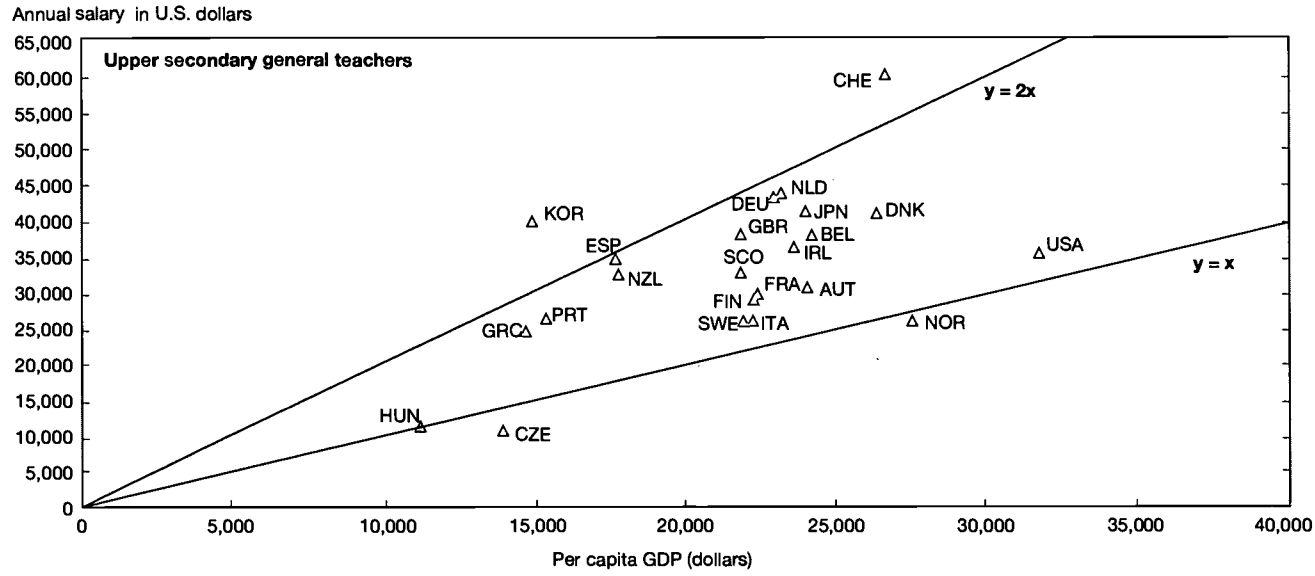
Computers and Internet access are used in a variety of ways in schools, and each use may have an independent effect on student learning. Relatively little research on the effect of technology on learning looks at the uses and effects of Internet access; most research examines the instructional power of the computer to teach discrete skills (NCES 2000d). Numerous studies conducted in the elementary and secondary grades have concluded that student learning is enhanced by computers when the computer is used to teach discrete skills in the style referred to as "drill and practice." The benefits appeared to be strongest for students of lower SES, low achievers, and those with certain learning problems (President's Committee of Advisors on Science and Technology 1997).

Research on the application of computers for developing higher order thinking skills, problem-solving, group work, and hands-on learning activities, however, is less extensive and less conclusive (NCES 2000d). Two studies show positive effects (Wenglinsky 1998; Glennan and Melmed 1996), but a third study concludes that it is not known whether computers can be used for this type of teaching in a cost-effective manner with any "degree of certainty that would be desirable from a public policy viewpoint" (President's Committee of Advisors on Science and Technology 1997). Although it is possible that these studies are less conclusive because teachers are less adept at teaching using these new tools, it is clear that IT is becoming increasingly important in the classroom and that there is widespread interest in how these tools are being applied.

This section first examines student and teacher access to IT at school. Variability in access across high- and low-poverty schools is emphasized. Next, teacher use of IT in the classroom and at home, teacher preparation and training in IT, and barriers to IT use are examined. Because computers are not the only technology used in schools, the section concludes with a discussion of calculator usage in mathematics classes and how this varies cross nationally.

Figure 1-16.
Annual statutory teacher salaries after 15 years of experience relative to per capita GDP: 1998





Australia	AUS	Germany	DEU	Mexico	MEX	South Korea	KOR
Austria	AUT	Greece	GRC	Netherlands	NED	Spain	ESP
Belgium	BEL	Hungary	HUN	New Zealand	NZL	Sweden	SWE
Czech Republic	CZE	Ireland	IRL	Norway	NOR	Switzerland	CHE
Denmark	DNK	Italy	ITA	Portugal	PRT	United Kingdom	GBR
Finland	FIN	Japan	JPN			United States	USA
France	FRA						

GDP = Gross Domestic Product

NOTE: Countries above the y = 2x line had teacher salaries more than twice their per capita GDP while countries below the y = x line had teacher salaries below their per capita GDP.

SOURCE: Organisation for Economic Co-operation and Development. *Education at a Glance: OECD Indicators*, 2000 Edition (Paris: 2000).

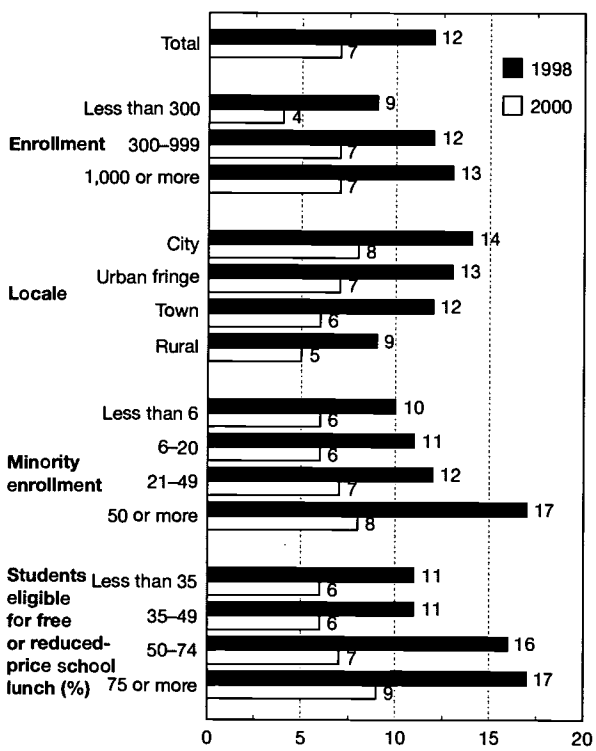
Science & Engineering Indicators – 2002

Access to IT

Computers and Internet access are becoming increasingly available in schools, although the distribution of these resources is not uniform. In 2000, the ratio of students to instructional computers in public schools was 5:1, down from 6:1 in 1999 and a dramatic change from 125:1 in 1983 (NCES 2000d, 2001d). The pace of change is rapid, however, and any measure of access quickly becomes out of date. For example, the ratio of students per instructional computer with Internet access in public schools declined from 12:1 in 1998 to 9:1 in 1999 and then to 7:1 in 2000 (NCES 2001d). Given this rapid degree of change, any data presented in this section run the risk of being a history lesson in disparities in IT access rather than a reporting of current conditions. That said, identifiable disparities can serve as benchmarks for increasing access to technology for all students.

The overall average student-to-computer ratio reported above hides two facts: the distribution of computers per student is skewed (see figure 1-17), and many computers included in that count may be old and have limited usefulness (NCES 2000d). In 1994, for example, 4 percent of the nation's schools had one computer per 4 students, while 46 percent of the schools had one computer per 16.5 students and 10 percent of the schools had one computer per 28.5 students (NCES 2000d). A 1998 study of elementary and secondary schools found that "over half of the computers are out of date.... And in elementary schools almost two-thirds are of limited capacity" (Anderson and Ronnkvist 1999). Older computers often do not have the capacity to link to the Internet or to run current multimedia applications, such as CD-ROM reference and encyclopedia programs (NCES 2000d). Older computers can, however, be used to perform drill and practice sessions and to develop keyboard skills. The ratio of students to instructional computers with Internet access may serve as a reasonable proxy for access to more recent technology.

Figure 1-17.
Ratio of students per instructional computer with Internet access, by school characteristics: 1998 and 2000



SOURCE: National Center for Education Statistics, *Internet Access in U.S. Public Schools and Classrooms: 1994–2000*, NCES 2001-071 (Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement: 2001c).

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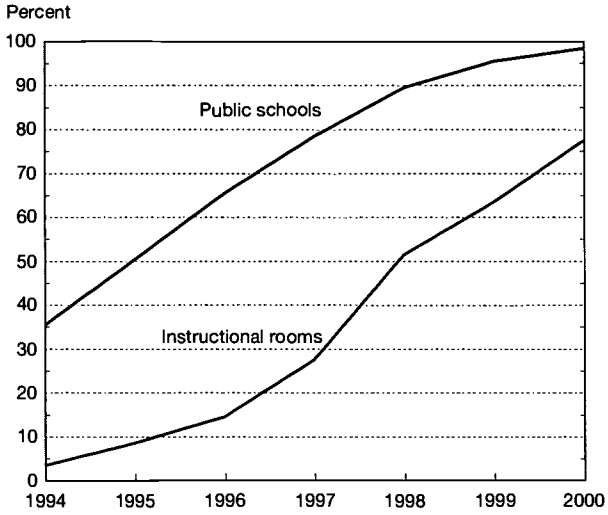
Although the vast majority of teachers have access to computers somewhere in their schools, they appear more likely to use them in instruction if the computers are located in their classrooms. Nearly all public school teachers (99 percent) reported having computers available somewhere in their schools in 1999 (NCES 2000g); 84 percent had computers available in their classrooms and 95 percent had computers available elsewhere in the school. Thirty-six percent of teachers had one computer in their classrooms, 38 percent reported having two to five computers in their classrooms, and 10 percent reported having more than five computers in their classrooms. Teachers were generally more likely to use computers and the Internet if the computers were located in their classrooms than if they were located elsewhere in the school. Furthermore, teachers and students with more computers or more computers connected to the Internet in their classrooms reported using these technologies more often than teachers with fewer computers or fewer Internet connections.

The Internet can open schools to a variety of external resources, and schools have been using it increasingly. Internet access existed at 35 percent of public schools in 1994, but this statistic soared to 98 percent by 2000 (NCES 2001d). (See figure 1-18.) In 1999, however, access to the Internet existed at only one location in 37 percent of schools, thus making regular instructional use difficult (NCES 2000d). Data on this measure are unavailable for 2000.

Although many schools have computers and Internet access, the distribution of these resources among schools with high and low concentrations of poverty is not uniform. A study based on data from the mid-1990s (Anderson and Ronnkvist 1999) found that schools with high concentrations of poor or minority students have fewer computers and are less likely to have Internet access. Although nationally representative data suggest that this gap is narrowing, the data also show that "large gaps...in the quality of the computer equipment available" still exist (Anderson and Ronnkvist 1999, 16). More recent data provide additional evidence for this trend. For high-poverty schools (those with 75 percent or more students eligible for free or reduced-price lunch), 60 percent of all instructional rooms had Internet access in 2000, up from 5 percent in 1996. Schools with less poverty tended to have a larger percentage of rooms with Internet access—77 percent or higher in 2000, up from 11–17 percent in 1996 (NCES 2001d).

Figure 1-18.
Percentage of public schools and instructional rooms with Internet access: 1994–2000



SOURCE: National Center for Education Statistics, *Internet Access in U.S. Public Schools and Classrooms: 1994–2000*, NCES 2001-071 (Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement: 2001c).

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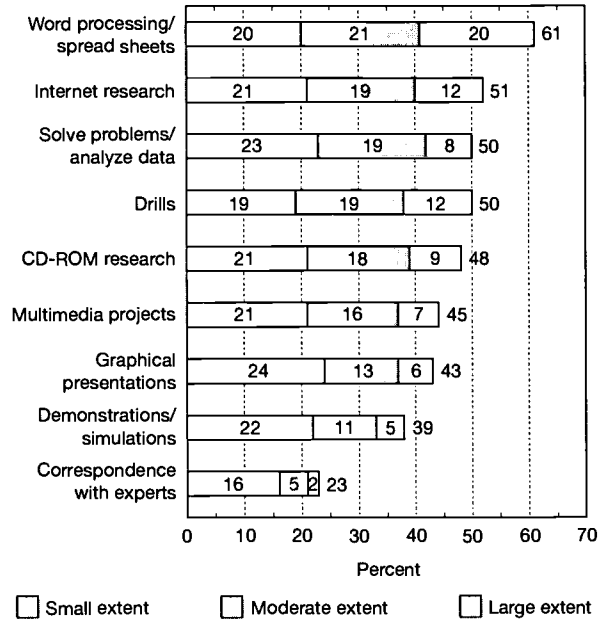
Figure 1-19.
Extent to which public school teachers assign different types of work using computers or Internet: 1999



NOTES: Teachers who reported that computers were not available to them anywhere in the school were excluded from analyses. Details may not add to totals because of rounding.

SOURCE: National Center for Education Statistics, *Teachers' Tools for the 21st Century: A Report on Teachers' Use of Technology*, NCES 2000-102 (Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement: 2000g).

Science & Engineering Indicators – 2002

Teacher Use of Technology

Even though computers are common in U.S. schools, many teachers feel unprepared to integrate technology into the subjects they teach. This section reviews data from a 1999 NCES survey on teacher use of computers and the Internet, describes teacher use of education technology in classrooms and schools, and then discusses teacher use of IT at home.

In 1999, approximately half of the public school teachers who had computers or the Internet available in their schools used them for classroom instruction. (See figure 1-19.) Teachers assigned students to use these technologies for word processing or creating spreadsheets most frequently (61 percent), followed by Internet research (51 percent), problem solving and data analysis (50 percent), and drills (50 percent). Additionally, many teachers used computers or the Internet to conduct a number of preparatory and administrative tasks (e.g., creating instructional materials, gathering information for planning lessons) and communicative tasks (e.g., communication with colleagues) (NCES 2000g).

Among those with technology available in their schools, teachers in low-minority and low-poverty schools were generally more likely than teachers in high-minority and high-poverty schools to use computers or the Internet for a wide range of activities, including gathering information at school, creating instructional materials at school, communicating with colleagues at school, and instructing students. For example, 57 percent of teachers in schools with less than 6 percent minority enrollments used computers or the Internet for research compared with 41 percent of teachers in schools with 50 percent or more minority enrollments.

Although the vast majority of teachers have computers at home, there is a strong generational difference associated with how teachers make use of these computers and the Internet. Eighty-two percent of public school teachers reported having a computer available at home, 63 percent of public school teachers had Internet access at home, and 27 percent reported that their schools had a network they could use to access the Internet from home (NCES 2000g). Among teachers with computers available at home, teachers with the fewest years of experience were more likely than teachers with the most years of experience to use computers or the Internet at home to gather information for planning lessons (76 percent compared with 63 percent) and creating instructional materials (91 percent compared with 82 percent). Less experienced teachers were also generally more likely than more experienced teachers to use these technologies to access model lesson plans at school and at home.

Teacher Preparation and Training in IT

Teacher preparation and training to use information technology is a key factor to consider when examining teacher use of computers and the Internet for instructional purposes. In 1999, approximately one-third of teachers reported feel-

ing well prepared or very well prepared to use computers and the Internet for classroom instruction, with less experienced teachers indicating they felt better prepared to use technology than their more experienced colleagues. For many instructional activities, teachers who reported feeling better prepared to use technology were generally more likely to use it than were teachers who indicated that they felt unprepared (NCES 2000g).

Teachers cited independent learning most frequently as the method they used to prepare for technology use (93 percent), followed by professional development activities (88 percent) and assistance from their colleagues (87 percent). Although half of all teachers reported that college and graduate work prepared them to use technology, less experienced teachers were generally much more likely than their more experienced colleagues to indicate that this education prepared them to use computers and the Internet.

Most teachers indicated that professional development activities on a number of topics were available to them, including training on software applications, use of the Internet, and use of computers and basic computer training (ranging from 96 percent to 87 percent). Among teachers reporting that these activities were available, participation was relatively high (ranging from 83 to 75 percent) and more experienced teachers were generally more likely to participate than less experienced teachers. Teachers indicated that followup and advanced training and use of other advanced telecommunications were available less frequently (67 and 54 percent, respectively), and approximately half of the teachers reporting that these two activities were available to them participated in those activities.

Over a three-year period, most teachers (77 percent) participated in professional development activities in the use of computers or the Internet that lasted the equivalent of four days or fewer (i.e., 32 or fewer hours). Teachers who spent more time in professional development activities were generally more likely than teachers who spent less time in such activities to indicate they felt well prepared or very well prepared to use computers and the Internet for instruction (NCES 2000g).

Perceived Barriers to Teacher Use of Technology

Certain characteristics of classrooms and schools, such as equipment, time, technical assistance, and leadership, may act as either barriers to or facilitators of technology use (NCES 2000g). In 1999, barriers to the use of computers and the Internet for instruction most frequently reported by public school teachers were not having enough computers (78 percent), lack of release time for teachers to learn how to use computers or the Internet (82 percent), and lack of time in the schedule for students to use computers in class (80 percent) (NCES 2000g).[12]

[12] Includes teachers reporting these as "small, moderate, or great barriers" NCES 2000g, figure 6-1.

Teacher perceptions of barriers to technology use varied by a number of teacher and school characteristics. For example, secondary teachers, teachers in large schools, and teachers in central-city schools were more likely than elementary teachers, teachers in small schools, and teachers in rural schools, respectively, to report that not having enough computers was a great barrier. (See text table 1-6.) Additionally, teachers in schools with more than 50 percent minority enrollments were more likely to cite outdated, incompatible, or unreliable computers as a great barrier than were teachers in schools with less than 6 percent minority enrollments (32 percent compared with 22 percent).

Generally, teachers who perceived lacking computers and time for students to use computers as great barriers were less likely than those who did not perceive these conditions as barriers to assign students to use computers or the Internet for some instructional activities. For example, teachers who reported insufficient numbers of computers as a great barrier were less likely than teachers reporting that this was not a barrier to assign students to use computers or the Internet to a "large extent" for practicing drills (9 percent compared with 19 percent), word processing or creating spreadsheets (14 percent compared with 25 percent), and solving problems and analyzing data (6 percent compared with 13 percent) (NCES 2000g).

Text table 1-6.
Percentage of public school teachers reporting great barriers to use of computers and the Internet for instruction, by type of barrier and school characteristics: 1999

School characteristics	Not enough computers	Outdated, incompatible, or unreliable computers	Internet not easily accessible
All public schools	38	25	27
Elementary	36	27	28
Secondary	43	21	23
Enrollment			
Less than 300	25	24	21
300–999	38	26	27
1,000 or more	46	24	27
Locale			
City	43	29	28
Urban fringe	39	25	27
Town	38	22	23
Rural	31	23	26
Minority enrollment			
Less than 6	35	22	24
6–20	35	22	20
21–49	38	26	27
50 or more	45	32	36

NOTE: Teachers who reported that computers were not available to them in school were excluded from analyses.

SOURCE: National Center for Education Statistics, *Teachers' Tools for the 21st Century: A Report on Teachers' Use of Technology*, NCES 2000-102 (Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement, 2000g).

Science & Engineering Indicators – 2002

Calculator Use in the United States and Other Countries

Handheld calculators are owned by almost every student in the United States and are fully integrated into the teaching of mathematics in many U.S. schools. Since 1985, many calculator models have featured built-in graphing software for enhancing teaching and learning by allowing mathematics students to visualize mathematical functions.

The NCTM Curriculum and Evaluation Standards (NCTM 1989) urge the use of calculators to reduce the time spent on paper and pencil methods of calculating so that students can have more time to work on problems that foster development of underlying concepts. NCTM suggests that by using this approach, students develop a stronger basis for understanding how to approach complex problems. Meanwhile, educators who do not share this view have expressed concern that young children in classrooms where calculators are heavily used may not develop proficiency with basic arithmetic operations. See sidebar, "Calculators and Achievement."

Both the NAEP and TIMSS surveys included questions for teachers and students on their level of calculator use in schools. The TIMSS surveys show that 99 percent of 8th-grade students and 95 percent of 4th-grade students in the United States owned calculators in 1995. The range was from 76 percent in Norway to 95 percent in the United States and the Czech Republic. In the United States, many schools provide calculators for use by students who do not own them. School-owned calculators used in 4th-grade U.S. classrooms increased from 59 percent to 84 percent between 1992 and 1996 (Hawkins, Stancavage, and Dossey 1998).

Classroom use of calculators is more common among U.S. elementary school students than among students in a number of other countries that participated in TIMSS. (See text table 1-7.) Although U.S. teachers were more likely than teachers in most other countries to use calculators in the lower grades, about 30 percent still reported that they never use calculators. However, about the same percentage of these teachers reported using calculators to solve complex problems in 4th-grade classrooms, a proportion similar to that for teachers in Canada and England (Mullis et al. 1997).

By grade 8, classrooms in nearly all countries use calculators for mathematics instruction, although the degree to which they are used varies widely. In 1999, 42 percent of U.S. 8th-grade students reported that they "almost always" use calculators in their mathematics lessons (Mullis et al. 2000). This percentage was higher than the international average (19 percent). Compared to the United States, two nations, the Netherlands and Australia, had a higher percentage of students responding that they almost always use calculators in their mathematics lessons. Eight percent of U.S. 8th-grade students reported never using calculators in their mathematics lessons, which was lower than the international average for students (32 percent).

Official policies on calculator use vary across the countries participating in the TIMSS-R; policies include encouraging unrestricted use, use with restrictions, and banning calculator use entirely (Mullis et al. 2000). Official documents of 23 countries included an explicit policy on the use of calculators. (See text table 1-8 for policies in selected countries.) Seven of these countries reported that their curriculum policy allows unrestricted use of calculators (Belgium, Finland, Hong Kong, Israel, Japan, the Netherlands, and New Zealand), and 14 allow restricted use. In Canada and the United States, policy varied across provinces and states, respectively. Several countries' policies do not permit calculator use in the lower grades of their primary school systems. For example, in Japan, calculators are not permitted until grade 5. Other countries reported that the use of calculators in these lower grades is limited so that students may master basic computational skills, both mentally and using pencil and paper.

Transition to Higher Education

Expectations of college attendance have increased dramatically over the past 20 years, even among low-performing students. More than two-thirds of high school graduates attend college, and a rising proportion have taken a college preparatory curriculum in high school. The use of AP exams to gain college credit in high school has also increased, although research has shown that some colleges are less likely to award AP credit now than in the past. Despite greater numbers of students aiming for college, some college faculty are concerned that today's students are less well prepared in mathematics than previous generations of students. College-level remediation is also on the rise, and policymakers are increasingly concerned about the number of students needing to take remedial courses in college. This section reviews changes in the immediate transition from high school to college over the past 30 years, including changes by sex and by race/ethnicity. The final section discusses the growth of remediation at the college level, a trend that troubles both educators and policymakers who are concerned about the efficacy of the S&E pipeline.

Transition from High School to College

Because most college students enroll in college immediately after completing high school, the percentage of high school graduates enrolled in college the October following graduation is an indicator of the total proportion who will ever enroll in college. College enrollment rates reflect both the accessibility of higher education to high school graduates and their assessments of the relative value of attending college compared with working, entering the military, or pursuing other possibilities.

Overall, immediate college enrollment rates for high school completers increased from 49 to 63 percent between 1972 and 1999. (See figure 1-20.) Much of the growth in these rates between 1984 and 1999 was due to increases in the immediate enrollment rates for females at four-year institutions (see below).

Some differences in immediate enrollment rates among groups of completers have not changed. The gap in rates be-

Text table 1-7.
Student mathematics score and percentage of students and teachers reporting hand-held calculator use in 4th and 8th grades, by country: 1995

			Calculator use and access (%)						
			4th grade						
	Average mathematics score (mean)		Students		Teachers		8th-grade teachers		
Country	4th grade	8th grade	Have calculators at home	Never use in class	Never use in class	Use for complex problems	Never use in class	Use daily	Use for complex problems
Singapore	625	643	93	96	97	1	1	82	82
South Korea	611	607	87	93	86	3	76	1	4
Netherlands	577	541	93	90	85	2	0	81	67
Czech Republic	567	564	95	63	54	8	3	74	80
Austria	559	539	95	96	98	0	2	87	70
Ireland	550	527	95	91	88	3	68	11	7
United States	545	500	95	34	29	26	8	62	76
Hungary	548	537	95	90	78	5	29	60	53
Canada	532	527	95	51	37	23	5	80	86
England	513	506	95	15	8	28	0	83	73
Norway	502	503	95	89	93	1	2	82	72
New Zealand	499	508	95	18	5	50	7	66	70

SOURCES: I. Mullis, M. Martin, A. Beaton, E. Gonzalez, D. Kelly, and T. Smith, *Mathematics Achievement in the Primary School Years: IEA's Third International Mathematics and Science Study (TIMSS)* (Chestnut Hill, MA: Boston College, TIMSS International Study Center, 1997); and A. Beaton, M. Martin, I. Mullis, E. Gonzalez, T. Smith, and D. Kelly, *Science Achievement in the Middle School Years: IEA's Third International Mathematics and Science Study (TIMSS)* (Chestnut Hill, MA: Boston College, TIMSS International Study Center, 1996). *Science & Engineering Indicators – 2002*

Calculators and Achievement

Although the National Council of Teachers of Mathematics (NCTM) recommends the integration of calculators into the school mathematics program at all grade levels (NCTM 1989), research on the effect of calculator use on achievement is not definitive. Some studies have concluded that calculator use does not undermine basic skills (Hembree and Dessart 1986, Suydam 1979) and that calculator use has a positive effect on achievement in early grades (B. Smith 1996, Hembree and Dessart 1986). Critics, however, have pointed to deficiencies in the majority of studies supporting calculator use. Many of these studies were of short duration, lasting only a few weeks, and lacked sufficient controls to equate comparable groups or to screen out other influences on student outcomes (Loveless and Diperna 2000).

A recent Brookings Institution study (Loveless and Diperna 2000) examining test results from both the National Assessment of Educational Progress (NAEP) and the Third International Mathematics and Science Study (TIMSS) raises additional questions about the influence of calculator use on achievement. For example, in both NAEP and TIMSS, students were asked how often they use calculators in class. On both tests, calculator use is correlated with lower math scores. On the 1996 National NAEP Mathematics Assessment, 4th graders who reported that they used calculators in class every day had the lowest NAEP scores of any response category. Students who reported using calculators only once or twice per month had the highest scores. A similar pattern was evident on 4th-grade TIMSS. Frequent calculator use is negatively correlated with math achievement in several countries. A vast majority of 4th-grade students in the highest scoring nations (Japan, Singapore, and South Korea) report that they never use calculators in math class.

Although Loveless and Diperna acknowledge that these results do not necessarily imply that calculator use results in lower academic achievement (low math skills may actually push individual students to rely on calculators more), their findings suggest that additional, high-quality research on the use of calculators at the elementary level is warranted, particularly because of the equity issues involved. In 1996, black and Hispanic students were about twice as likely as white students to report that they use calculators every day (Loveless and Diperna 2000).

tween those from high- and low-income families persisted for each year between 1990 and 1999. Likewise, completers whose parents had attained a bachelor's degree or higher were more likely than those with parents who had less education to enter college immediately after high school graduation for each year between 1990 and 1999 (NCES 2001b).

Transition Rates by Sex

Females are slightly more likely than males to make an immediate transition from high school to college. Between 1972 and 1999, immediate enrollment rates for female high school graduates increased faster than those for males. (See

figure 1-20.) Much of the increase between 1984 and 1999 was due to increases in female enrollment rates at four-year colleges, which rose from 34 to 43 percent over this 15-year period. In 1999, the enrollment rate at four-year institutions was 43 percent for females compared with 41 percent for males. That year, females were about as likely as males to enroll in two-year institutions after high school graduation (both about 21 percent) (NCES 2001b).

Although males and females are similarly prepared to enter the math and science pipeline upon entering college, a large gender gap occurs in the selection of college majors (see sections on achievement and coursetaking in this chapter and chapter 2). However, the divergence in interest in math and science careers may start much earlier.

Text table 1-8.
Policies on calculator usage in selected countries/economies participating in TIMSS-R: 1999

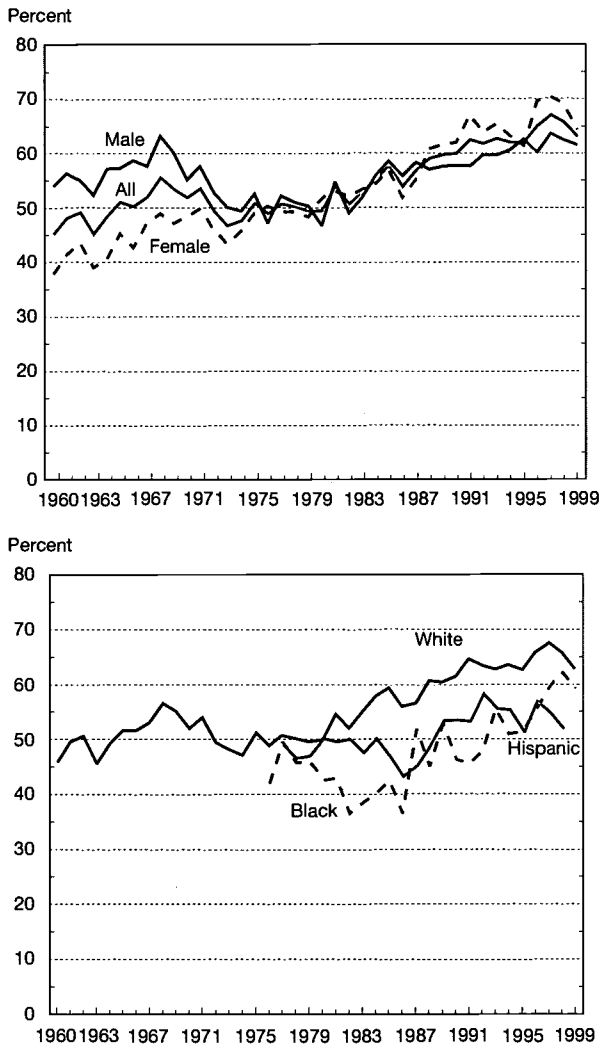
Country/economy	Type of policy	Comments
Australia	Unrestricted	Calculators are unrestricted as a learning tool. Computational skills like mental arithmetic are also promoted.
Belgium (Flemish)	Restricted	Calculators are permitted on a limited basis so that students can master the basic skills of computation and mental calculation. Calculator use increases and is compulsory after grade 9.
Canada	Unrestricted, 2 provinces; restricted, 8 provinces	In general, calculator use is encouraged, except in lower grades in some provinces.
Taiwan	Restricted	Calculators are not allowed on entrance exams, so teachers can limit their use in classroom.
Czech Republic	Restricted	Computational skills are practiced without calculators.
England	Restricted	Calculator use increases as students progress through school. The emphasis is on pupils having a range of skills: calculator, pencil and paper, and mental computation. Graphic calculators are required at higher levels.
Finland	Unrestricted	Although permitted at the lower levels, policy indicates that the use of calculators is more appropriate at the upper levels (grades 7–9).
Hong Kong	Unrestricted	Calculators may be used for exploration only from grades 1 to 6. No restrictions are set on the use of calculators for students from grade 7 onward.
Hungary	Restricted	Calculator use is considered appropriate in higher grades.
Indonesia	Restricted	Calculators are not permitted in lower grades.
Israel	Unrestricted	Calculators are permitted through all school levels (grades 1–12)
Italy[a]		
Japan	Unrestricted	Calculators are not permitted until grade 5.
Netherlands	Unrestricted	Calculators are compulsory at national exam level. In grades 11–12, the graphic calculator is compulsory for mathematics students.
New Zealand	Unrestricted	The policy assumes that calculators will be available and used "appropriately" at all levels.
Russian Federation	Restricted	There is some use of calculators in elementary school. Recommended use of calculators on a level with oral and written calculations in secondary school. Students are not allowed to use calculators for public exams in grades 9 and 11.
Singapore	Restricted	In primary school, students are not allowed to use calculators in mathematics. In secondary school, the use of calculators is allowed from grade 7, although the use is restricted.
Slovenia[a]		
South Korea	Restricted	Currently, calculators are not used in class. However, the new curriculum, to be implemented in 2000/01, recommends the wide use of calculators.
United States	Varies from state to state	

[a]Curriculum does not contain recommendations about use of calculators.

SOURCE: I. Mullis, M. Martin, E. Gonzalez, K.D. Gregory, R.A. Garden, K.M. O'Connor, S.J. Chrostowski, and T. Smith. *TIMSS 1999 International Mathematics Report* (Chestnut Hill, MA: Boston College, TIMSS International Study Center, 2000).

Science & Engineering Indicators – 2002

Figure 1-20.
Percentage of high school graduates enrolled in college the October after completing high school, by sex and race/ethnicity: 1960–99



NOTE: Data for Hispanics are calculated as three-year moving average.

SOURCE: National Center for Education Statistics, *The Digest of Education Statistics 2000*, NCES 2001-034 (Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement: 2001b).

Science & Engineering Indicators – 2002

Transition Rates by Race/Ethnicity

College transition rates for white and black high school graduates have increased over the past 30 years, while rates for Hispanic graduates have been stable. (See figure 1-20.) Transition rates for white high school graduates increased from 50 percent in the early 1970s to about 60 percent in the mid-1980s and have fluctuated between 60 and 67 percent since then. After a period of decline in the late 1970s and early 1980s, the percentage of blacks enrolling in college immediately after high school graduation rose through the late 1980s, stagnated in the early 1990s, and increased again in the late 1990s. Since 1984, college transition rates for black graduates have increased faster than those for whites, thus closing much of the gap between the two groups. The enrollment rates for Hispanic graduates have shown no consistent growth since 1972, fluctuating between 45 and 65 percent from 1972 to 1997 (NCES 2001b).

The type of institutions that high school graduates first attend can affect their likelihood of completing a bachelor's degree. Students who begin their higher education at a two-year college are far less likely to earn a bachelor's degree than are their counterparts who begin at a four-year college. In 1994, white graduates were twice as likely to enroll in a four-year college as a two-year college after high school, black graduates were about 1.5 times as likely, and Hispanic graduates were equally likely to enroll in a four-year college as a two-year college (NCES 1996b).

Students who initially enroll part time in college are less likely to persist toward a bachelor's degree than those who enroll full time (NCES 1996b). Hispanic high school graduates ages 18–24 were far more likely to be enrolled in college part time, as opposed to full time, than were their white or black counterparts in 1994. (See sidebar, "Who Is Prepared for College?")

Remedial Education in College

Many students enter postsecondary education institutions lacking the reading, writing, or mathematics skills necessary to perform college-level work. Therefore, most institutions enrolling freshmen offer remedial courses to bring these students' skills up to the college level (NCES 2000a). Although some consider remedial courses as one way to expand educational opportunities for students with academic deficiencies, others feel that remedial instruction should be eliminated or strictly limited in four-year institutions.

In 1995, all public two-year and 81 percent of public four-year institutions offered remedial reading, writing, or mathematics courses. Fewer private four-year institutions (63 percent) offered remedial courses in one or more of these subjects. (See figure 1-22.)

Public two-year institutions were more likely than either public or private four-year institutions to offer remedial courses because of their particular mission and the types of students they serve. In 1995, about one-half of public two-year institutions had open admissions compared with less than 10 percent of public and private four-year institutions (NCES 2000a). Freshmen at public two-year institutions were almost twice as likely as their peers at public four-year institutions to enroll in remedial courses in reading, writing, or mathematics (41 versus 22 percent) (NCES 2000a).

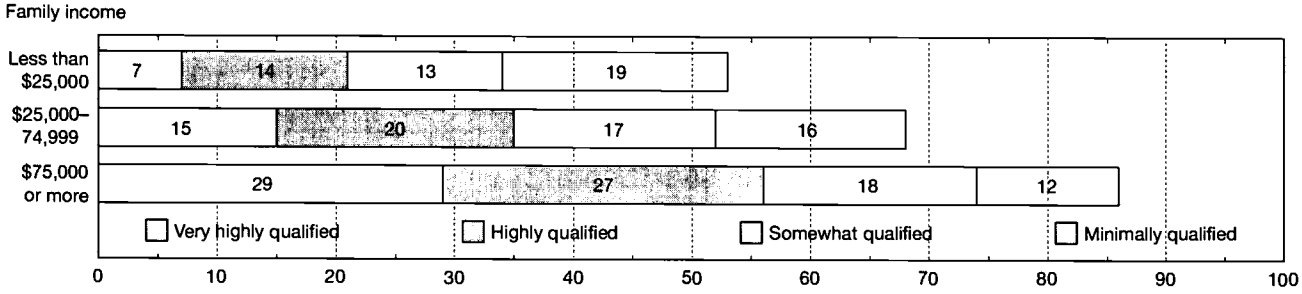
Who is Prepared for College?

High school graduates from low-income families enter four-year institutions at lower rates than their higher income peers (NCES 2000a). Although financial barriers to college attendance exist for many low-income students, another reason for their lower enrollment rate is that they are less qualified academically. (See figure 1-21.) NCES constructed a 4-year College Qualification Index, based on high school grade point average, senior class rank, aptitude test scores from the National Educational Longitudinal Study of 1988, SAT or ACT scores, and a measure of curricular rigor (see NCES 2000a for details). On this index, 86 percent of 1992 high school graduates from families with high incomes ($75,000 or more) were at least minimally academically qualified for admission to a four-year institution compared with 68 percent of those from middle-income ($25,000 to $74,999) and 53 percent from low-income (less than $25,000) families. Moreover, high-income graduates were almost twice as likely as middle-income graduates and four times as likely as low-income graduates to be very highly qualified for four-year college admission. The proportion of college-qualified students was also directly related to their parents' educational attainment.

Asian/Pacific Islander and white graduates have higher average family income and parental education levels than their black and Hispanic counterparts. Reflecting this pattern, Asian/Pacific Islander and white graduates were more likely than black and Hispanic graduates to be at least minimally qualified for four-year college admission. The proportion of very highly qualified graduates was largest among Asians/Pacific Islanders.

SOURCE: NCES 2000a.

Figure 1-21.
Percentage of 1992 high school graduates qualified for admission at a four-year institution, by level of qualification and family income



NOTE: Four-year college qualification index is based on high school grade point average, senior class rank, National Educational Longitudinal Study (NELS) 1992 aptitude test, SAT scores, and a measure of curricular rigor.

SOURCE: National Center for Education Statistics, *The Condition of Education 2000*, NCES 2000-062 (Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement: 2000a).

Science & Engineering Indicators – 2002

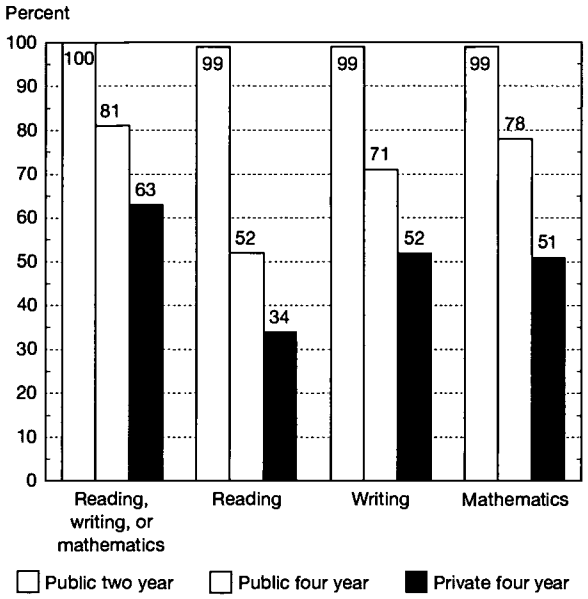
Conclusion

This chapter presented indicators of the status and change in U.S. elementary and secondary schools regarding student achievement, math and science coursetaking, implementation of content standards and state-level testing, curriculum structure and amount of time allocated to math and science compared with other countries, teacher quality (including initial training and professional development), teacher working conditions, access to and use of technology in schools, and transition to higher education. Although these indicators do not tell the whole story, they do highlight improvements in our K–12 education system over the past few decades while pointing to areas of enduring concern.

Observations made about U.S. mathematics and science education in 1947 noted that textbooks were thick and included unnecessary information and that teachers did not have sufficient training in mathematics (NSB 2000). Significant efforts have been made to reform elementary and secondary schools since 1947, such as those stimulated by *Sputnik* in 1957, the National Commission on Excellence in Education in 1983, and the National Education Goals that grew out of the Governor's summit of 1990. The national policy goals and educational standards for mathematics and science education set new and higher expectations for U.S. schools, students, and teachers. The indicators in this chapter were chosen to measure how close the nation has come to meeting those expectations.

A higher proportion of students graduate from high school with advanced courses in mathematics and science than did their counterparts three decades ago. As measured by NAEP, student achievement in mathematics and science has increased since the mid-1970s, although relatively few students are attaining levels deemed Proficient or Advanced by NAGB, and the performance of U.S. students continues to rank substantially below that of students in a number of other countries. Furthermore, the relative performance of U.S. students compared to their counterparts in other countries appears to de-

Figure 1-22.
Percentage of postsecondary education institutions offering remedial courses, by type of course and type of institution: fall 1995



SOURCE: National Center for Education Statistics, *The Condition of Education 2000*, NCES 2000-062 (Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement: 2000a).

Science & Engineering Indicators – 2002

cline as students progress through school and it also affects our most advanced students.

Girls have closed much of the gender gap in mathematics achievement, although a larger share of boys continue to perform at the most advanced levels; the gender gap in science achievement has also narrowed. The gap between high and low performers remains wide, however, and black and Hispanic students continue to perform far below their white counterparts.

An explicit goal of educational standards for mathematics and science is that all students, without regard to gender, race, or income, participate fully in challenging coursework and achieve at high levels. The disparate performance among racial/ethnic groups is still observed when transcripts are examined. Asian/Pacific Islander and white students are much better represented in advanced courses than are black and Hispanic students. Racial/ethnic differences in math and science achievement persist among students taking similar courses in high school, primarily reflecting the large achievement gaps evident before high school entry.

In the 1980s, most states approved policies aimed at improving the quality of K–12 education by implementing statewide curriculum guidelines and frameworks as well as assessments. At present, half of the states require students to pass some form of exit examination to graduate from high school, and others report that they are developing such tests. Teachers remain concerned, however, that standards do not always provide clear guidance regarding the goals of instruction and that schools do not yet have access to top-quality curriculum materials aligned with the standards. Although some states have recently delayed the introduction of high-stakes tests (i.e., tests that students must pass to either graduate or advance a grade), public support for the standards movement remains strong.

Public school teachers generally support the movement to raise standards, but they are less supportive than the general public. The vast majority of public school teachers feel that the curriculum is becoming more demanding of students, although they also feel that new statewide standards have led to teaching that focuses too much on state tests and that a significant amount of "teaching to the test" occurs.

Measuring the extent to which standards are linked to instruction that challenges students is difficult because available methods cannot measure quality directly. Available indicators focus on the amount of time students spend studying a subject (classwork and homework), the content of lessons, and the types of instructional resources used (e.g., textbooks). These data show that although U.S. students appear to receive at least as much classroom time in mathematics and science instruction as students in other nations, instruction in U.S. 8th-grade classrooms tends to focus on the development of low-level skills rather than on understanding and provides few opportunities for students to engage in high-level mathematical thinking.

Improvements in the quality of U.S. education cannot occur without the concurrence of teachers. Research suggests that the following factors are associated with teacher quality: having academic skills, teaching in the field in which the teacher received training, having more than a few years of experience (to be most effective), and participating in high-quality induction and professional development programs. It is still common for students to be taught math and science by teachers without academic training in those subjects, and this mismatch is worse in high-poverty schools.

Salaries for math and science teachers remain well below those of bachelor's and master's degree scientists and engineers in industry. Given that teacher retirements are on the rise, increased salaries provide a means of retaining good teachers and attracting the number of quality teachers needed to replace retirees. The difference between the annual median salaries of all bachelor's degree recipients and teachers has declined over the past 20 years, mainly due to increases in the relative size of the older teaching workforce and in salaries of older teachers.

The role of education technology in U.S. schools has been changing rapidly. Handheld calculators are commonly used in both U.S. homes and classrooms. About one-fourth of 4th-grade teachers and three-fourths of 8th-grade teachers report that they use calculators for solving complex problems. By 2000, nearly all schools reported that at least one computer was linked to the Internet and half of the classrooms had access to the Internet.

Finally, expectations of college attendance have increased dramatically over the past 20 years, even among low-performing students. More than two-thirds of high school graduates attend college, and a rising proportion have taken a college

preparatory curriculum in high school. The use of AP exams to gain college credit in high school has also increased, although research has shown that some colleges are less likely to award AP credit now than in the past. College-level remediation is also on the rise, and policymakers are increasingly concerned about the number of students needing to take remedial courses in college. The impact of these changes on the S&E pipeline is addressed in the next chapter.

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Chapter 2
Higher Education in Science and Engineering

Highlights

Demographics

♦ **The size of the college-age population has decreased in all major industrialized countries although within different time frames.** The U.S. college-age population decreased from 22 million in 1980 to 17.5 million in 1997, a reduction of 23 percent. Europe's college-age population has begun a steeper decline, from 30 million in 1985 to 22 million in 2005, a reduction of 27 percent. Japan's college-age population of 10 million, which began to decline in 1995, is projected to reach a low of 7 million in 2015, representing a loss of 30 percent.

♦ **In the United States, the nearly 20-year population decline in the size of the college-age cohort reversed in 1997 and is projected to increase from 17.5 million to 21.2 million by 2010, with strong growth among minority groups.** This increase in the college-age population by more than 13 percent in the first decade of the 21st century signals another wave of expansion in the nation's higher education system and growth in science and engineering (S&E) degrees at all levels.

♦ **Demographic trends show an increase in the minority population in the United States.** The traditional college-age population of white students will expand slowly until 2010 and then decline, whereas the traditional college-age population of racial and ethnic minorities will continue to rise. These trends offer a challenge to the United States to educate students who have been traditionally underrepresented in S&E.

Characteristics of Higher Education by Type of Institution

♦ **Overall enrollment in the nation's institutions of higher education increased from 7 million in 1967 to 15 million in 1992 and then continued essentially unchanged through 1997.** Enrollment in higher education is expected to increase in the first decade of the 21st century because of a predicted 13 percent increase in the population of the college-age cohort during this period.

♦ **Research universities enroll only 19 percent of the students in higher education, but they play the largest role in S&E degree production.** They produce most of the engineering degrees and a large proportion of natural and social science degrees at both the graduate and undergraduate levels. In 1998, the nation's 127 research universities awarded more than 42 percent of all S&E bachelor's degrees and 52 percent of all S&E master's degrees.

♦ **By 1997, enrollment in community colleges was 38 percent of the total enrollment in higher education.** Community colleges serve a diverse population of students and have a broad set of missions. They confer associate degrees, serve as a bridge for students to attend four-year colleges, and expand the supply of information technology workers through certificate programs. They offer a wide array of remedial courses and services and enroll millions of students in noncredit and workforce training classes.

♦ **Traditional institutions of higher education are augmented by industrial learning centers, distance education, and certificate programs.** Substantial education within industry is at the level of higher education and oriented toward engineering, design, and business management. Interest in taking S&E courses and entire programs via distance education is growing. In 1997, more than 50,000 different on-line courses were offered by postsecondary institutions, and 91 percent of those were college-level credit courses.

Undergraduate S&E Students and Degrees in the United States

♦ **A key challenge for undergraduate education is preparing K–12 teachers in science and mathematics.** In the upcoming decade, the nation's school districts will need to hire 2.2 million new teachers, including 240,000 middle and high school mathematics and science teachers. Of the total, 70 percent will be new to the profession because of older teachers retiring and the increase in student population.

♦ **The percentage of high school graduates enrolling in college is increasing for some racial groups.** By 1999, approximately 45 percent of white and 39 percent of black high school graduates were enrolled in college, up from approximately 31 and 29 percent, respectively, in 1979. In contrast, during this period, enrollment rates in higher education for Hispanic high school graduates increased only slightly, from 30 to 32 percent.

♦ **In the past two decades, the proportion of white students in the nation's undergraduate student enrollment decreased, falling from 80 percent in 1978 to 70 percent in 1997.** The proportion of underrepresented minorities increased the most, from 15.7 to 21.7 percent; Asians/Pacific Islanders increased from 2.0 to 5.8 percent, and foreign students remained at approximately 2 percent of undergraduate enrollment.

♦ **Women outnumber men in undergraduate enrollment for every race and ethnic group.** White women constitute 55 percent of white undergraduate students, and black women constitute 62 percent of black undergraduate enrollment.

♦ **The long-term trend has been for fewer students to enroll in engineering.** Undergraduate engineering enrollment declined by more than 20 percent, from 441,000 students in 1983 (the peak year) to 361,000 students in 1999. Graduate engineering enrollment peaked in 1993 and continues to decline.

- **Approximately 25–30 percent of students entering college in the United States intend to major in S&E fields, but a considerable gap exists between freshman intentions and successful completion of S&E degrees.** Fewer than 50 percent of those who intend to major in S&E fields complete an S&E degree within five years. Underrepresented minorities drop out of S&E programs at a higher rate than other groups.
- **For the past several decades, about one-third of bachelor's degrees have been awarded in S&E fields, but from 1986 to 1998, the percentage of engineering degrees decreased from 8 to 5 percent of total undergraduate degrees.** Since 1986, the percentage of bachelor's degrees earned by undergraduates also has declined slightly in physical sciences, mathematics, and computer sciences. In contrast, since 1986, students have earned a higher percentage of bachelor's degrees in social and behavioral sciences and in biological sciences.
- **The ratio of natural science and engineering (NS&E) degrees to the population of 24-year-olds in the United States has been between 4 and 5 per 100 for the past several decades and reached 6 per 100 in 1998.** Several Asian and European countries, however, have higher participation rates, and the U.S. gap in educational attainment between whites and racial/ethnic minorities continues to be wide; the rate of earning NS&E degrees for racial/ethnic minorities is still less than half the rate of the total population.

Graduate S&E Students and Degrees in the United States

- **Long-term trends show that the proportion of women enrolled in all graduate S&E fields is increasing.** By 1999, women constituted 59 percent of the graduate enrollment in social and behavioral sciences, 43 percent of the graduate enrollment in natural sciences, and 20 percent of the graduate enrollment in engineering. Women in underrepresented minority groups have a higher proportion of graduate enrollment than women in other groups; one-third of black graduate students in engineering and more than one-half of the black graduate students in natural sciences are women.
- **Long-term trends show that the enrollment of foreign graduate students in S&E fields in the United States is increasing.** This increase, coupled with a declining number of American white (majority) students, resulted in an approximately equal number of American white and foreign students in U.S. graduate programs in mathematics, computer sciences, and engineering in 1999.
- **After a steady upward trend during the past two decades, the overall number of earned doctoral degrees in S&E fields declined in 1999.** Trends differ by field. Degrees in biological sciences followed the overall pattern and declined for the first time in 1999. Strong increases in the number of degrees earned in engineering peaked in 1996 and were followed by three years of decline. This decrease in the number of engineering degrees earned is accounted for mainly by the decrease in the number of degrees earned by foreign students from 1996 to 1999.
- **At the doctoral level, the proportion of S&E degrees earned by women has risen considerably in the past three decades, reaching a record 43 percent in 1999.** However, dramatic differences by field exist. In 1999, women earned 42 percent of doctoral degrees in the social sciences; 41 percent of those in biological and agricultural sciences; 23 percent of those in physical sciences; 18 percent of those in computer sciences; and 15 percent of those in engineering.
- **Each year from 1986 to 1996, the number of foreign students earning S&E doctoral degrees from universities in the United States increased; it declined every year thereafter.** During the period 1986–99, foreign students earned 120,000 doctoral degrees in S&E fields. China was the top country of origin of these foreign students; almost 24,000 Chinese earned S&E doctoral degrees at universities in the United States during this period.
- **The National Institutes of Health (NIH) and the National Science Foundation support most of the S&E graduate students whose primary support comes from the Federal Government, 17,000 and 14,000 students, respectively.** The proportion of students supported primarily by NIH increased from less than 22 percent in 1980 to 29 percent in 1999; those supported primarily by NSF increased from less than 18 percent in 1980 to 21 percent in 1999. In contrast, the Department of Defense provided primary support for a declining proportion of students funded primarily by Federal sources, 17 percent in 1988 and 12 percent in 1999.
- **By 1999, more than 72 percent of foreign students who earned S&E doctoral degrees at universities in the United States reported that they planned to stay in the United States after graduation, and 50 percent accepted firm offers to do so.** These percentages in the late 1990s represent significant increases. Historically, approximately 50 percent of foreign doctoral recipients planned to stay in the United States after graduation, and a smaller proportion had firm offers to do so.
- **Although the number of foreign doctoral recipients planning to stay in the United States increased in the 1990s, opportunities are expanding for returning to their home countries or for collaborative research and networking with home-country scientists.** Taiwan and South Korea have been the most able to absorb Ph.D.-holding scientists and engineers trained abroad. Some of this recruitment occurs after a distinguished science career abroad.

Increasing Global Capacity in S&E

- **In 1999, more than 2.6 million students worldwide earned a bachelor's degree in science or engineering.** More than 1.1 million of the 2.6 million S&E degrees were earned by Asian students at Asian universities. Students across Europe (including Eastern Europe and Russia) earned almost 800,000 first university degrees in S&E fields. Students in North America earned more than 600,000 S&E bachelor's degrees.

- **Trend data for bachelor's degrees show that the number of degrees earned in the United States remained stable or declined in the 1990s in all fields except psychology and biology.** In contrast, trend data available for selected Asian countries show strong growth in degree production in all S&E fields. At the bachelor's level, institutions of higher education in Asian countries produce approximately six times as many engineering degrees as do institutions in the United States.

- **Although the United States has traditionally been a world leader in providing broad access to higher education, other countries have expanded their higher education systems, and the United States is now 1 of 10 countries providing a college education to approximately one-third or more of their college-age population.** The ratio of natural science and engineering (NS&E) degrees to the college-age population is higher than in the United States in more than 16 other countries.

- **Among some Asian countries, women earn first university degrees at a rate similar to or higher than the corresponding rate in many European countries.** However, only in South Korea do women have high participation rates in NS&E degree programs. In 1998, the ratio of women-earned degrees in these fields to the female population of 24-year-olds was 4.6 per 100, higher than the participation rate of women in other Asian countries, Germany, or the United States.

- **The group of traditional host countries for many foreign students (United States, France, and United Kingdom) is expanding to include Japan, Germany, and Australia, and the proportion of foreign graduate students is increasing in these countries.** Foreign S&E graduate student enrollment in the United Kingdom increased from 28.9 percent in 1995 to 31.5 percent in 1999. Percentages differ by field; foreign student graduate enrollment in U.K. universities reached 37.6 percent in engineering and 40 percent in social and behavioral sciences.

- **Developing Asian countries, starting from a very low base in the 1970s and 1980s, have increased their S&E doctoral production by several orders of magnitude. China now produces the most S&E doctoral degrees in Asia and ranks fifth in the world.** Within Europe, France, Germany, and the United Kingdom have almost doubled their S&E doctoral degree production in the past two decades, with slight declines in 1998.

- **Because of the growing capacity of some developing Asian countries and economies (China, South Korea, and Taiwan) to provide advanced S&E education, the proportion of doctoral degrees earned by their citizens in the United States has decreased.** In the past five years, Chinese and South Korean students earned more S&E doctoral degrees in their respective countries than in the United States; in 1999, Taiwanese students for the first time earned more S&E doctoral degrees at Taiwanese universities than at U.S. universities.

- **In 1999, Europe produced far more S&E doctoral degrees (54,000) than the United States (26,000) or Asia (21,000).** Considering broad fields of science, most of the doctorates earned in natural sciences, social sciences, and engineering are earned at European universities. The United States awards more doctoral degrees in natural and social sciences than Asian countries.

- **Like the United States, the United Kingdom and France have a large percentage of foreign students in their S&E doctoral programs.** In 1999, foreign students earned 44 percent of the doctoral engineering degrees awarded by U.K. universities, 30 percent of those awarded by French universities, and 49 percent of those awarded by universities in the United States. In that same year, foreign students earned more than 31 percent of the doctoral degrees awarded in computer sciences in France, 38 percent of those awarded in the United Kingdom, and 47 percent of those awarded in the United States.

Introduction

Chapter Overview

Among the diverse goals of the U.S. higher education system, two are particularly important to the science and engineering (S&E) fields. In addition to enhancing the broad intellectual capabilities of students, higher education prepares students to meet the needs of the 21st-century workforce. With the decline in the U.S. college-age population from 1980 to 1997 and subsequent falloff in degrees in many S&E fields, U.S. universities began to rely on foreign students to fill graduate S&E programs, particularly in the physical sciences, engineering, and computer sciences. As national demographic trends shift and minority populations become a larger proportion of the college-age cohort, U.S. higher education institutions are being challenged to attract and retain minority students who have been underrepresented in the S&E fields.

The U.S. higher education system also is responding to a growing movement across countries to enlist universities more explicitly into national innovation systems. For several decades, many countries have strengthened their higher education in S&E fields as a strategy for development, based on an assertion that advanced S&E knowledge would bolster their economies. In the 1990s, this assertion gained widespread acceptance, and most industrial and developing countries began improving their higher education systems, particularly in natural sciences, mathematics, engineering, and technology, as a necessary part of preparing for a "knowledge economy." Indicators of this international movement toward science and technology (S&T) education for development are:

- increased growth rate in the number of degrees in S&E fields among industrialized countries and developing nations,
- increased flow of foreign graduate students to study S&E fields in advanced countries,
- increased recruiting of foreign students by advanced countries that have a declining college-age population, and
- expanded options for mobility by foreign S&E doctorate-holders in terms of remaining abroad, returning home, or circulating between home and abroad during their careers.

As higher education in the United States contributes to these international trends[1] and also attempts to better prepare U.S. students for S&E careers, various changes are taking place:

- The infrastructure for S&E education is expanding beyond the traditional institutions of higher education to an array of flexible and interconnected learning modes.
- The scope of concern in S&E education is expanding to include both the focused education of S&E majors and the goal that all college students acquire scientific and technical literacy.
- The delivery of S&E instruction is changing through new teaching methods and innovative uses of information technology (IT).
- Student strategies for acquiring knowledge are changing to incorporate both traditional and new modes of higher education delivery.
- The growing proportion of underrepresented minority groups in the student body is forcing a movement to raise their participation in S&E.

Chapter Organization

The chapter begins with U.S. higher education and traditional education indicators of enrollment and degrees in S&E fields in different types of institutions. Overall demographic trends are discussed, including trends among U.S. subpopulations that are increasing minorities among the college-age cohort. The chapter describes traditional and new mechanisms for delivering higher education in S&E fields and, when possible, quantifies the activity outside formal academic institutions. For each level of higher education, enrollment and degrees are analyzed by sex, race/ethnicity, and citizenship. The chapter provides indicators of U.S. undergraduate students' initial interest in studying S&E, the persistent need during the past 20 years for remedial coursework, and the recently declining number of degrees in most S&E fields at all levels within traditional institutions of higher education. Efforts to reform undergraduate education aimed at raising the quantity and quality of U.S. students in S&E fields and at meeting all student needs for quantitative and scientific understanding are discussed. The chapter highlights trends in U.S. graduate S&E education and discusses reforms that attempt to broaden education and career options. Changing patterns of mobility and reverse flow of foreign students also are discussed.

The final section describes global trends that place U.S. higher education in an international context. For example, cross-regional trends in S&E degrees conferred show the acceleration of such degrees at the bachelor's and doctoral levels. The stronger participation rates in S&E among college-age cohorts in Europe and Asia are contrasted with participation rates in the United States. The flow of foreign students to the United States is compared with the increasing flow to the United Kingdom and Japan. The reverse flows of foreign doctorate-holders by field and country of origin are compared across the United States, United Kingdom, and France.

[1]U.S. institutions and S&E faculty are active in international distance education in developing countries, advise on establishing centers of excellence, accept students from abroad, and establish international collaborative research with their former students. (See, for example, Michael Arnon, 2001, "U. of Maryland Will Help Uzbekistan Create a Virtual University," *The Chronicle of Higher Education*, August 29; Eugene S. Takle, "Global Climate Change Course," Iowa State University, International Institute of Theoretical and Applied Physics, available at <http://www.iitap.iastate.edu/gccourse>: and E.S. Takle, M.R. Taber, and D. Fils, "An Interdisciplinary Internet Course on Global Change for Present and Future Decision-makers," Keynote presentation at the International Symposium on the Learning Society and the Water Environment, Paris, June 2–4, 1999.)

U.S. Higher Education in S&E

A key challenge for the higher education system in the United States is to remain a leader "in generating scientific and technological breakthroughs and in preparing workers to meet the evolving demands for skilled labor" (Greenspan 2000). The needs of the workplace are changing in today's information- and service-oriented economy; all workers require increased competency in mathematics and critical thinking and, at minimum, an understanding of basic science and technology concepts (Romer 2000). Despite the rising number of college-age adults (see "Demographics and Higher Education"), the National Science and Technology Council (NSTC 2000) has expressed concern about the nation's ability to meet its technical workforce needs and to maintain its international position in S&E. This section explains demographic trends that may affect higher education in the United States as well as institutional resources, both traditional and emerging, that are being mobilized to meet this challenge. The section includes data on the growing enrollment in S&E degree programs and the production of S&E degrees by type of institution. The growing importance of community colleges in lifelong learning and their role in teaching IT are also described.

Demographics and Higher Education

Past Trends

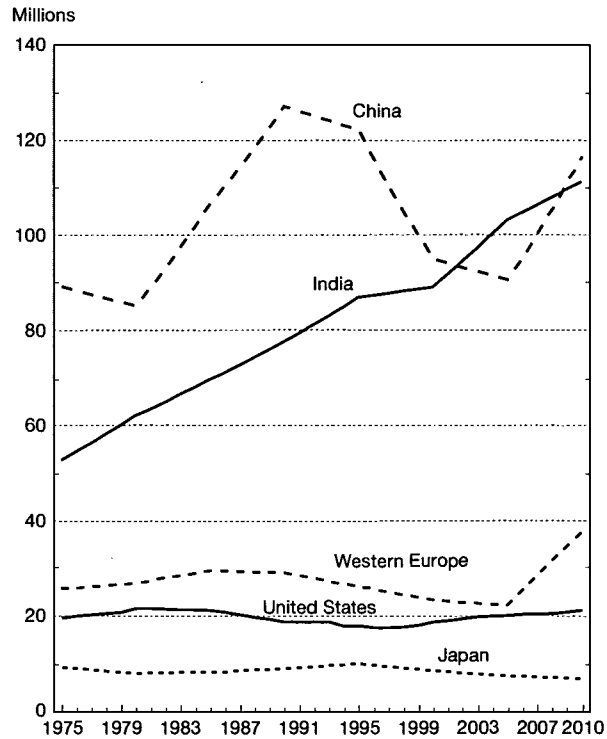
The size of the college-age cohort has decreased in all major industrialized countries, although within somewhat different time frames. The U.S. college-age population decreased from 22 million in 1980 to 17 million in 1997, a reduction of 23 percent. Europe's college-age population has begun an even steeper decline, from 30 million in 1985 to a projected 22 million in 2005, a reduction of 27 percent. Japan's college-age population of 10 million, which began to decline in 1995, is projected to reach a low of 7 million in 2010, representing a loss of 30 percent. (See appendix table 2-1.)

Based on these trends, the major industrialized countries have recruited foreign students to help fill their graduate S&E departments. See "International Comparisons of Foreign Student Enrollment in S&E Programs" at the end of this chapter. Most of these foreign students have been drawn from developing countries with far larger populations of potential college students. For example, China and India are major countries of origin for foreign graduate students in the United States, each with approximately 90 million in their college-age cohort. (See figure 2-1.)

Current Trends

In the United States, the almost 20-year decline of the college-age cohort reversed in 1997 and is projected to increase from 17.5 million to 21.2 million by 2010, with strong growth among minority groups. (See appendix tables 2-1 and 2-2.) This projected increase in the college-age population by more than 13 percent in the first decade of the 21st century, coupled with the high percentage of the college-age population electing to attend college, signals another wave of expansion in enrollment in the U.S. higher education system and growth in S&E degrees at all levels.

Figure 2-1.
Trends in population of 20- to 24-year-olds in selected countries and regions: 1975–2010



See appendix table 2-1. *Science & Engineering Indicators – 2002*

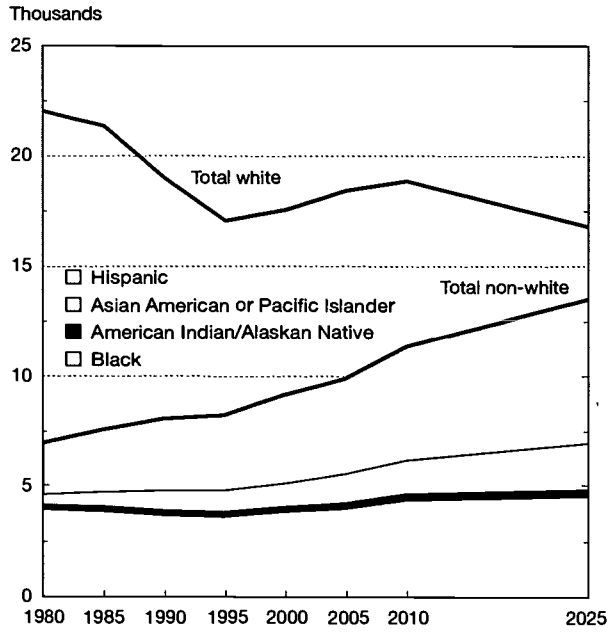
Demographic trends show an increase in the minority group population in the United States. (See figure 2-2.) The white college-age population will expand slowly until 2010 and then decline, whereas the college-age population of racial and ethnic minorities will continue to rise. These trends offer a challenge to the United States and an opportunity to educate students who have been traditionally underrepresented in S&E fields (e.g., women, blacks, Hispanics, and American Indians/Alaskan Natives).

Characteristics of U.S. Higher Education Institutions

The defining characteristics of the U.S. higher education system include broad access to an array of institution types and sizes with public and private funding and flexible attendance patterns. New ways of acquiring advanced training and skills outside these institutions are augmenting access (see "New Modes of Delivery"). As other countries broaden their access to higher education, a wider array of institution types and attendance patterns is also evolving internationally.

U.S. higher education includes nearly 3,400 degree-granting colleges and universities serving 14.5 million students, nearly 80 percent of whom attend public institutions. In 1997, approxi-

Figure 2-2.
U.S. population of 18- to 24-year-olds, by race/ethnicity: 1980–2025



See appendix table 2-2. *Science & Engineering Indicators – 2002*

mately 5.5 million of these students attended two-year institutions. Institutions of higher education at all levels awarded 2.2 million degrees in 1998, almost one-quarter of which were in S&E fields. (See figure 2-3.) Less than 8 percent of all students are enrolled in private liberal arts I and II institutions, and 19 percent attend research universities, as defined by the Carnegie Classification. (See appendix table 2-3 and sidebar, "Carnegie Classification of Academic Institutions.") The demographic and college attendance patterns of the student population are changing. More than 50 percent of all undergraduates are age 22 or older, almost 25 percent are age 30 or older, and 40 percent of all students are attending college part time (Edgerton 1997).

Traditional Institutions of Higher Education

The Carnegie Foundation for the Advancement of Teaching (1994) has clustered institutions with similar programs and purposes to better describe the diverse set of traditional institutions serving various needs. The 2000 Carnegie Classification is under review, and new categories are being defined that combine doctoral and research universities. The changes omit references to the amount of research support different institutions have received (McCormick 2000). For the 1997/98 academic year enrollment and degree data used in this chapter, the former 1994 Carnegie Classification applies.

Enrollment in U.S. Higher Education by Type of Institution

Overall enrollment in U.S. institutions of higher education increased from 7 million in 1967 to 15 million in 1992 and then continued essentially unchanged through 1997. (See figure 2-4.) The expansion period represented an average annual growth rate of 3 percent, but growth rates differed greatly by type of institution. For example, two-year colleges grew at twice this rate and accounted for the largest share of the growth, from 1.5 million students in 1967 to 5.5 million in 1997 (including full- and part-time students).[2] By 1997, enrollment in two-year colleges was 38 percent of total higher education enrollment. In contrast, total student enrollment in research universities I grew more modestly, from 1.5 million students in 1967 to 2.1 million in 1992, with fluctuations around 2.1 million enrollments until 1997. Research universities enroll only 19 percent of the students in higher education, but they play the largest role in S&E degree production. (See figure 2-3 and appendix table 2-5.) Enrollment in higher education is expected to increase in the first decade of the 21st century because of a 13 percent increase in the college-age cohort during this period. (See appendix table 2-1.)

S&E Degree Production at All Levels of Higher Education by Type of Institution

Research-intensive universities produce most of the engineering degrees and a large proportion of natural and social science degrees at both the graduate and undergraduate levels. (See figures 2-5 and 2-6.) In 1998, the nation's 127 research universities awarded more than 42 percent of all S&E bachelor's degrees and 52 percent of all S&E master's degrees. In addition, comprehensive and liberal arts I institutions awarded significant numbers of bachelor's and master's degrees in S&E. Associate degrees awarded by community colleges accounted for only a small percentage of total S&E degrees awarded but serve other important functions.

S&E Faculty by Type of Institution

More than 1.1 million faculty teach in the approximately 3,400 degree-granting institutions of higher education. A large proportion (approximately two-fifths) of all faculty work part time. Some institutions rely on part-time faculty to a greater degree than others; almost two-thirds (65 percent) of faculty at public two-year institutions hold part-time appointments, and approximately one-fifth of faculty at public research institutions work part time. (See text table 2-1.)

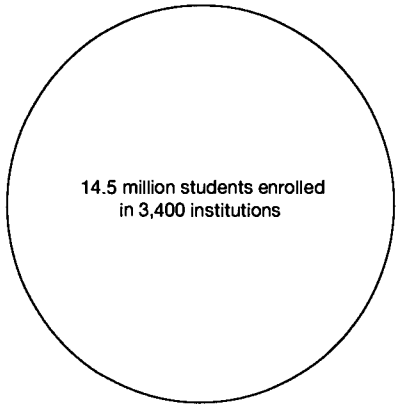
Underrepresented minority faculty in S&E fields are more concentrated at the associate level or in part-time positions at four-year institutions. They constituted only 6 percent of the full-time faculty who teach engineering and computer sciences at four-year institutions but 10 percent of the full-time faculty teaching subjects in these fields at community colleges. (See text table 2-2 and appendix table 2-6.)

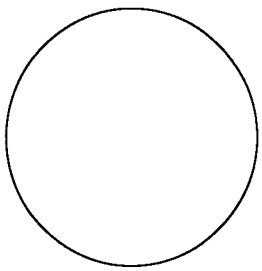
Community Colleges

Community colleges serve a diverse student population and have a broad set of missions: they confer certificates and

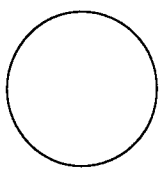
[2]An additional 5 million students are estimated to be enrolled in noncredit courses in community colleges and are not counted in the overall enrollment in higher education.

Figure 2-3.
Profile of U.S. higher education by students, institutions, and degrees at all levels: 1998





2.2 million degrees earned



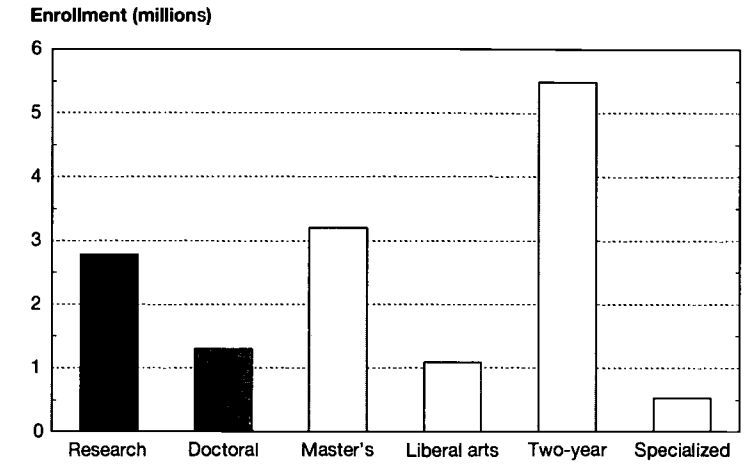
540,491 degrees in
science and engineering

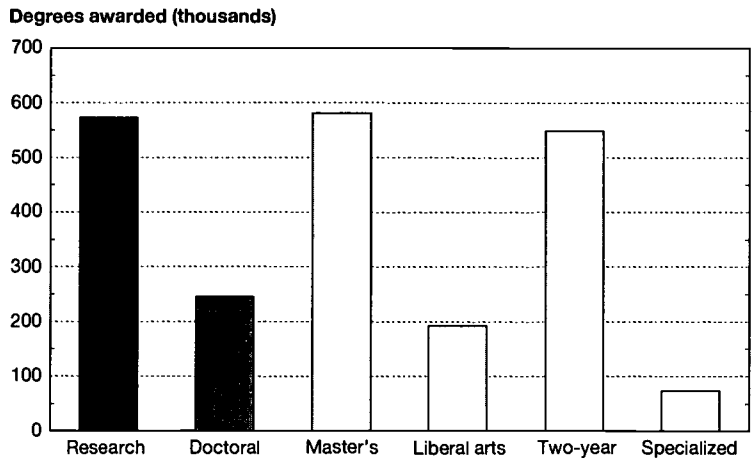
of which:

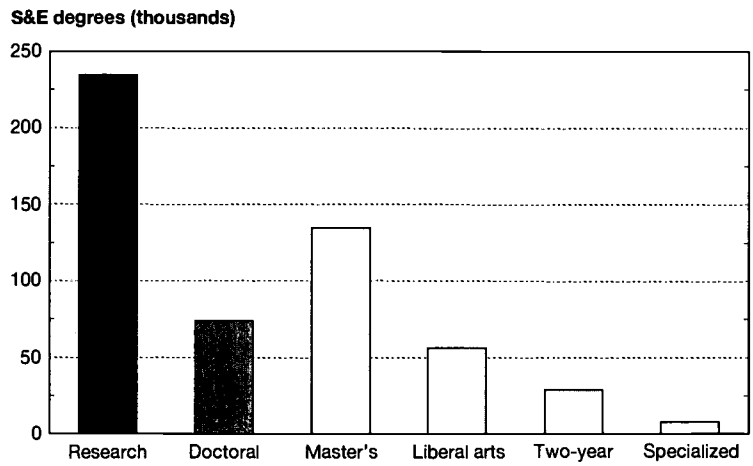
28,646	Associate's degrees
390,618	Bachelor's degrees
93,918	Master's degrees
27,309	Doctorate degrees

The number of institutions are as follows:

- ■ 127 research I & II
- ■ 108 doctoral I & II
- □ 529 master's I & II
- □ 612 liberal arts I & II
- □ 1,600 two-year institutions
- □ 418 specialized







NOTES: The 355 institutions classified as "other" are not included. Enrollment data are for fall 1997; degree data are for 1998.

See appendix tables 2-3, 2-4, and 2-5.

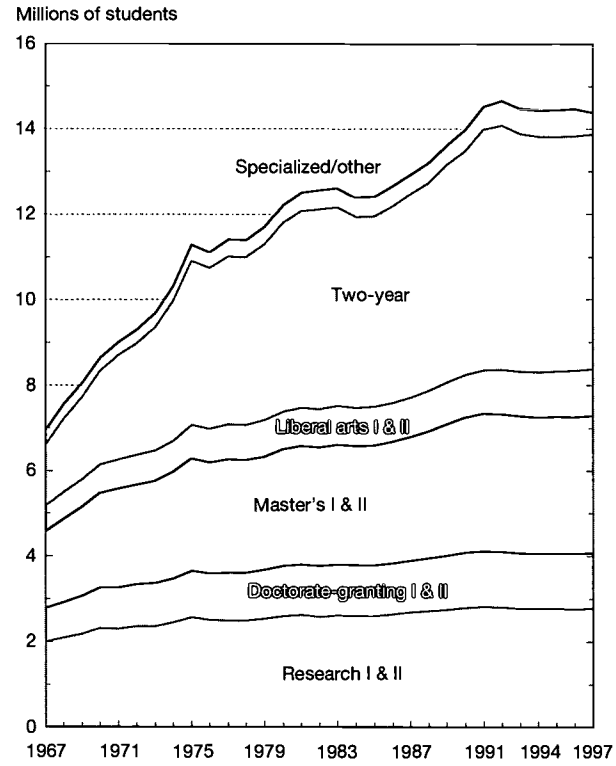
Science & Engineering Indicators – 2002

Carnegie Classification of Academic Institutions

- **Research universities I** (89)* offer a full range of baccalaureate programs, are committed to graduate education through the doctorate level, award 50 or more doctoral degrees, and receive $40 million or more in Federal research support annually.
- **Research universities II** (38) are the same as research universities I, except that they receive between $15.5 million and $40 million in Federal research support annually.
- **Doctorate-granting I** (50) institutions offer a full range of baccalaureate programs, are committed to graduate education through the doctoral degree, and award 40 or more doctoral degrees annually in at least five academic disciplines.
- **Doctorate-granting II** (58) institutions award 20 or more doctoral degrees annually in at least one discipline or 10 or more doctoral degrees in three disciplines.
- **Master's (comprehensive) universities and colleges I** (438) offer baccalaureate programs and, with few exceptions, graduate education through master's degrees. More than 50 percent of their bachelor's degrees are awarded in two or more occupational or professional disciplines, such as engineering and business administration. All of the institutions in this group enroll at least 2,500 students.
- **Master's (comprehensive) universities and colleges II** (91) enroll between 1,500 and 2,500 students.
- **Baccalaureate (liberal arts) colleges I** (162) are highly selective, primarily undergraduate colleges that award more than 40 percent of their bachelor's degrees in the liberal arts and science fields.
- **Baccalaureate (liberal arts) colleges II** (450) award fewer than 40 percent of their degrees in the liberal arts and science fields and are less restrictive in admissions than baccalaureate colleges I.
- **Associate of arts colleges** (1,155) offer certificate or degree programs through the associate degree level and, with few exceptions, offer no bachelor's degrees.
- **Professional schools and other specialized institutions** (418) offer degrees ranging from bachelor's to doctoral. At least 50 percent of the degrees awarded by these institutions are in a single specialized field. Institutions include theological seminaries, Bible colleges, and other institutions offering degrees in religion; medical schools and centers; other health profession schools; law schools; engineering and technology schools; business and management schools; art, music, and design schools; teachers' colleges; and corporate-sponsored institutions.

* The number of institutions is given in parentheses. For the number of institutions that award science and engineering degrees, by degree level and institution type, see appendix table 2-4.

Figure 2-4.
Enrollment in U.S. higher education, by institution type: 1967–97



NOTE: Enrollment data include part-time students.

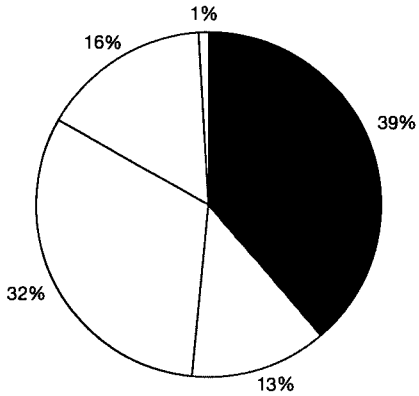
See appendix table 2-3. *Science & Engineering Indicators – 2002*

associate degrees, serve as a bridge for students to attend four-year colleges, offer an array of remedial courses and services, and enroll millions of students in noncredit and workforce training classes (Bailey and Averianova 1999). Community colleges are an accessible and low-cost group of institutions for lifelong learning. In 1998, 63 percent of the students in community colleges were enrolled part time, and more than 60 percent of these part-time students were older than age 25; in general, enrollment in remedial courses includes a significant number of older adults taking refresher courses (Phillippe and Patton 1999; American Association of Community Colleges 2001).

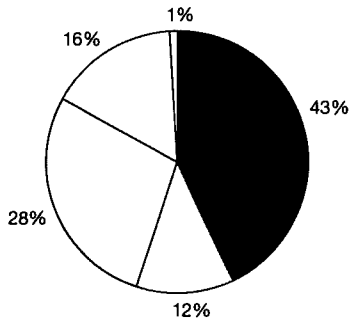
The role of community colleges as a bridge to four-year schools is difficult to determine because many students transfer to four-year schools before earning an associate degree.

Approximately 25 percent of community college students transfer to four-year institutions, but percentages differ by field and by state. Eighteen percent of physical science students attending four-year schools in 1994 had previously attended a community college, and 15 percent of those earning bachelor's degrees in computer sciences in 1994 had also earned associate degrees (U.S. Department of Education 1998). In Indiana, 67 percent of teachers surveyed took community college courses as part of their formal education. Some

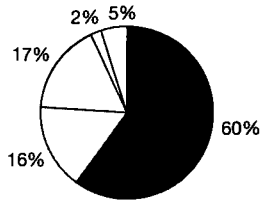
Figure 2-5.
Bachelor's degrees awarded in S&E, by institution type: 1998



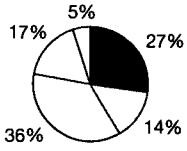
Social and behavioral sciences
N = 185,263



Natural sciences
N = 104,673



Engineering
N = 60,914



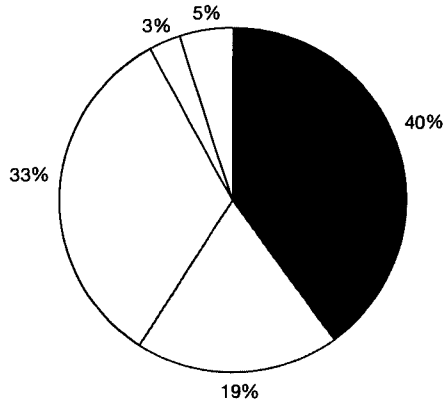
Mathematics/computer sciences
N = 39,768

■ Research I & II
□ Master's I & II
□ Specialized/other
□ Doctorate granting I & II
□ Liberal arts I & II

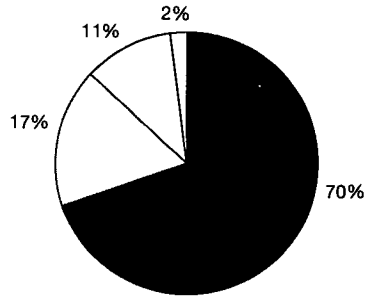
NOTE: Natural sciences include physics, chemistry, astronomy, earth, atmospheric, ocean, biological, and agricultural sciences.

See appendix table 2-4. *Science & Engineering Indicators – 2002*

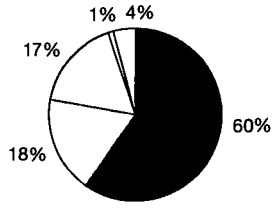
Figure 2-6.
Master's degrees awarded in S&E, by institution type: 1998



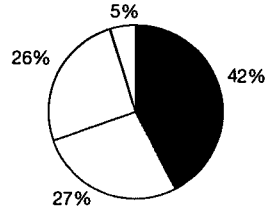
Social and behavioral sciences
N = 36,878



Engineering
N = 26,138



Natural sciences
N = 15,625



Mathematics/computer sciences
N = 15,277

■ Research I & II
□ Master's I & II
□ Specialized/other
□ Doctorate granting I & II
□ Liberal arts I & II

NOTE: Natural sciences include physics, chemistry, astronomy, earth, atmospheric, ocean, biological, and agricultural sciences.

See appendix table 2-4. *Science & Engineering Indicators – 2002*

states encourage students to begin a bachelor's program at a community college: 50 percent of students in the California State University system attended a community college before entering a bachelor's degree program at a four-year institution. In addition, 75 percent of upper division education majors in the California State University system began their studies at community colleges (American Association of Community Colleges 2001; Pierce 2000; and Chancellor's Office 1999).

Text table 2-1.
Distribution of faculty employment status by type of institution: 1999
(Percentages)

Institution type	Full time	Part time
All institutions	57	43
Research		
Public	79	21
Private	69	31
Doctoral		
Public	72	28
Private	49	51
Master's		
Public	64	36
Private	50	50
Liberal arts, private	63	37
Two-year, public	35	65
Other	53	47

NOTE: Faculty includes all instructional staff.

SOURCE: U.S. Department of Education, National Center for Education Statistics, "1999 National Study of Postsecondary Faculty" (Washington, DC, 2001).

Science & Engineering Indicators – 2002

Of all students in higher education in 1997, minority populations were concentrated in community colleges as follows: 46 percent of Asians/Pacific Islanders, 46 percent of blacks, 55 percent of Hispanics, and 55 percent of American Indians/Alaskan Natives (Phillippe and Patton 1999). A recent study indicates that minority students attending community colleges are more likely to transfer to selective four-year institutions than their colleagues who begin their academic career at a four-year school. Also, the completion rate for these transfer students is comparable with that of transfer students from other colleges (Eide, Goldhaber, and Hilmer, forthcoming).

The importance of community colleges in advancing the nation's technical workforce is indicated by the number of associate degrees and certificates in S&E fields and the number of information technology (IT) workers reporting "some" college experience. See sidebar, "Role of Community Colleges in Expanding Supply of Information Technology Workers."

New Modes of Delivery

The number of earned degrees from traditional institutions does not adequately represent the knowledge being acquired by students in science, engineering, mathematics, and computer sciences in a given year. Lifelong learning and various new ways of acquiring knowledge are not all quantified or captured in current education indicators. No indicators ad-

Text table 2-2.
Postsecondary faculty in S&E, by race/ethnicity, field, and employment status: 1999
(Percentages)

Race/ethnicity and field	Full time: 2-year institutions	Full time: 4-year institutions	Part time, 4-year institutions
White			
Natural sciences and mathematics	82.4	83.3	80.8
Life sciences	88.5	85.0	91.4
Social and behavioral sciences	80.6	86.1	86.6
Engineering and computer sciences	85.4	80.5	82.7
Asian/Pacific Islander			
Natural sciences and mathematics	3.8	10.9	5.6
Life sciences	4.9	9.7	6.0
Social sciences	1.8	4.8	2.2
Engineering and computer sciences	4.9	13.5	7.2
Underrepresented minorities			
Natural sciences and mathematics	13.9	5.8	13.7
Life sciences	6.6	5.3	2.7
Social sciences	17.6	9.1	11.2
Engineering and computer sciences	9.7	6.0	10.0

NOTE: Natural sciences include physics, chemistry, astronomy, and earth, atmospheric, and ocean sciences.

SOURCE: U.S. Department of Education, National Center for Education Statistics, "1999 National Study of Postsecondary Faculty" (Washington, DC, 2001).

Science & Engineering Indicators – 2002

Role of Community Colleges in Expanding Supply of Information Technology Workers

A recent study on the educational background of the expanding information technology (IT) workforce indicates that the contribution of associate degree holders to that pool has declined. The number of IT workers with associate degrees newly entering the workforce (IT workers 25–34 years of age) declined by more than 20 percent from 1994 to 1999. (See text table 2-3.) However, case studies of selected community colleges (American River in Sacramento, California, and Bellevue in Bellevue, Washington) show other contributions of these institutions to the nation's IT workforce (Lerman, Riegg, and Salzman 2000).

Enrollment in IT classes at these institutions continues to grow, as does the proportion of workers reporting that they have some college background but lack a formal degree. Between 1994 and 1999, the number of IT workers who had "some college" experience but no degree increased by about 43 percent. (See text table 2-3.) Although there is no way to know where the "some" college group is getting its schooling, IT workers who report some college education have probably received their related education from community colleges.

Much of the information on IT education contributed by community colleges does not appear in the statistics on IT-related associate degrees and certificates. Many students leave before obtaining a degree or certificate, either because they find employment or because they already have a four-year degree and are not concerned with an associate degree or a certificate. At Bellevue Community College in 1998, 827 students were enrolled in IT programs, but only 67 graduated with associate degrees and 21 graduated with certificates. The lack of interest in obtaining a degree may partly reflect the fact that many (198) Bellevue IT students (24 percent of the total IT enrollees) had already earned a four-year degree. Interviews with faculty indicate that 85 percent of students who left their institutions without a degree or certificate were employed. The colleges reported that almost one-third of all IT program participants between 1994 and 1997 left before completing even 10 class credits (Lerman, Riegg, and Salzman 2000).

Text table 2-3.
IT workforce, by education and age: 1994 and 1999

Education and age	1994 Number	1994 Percent	1999 Number	1999 Percent
Total, all IT workers	1,668,000	100.0	2,347,000	100.0
Less than high school graduate	11,000	0.7	12,000	0.5
High school graduate	141,000	8.5	195,000	8.3
Some college	267,000	16.0	381,000	16.2
Associate of arts	182,000	10.9	205,000	8.9
Bachelor's degree	793,000	47.5	1,143,000	48.7
Graduate degree	274,000	16.4	411,000	17.5
25- to 34-year-old IT workers	702,000	100.0	880,000	100.0
Less than high school graduate	3,000	0.4	4,000	0.5
High school graduate	49,000	7.0	48,000	5.5
Some college	76,000	10.8	125,000	14.2
Associate of arts	85,000	12.1	67,000	7.6
Bachelor's degree	386,000	55.0	466,000	53.0
Graduate degree	103,000	14.7	170,000	19.3

SOURCE: R.I. Lerman, S.K. Riegg, and H. Salzman, "The Role of Community Colleges in Expanding the Supply of Information Technology Workers" (Washington, DC, The Urban Institute, 2000).

Science & Engineering Indicators – 2002

equately capture the nontraditional education acquired through industrial training, certificate programs, and distance learning. See sidebars, "New Horizons in Science and Engineering Education" and "Certificate Programs."

Limited data exist on student participation and completion rates for many of the cited mechanisms. For example, national education surveys do not capture the number and types of students enrolled in most certificate programs or those taking an array of related courses that could lead to upgraded job skills but not a formal degree. Such data are needed to gain a more complete picture of the nation's S&E education and training system.

New Horizons in Science and Engineering Education

The advent of technologies that support distance education and the demands of science and engineering (S&E)-related business and industry (e.g., information technology (IT) and bioinformatics) have been accompanied by the development of alternative mechanisms of delivering higher education, such as industrial learning centers and distance education. An increasing number of people are taking advantage of these alternatives either to enter new fields or to upgrade their skills in existing but rapidly changing fields. Many of the mechanisms, whether offered through traditional institutions (whose data are captured in national education surveys) or outside those institutions, could be defined as within the realms of continuing education or workplace training.

Industrial Learning Centers

Currently, approximately 2,000 industrial learning centers exist in the United States (compared with 400 in 1986), and this number will likely continue to increase rapidly. In general, these centers serve employees within a specific company or industry and are business management oriented. Some large industries, however, have internal training at the level of higher education in engineering and design. For example, the so-called "Motorola University" has an annual $2 billion budget (similar to that of the University of Indiana and Purdue University) and contracts with 1,200 faculty worldwide. These faculty teach business and engineering wherever Motorola is designing innovative products

Many industrial centers are partnered with traditional institutions of higher education and use traditional courses and university faculty to supplement industry-developed training courses (Meister 2001). For example, Motorola University has partnerships with traditional institutions for sharing technology, faculty, and facilities. Motorola is part of a Ph.D. program at the Indian Institute of Information Technology (IIIT) in Hyderabad, India, and degree programs at Morehouse University in Atlanta and Roosevelt University in Chicago. At the associate level, Motorola University works with faculty from Pretoria University's engineering school in South Africa (Wiggenhorn 2000).

Distance Education

Distance education is a rapidly growing and relatively unregulated aspect of higher education. In 2001, the Regional Accrediting Commissions issued their first set of guidelines for the evaluation of electronically offered degree and certificate programs (Regional Accrediting Commissions 2001). Comprehensive data are not available on the number of undergraduate and graduate S&E degrees or the number of programs fully or partially offered through distance education. However, interest in delivering and taking S&E courses and entire programs via distance education is growing (Office of Government and Public Affairs 2000). In 1997, more than 50,000 different on-line courses were offered by postsecondary institutions; 91 percent were college-level credit courses. Approximately 1.6 million people registered for on-line courses in 1998, 82 percent in college-level credit courses at the undergraduate level (University Continuing Education Association 2000). In many ways, these programs are comparable to correspondence programs offered either by for-profit institutions, such as the International Correspondence Schools, or by traditional universities through their correspondence or continuing education units. In IT-related certification programs, this method of delivering postsecondary education may be one of the dominant modes, at least on an international basis.

Undergraduate S&E Students and Degrees in the United States

Key challenges for undergraduate education in S&E include preparing teachers for K–12 and college levels (Committee on Science and Mathematics Teacher Preparation (CSMTP) 2001), preparing scientists and engineers to fill needed workforce requirements and provide the capacity for long-term innovation (Romer 2000; NSTC 2000), providing understanding of basic science and mathematics concepts for all students, and measuring what students learn (National Center for Public Policy and Higher Education 2000). These challenges relate to the nation's ability to retain its innovation capacity and international position in S&T.

The need for undergraduate teaching that could attract and retain students in S&E fields has been widely noted and discussed (National Commission on Mathematics and Science Teaching for the 21st Century 2000). Professional associations (Gaff et al. 2000; Sigma Xi 1999), private foundations (Kellogg Commission on the Future of State and Land-Grant Universities 1997), public officials (National Governors Association 2001), and universities themselves (NSF/EHR Advisory Committee 1998) have each expressed concern regarding the delivery of undergraduate education.

The nation must also meet its growing need for K–12 teachers, particularly in mathematics and science. Recent studies indicate that in the upcoming decade, the nation's school districts will need to hire 2.2 million new teachers (U.S. Department of Education 1999), including 240,000 middle and high school mathematics and science teachers (National Commission on Mathematics and Science Teach-

Certificate Programs

Three types of certificate programs are described below, based on mode of delivery (i.e., university based, community college based, or exam based).

University Based

A recent survey by the Council of Graduate Schools revealed that of the 179 university-based certificate programs reported, 34 percent were in engineering-, health-, or science-related fields, and 15 percent were in computing (Patterson 1999, 1998). The council is considering mechanisms for accrediting these university-based certificate programs and has divided them into three categories:

- **Specialty**—do not require a prior degree, are typically narrow in scope, and are oriented toward nontraditional students hoping to develop or upgrade career-related skills.
- **Professional**—require a prior degree and are typically designed to upgrade the licensure of professionals such as nurses or social workers.
- **Graduate**—augment and broaden skills and knowledge acquired through graduate degrees in the traditional disciplines and are typically interdisciplinary in scope (e.g., a graduate certificate program in environmental ethics).

Community College Based

Community colleges are an important source of science and engineering-related certification programs. (See text table 2-4.) The importance of community colleges as sources of information technology (IT)-related certificates can be estimated from the distribution of academic providers authorized by Microsoft in August 2000. Of 650 total providers, 46 percent (298) are listed as being at community colleges or two-year schools (either public/not for profit or for profit) (U.S. Department of Education 2000). (See text table 2-5.)

Exam Based

These certificates are earned by passing skill-based examinations offered globally and do not always require formal coursework, although applicants may elect to take related courses. To prove continuous updating of skills, some levels of certification require applicants to pass exams based on advances in the field. In the field of IT, for example, in 1999, 5,000 sites in 140 countries were administering an estimated 3 million assessments in 25 languages. The growth of this type of certificate for the IT industry has been rapid. More than 300 discrete certifications have been established since 1989, when the first IT certificate (Certified Novell Engineer) was issued. Approximately 1.6 million individuals worldwide earned approximately 2.4 million IT certificates by early 2000, mostly after 1997; more than 50 percent of these certificates were earned outside the United States. The exams are administered by one of three corporations (Prometric, CatGlobal, and Virtual University Enterprises), but the courses often are offered by vendors related to or licensed by the corporations whose systems are designated on the certificates (e.g., Microsoft, Cisco, Oracle, or Novell) (U.S. Department of Education 2000).

Text table 2-4.
Certificates conferred by community colleges, by field and duration: 1996–97

Field	Total	<1 year	1–2 years	>2 years
Total	166,776	69,400	85,745	11,631
S&E	60,296	24,953	32,470	2,873
Health and related sciences	56,659	23,401	30,585	2,673
Computer and information sciences	3,423	1,506	1,723	194
Other S&E-related fields	214	46	162	6
Non-S&E	106,480	44,447	53,275	8,758
Science technologies	137	78	53	6
Engineering technologies	6,203	1,705	3,705	793

SOURCE: K.A. Phillippe and M. Patton, *National Profile of Community Colleges: Trends & Statistics*, 3d ed. (Washington, DC, Community College Press, American Association of Community Colleges, 1999).

Science & Engineering Indicators – 2002

Text table 2-5.
Microsoft-authorized academic training providers, by level and control: 2000

Level and control	Number	Comment
Four-year public and not for profit	142	Approximately one-third are continuing education units.
Four-year for profit	42	Two-thirds are campuses of the University of Phoenix.
Two-year public and not for profit	298	Includes multiple campuses of large community college districts such as Houston and Allegheny (Pittsburgh).
Indeterminable post secondary status	39	Not listed in Barbett and Lin (1998) or otherwise located.
High schools	129	More than half are technical/vocational high schools.

SOURCE: U.S. Department of Education, Office of Educational Research and Improvement, *A Parallel Postsecondary Universe: The Certification System in Information Technology*, by C. Adelman (Washington, DC, 2000).

Science & Engineering Indicators – 2002

ing 2000). Of the total, 70 percent will be new to the profession, as teachers retire and the student population increases. The need for new teachers also reflects changes in course-taking patterns; student demand for high-level mathematics and science courses in high school is increasing. In addition, the need to improve teacher preparation is reflected in the number of teachers teaching in fields other than those for which they were prepared. For example, 20 percent of the middle and high school mathematics teachers hired during the 1993/94 academic year were not certified to teach mathematics (Blank and Langesen 1999). See chapter 1, "Elementary and Secondary Education," for the magnitude of the problem of teachers teaching out of field.

Workplace needs are changing in our information- and service-oriented economy. The workforce requires people competent in mathematics, S&E, critical thinking, and the ability to work in teams (NSTC 2000). Availability of high-level, diverse personnel for basic research, discovery, and innovation depends on a sufficient pool of well-prepared students with bachelor's degrees who are willing and able to persist through doctoral education.

The growing pressure for accountability calls for measuring the value of higher education by what students learn rather than by campus offerings. A recent study of higher education efforts found all states in the nation deficient in this area (National Center for Public Policy and Higher Education 2000).

This section gives indicators related to some of these challenges, particularly the challenge of preparing a diverse S&E workforce. These indicators include the growing diversity in undergraduate enrollment and intentions to major in S&E fields, the relatively low completion rates of S&E degrees among underrepresented minority students, the need for remediation at the college level, and recent declining trends in the number of earned degrees in most S&E fields. The section also includes recommended reforms to meet the challenges of preparing teachers and measuring student learning and describes programs showing initial signs of success.

Enrollment and Retention in S&E

Undergraduate Enrollment by Sex and Race/Ethnicity

The U.S. college-age population has grown since 1997, and the percentage of high school graduates enrolling in college is increasing for some groups. By 1999, approximately 45 percent of white and 39 percent of black high school graduates were enrolled in college, up from approximately 31 and 29 percent, respectively, in 1979. (See text table 2-6.) However, during this period, enrollment rates in higher education for Hispanic high school graduates increased only slightly, from 30 to 32 percent. An even greater racial/ethnic disparity exists with respect to Hispanic college enrollment rates based on the total college-age population (including students who did not complete high school or those who recently immigrated to the United States with little education) (Tienda and Simonelli 2001).

In the past two decades, the proportion of white students in U.S. undergraduate enrollment decreased, falling from 80 percent in 1978 to 70 percent in 1997. The proportion of underrepresented minorities increased the most, from 15.7 to 21.7 percent. Asians/Pacific Islanders increased from 2.0 to 5.8 percent, and foreign students remained approximately 2 percent of undergraduate enrollment. Women outnumber men in undergraduate enrollment for every race and ethnic group. White women constitute 55 percent of white undergraduate students, and black women constitute 62 percent of black undergraduate enrollment, which is the greatest difference found among racial groups. (See appendix table 2-8.)

Engineering Enrollment

Generally, engineering programs require students to declare their major in the first year of college, which makes enrollment an early indicator of undergraduate engineering degrees and interest in engineering careers. The annual fall

Text table 2-6.
Enrollment rates of high school graduates in higher education, by race/ethnicity: 1979–99

Race/ethnicity	1979	1989	1999
Total	31.2	38.1	43.7
White	31.3	39.8	45.3
Black	29.4	30.7	39.2
Hispanic	30.2	28.7	31.6

NOTE: Data are enrollment as a percentage of all 18- to 24-year-old high school graduates.

See appendix table 2-7. *Science & Engineering Indicators – 2002*

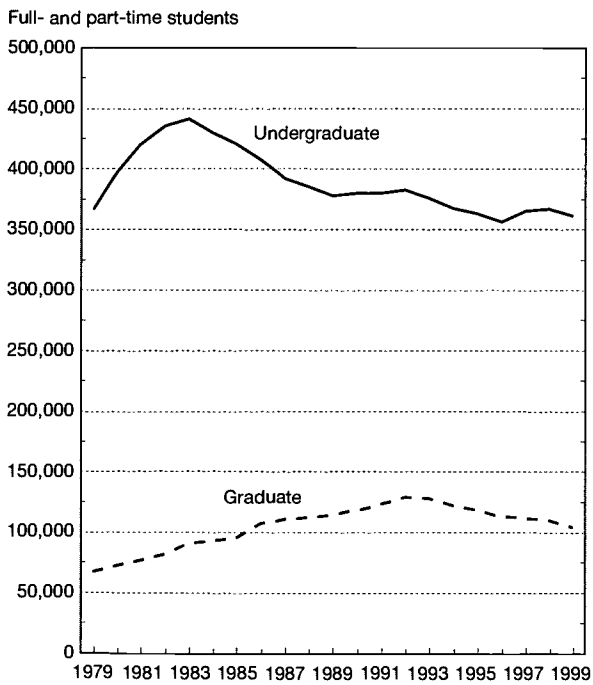
survey of the Engineering Workforce Commission (2000) obtains data on actual enrollment in graduate and undergraduate programs.

The long-term trend has been for fewer students to enter engineering programs. From 1983 to 1990, engineering enrollment decreased sharply, followed by fluctuating and slower declines in the 1990s. Trends differ by degree level. At the bachelor's degree level, undergraduate enrollment declined by more than 20 percent from 441,000 students in 1983 (the peak year) to 361,000 students in 1999. (See figure 2-7 and appendix table 2-9.) At the associate degree level, enrollment in engineering technology dropped precipitously from 1998 to 1999. The number of first- and second-year students enrolling in such programs declined by 25 and 36 percent, respectively. This associate degree level of engineering technology may be shifting somewhat to workplace training. Graduate engineering enrollment peaked in 1993 and has continued downward since. (See appendix table 2-10.)

Freshmen Intentions to Major in S&E

Whether students in the United States are interested in studying S&E fields is of growing concern. Whether women and minorities are attracted to S&E majors is also of national interest because together they make up the majority of the labor force, and they have traditionally not earned S&E degrees at the same rate as the male majority. Their successful completion of S&E degrees will determine whether there will be an adequate number of entrants into the S&E workforce in the United States. Since 1972, each fall, the Higher Education Research Institute's Freshman Norms Survey asks a national sample of first-year students in four-year colleges and universities about their intentions to major in an S&E field and their readiness for college-level S&E coursework (Higher Education Research Institute (HERI) 2001). See sidebar, "Freshman Norms Survey."

Figure 2-7.
U.S. engineering enrollment, by level: 1979–99



See appendix table 2-10. *Science & Engineering Indicators – 2002*

Retention in S&E

Although approximately 25–30 percent of students entering college in the United States intend to major in S&E fields, a considerable gap exists between freshman intentions and successful completion of S&E degrees. A National Center for Educational Statistics (NCES) longitudinal study of first-year S&E students in 1990 found that fewer than 50 percent had completed an S&E degree within five years (U.S. Department of Education (NCES) 2000).[3] Students intending an S&E major in their freshman year explore and switch to other academic departments in undergraduate education, and approximately 20 percent drop out of college. The study also shows that underrepresented minorities complete S&E programs at a lower rate than other groups. A more recent longitudinal study, from 1992 to 1998, traces freshmen retention in S&E by sex, race/ethnicity, and selectivity of the institution. See sidebar, "Retention and Graduation Rates."

Associate Degrees

Trends in S&E Associate Degrees

For more than a decade, the number of associate degrees earned in S&E has fluctuated between 20,000 and 25,000. At the associate level, computer sciences represented the most sought-after S&E field; in 1998, the 13,000 computer science degrees represented 45 percent of all S&E degrees. After a five-year decline from the peak year of 1986, the number of earned degrees in computer sciences increased at an average annual rate of 5.6 percent in the 1990s. Degrees earned in engineering technology (not included in S&E total degrees) are far more numerous than degrees in S&E fields; however, they have experienced a long, steady decline during the past two decades. At the associate level, the number of degrees earned in engineering technology dropped from more than 52,000 in 1981 to 33,000 in 1997, a 36 percent decline. (See appendix table 2-14.)

Associate Degrees by Race/Ethnicity

Trends in the number of associate degrees earned by minority students differ from overall trends. Among Asians/Pacific Islanders, growth in the number of earned computer science degrees occurred during the past several years, from 1995 to 1998; the declining trend in engineering technology was neither as continuous nor as long. Among blacks, the number of degrees earned in engineering technology remained approximately 3,000 per year for the past decade, and degrees earned in computer sciences increased slightly from 1989 to 1997, with strong growth in 1998. Trends among Hispanics showed increases in the number of degrees earned in engineer-

[3]A longitudinal study follows the same students for several years.

Freshman Norms Survey

The Freshman Norms trend data show that freshmen of every race and ethnicity have high aspirations to study science or engineering (HERI 2001). For the past few decades, approximately 30 percent of white freshmen reported their intention to major in science, engineering, mathematics, or computer sciences; a higher percentage of Asian American students intended to pursue such a major (40–50 percent). In the 1990s, more than one-third of freshmen in underrepresented minority groups intended to major in science and engineering (S&E) fields. The proportion was higher for men in every racial/ethnic group and lower for women. In the 1990s, men in every group reported increased interest in computer sciences. (See appendix table 2-11.)

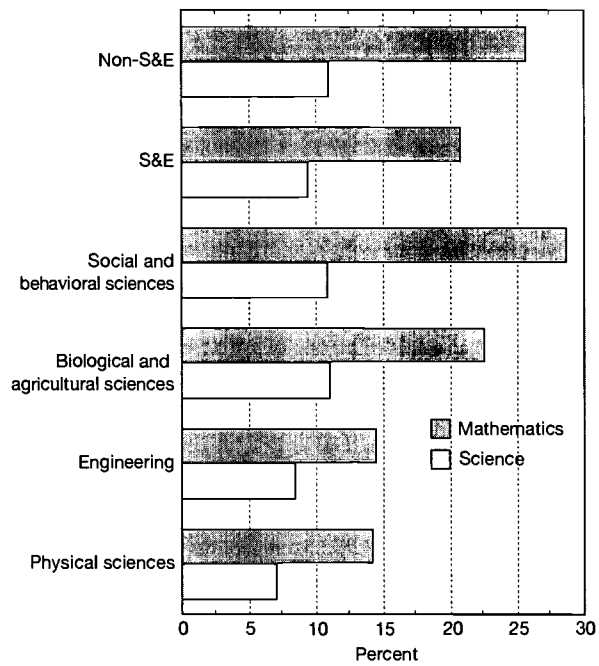
By 2000, women constituted 44 percent of the first-year college students reporting intentions to major in S&E; 56 percent were men. The data also show increasing racial diversity among freshmen intending to choose an S&E major. By 2000, underrepresented minority groups represented more than 20 percent of those intending to choose an S&E major,* up from 8 percent in 1971. The general trend is an increasing proportion of black and Hispanic freshmen among students intending to pursue a natural science or engineering major. (See appendix table 2-12.) For example, from 1986 to 2000, the proportion of underrepresented minorities intending to major in biological sciences or engineering rose from approximately 10 to 18 percent of first-year college students.† During the same period, 22–23 percent of underrepresented minority students intended to major in computer sciences, but the proportion intending to study mathematics and statistics declined from 12 to 8 percent. (See appendix table 2-12.)

*In 2000, white students constituted 66 percent of the 18- to 24-year-old population in the United States; underrepresented minority groups constituted 30 percent. (See appendix table 2-2.)

†Underrepresented minority students are not uniformly distributed across all institutions, however. They are more concentrated in minority-serving institutions: comprehensive universities and liberal arts colleges, tribal colleges, and historically black colleges and universities.

Are freshmen in the United States ready for college-level coursework? In 2000, more than 20 percent of first-year college students intending to undertake an S&E major reported that they needed remedial work in mathematics; almost 10 percent reported they needed remedial work in the sciences. This percentage has been relatively stable during the past 25 years. (See appendix table 2-13 and *S&E Indicators–2000*, appendix table 2-12.) There are some differences, however, by field of intended major. Students intending to major in the physical sciences and engineering report a lesser need for remedial work than students in other fields. In contrast, students intending to major in social and biological sciences, as well as in non-S&E fields, report more need for remedial work. (See figure 2-8.)

Figure 2-8.
Freshmen reporting need for remedial work in science or mathematics, by intended major: 2000



See appendix table 2-13. *Science & Engineering Indicators – 2002*

ing technology until 1995, followed by three consecutive years of decline and strong growth in computer sciences in the 1990s but from a low base. The number of degrees earned by American Indians/Alaskan Natives increased in all S&E fields from a very low base in 1985. (See appendix table 2-15.)

Although the proportion of degrees earned by students from underrepresented minority groups continues to increase slightly at all levels of higher education, the proportion of degrees earned at the associate level by these groups is considerably higher than that at the bachelor's or more advanced levels. The proportion of social science degrees earned by these groups at the associate level has traditionally been high (25–28 percent), and the proportion of computer science degrees earned by these students has almost doubled since 1985. (See appendix table 2-15.) In 1998, these students earned approximately 23 percent of the mathematics and computer science degrees at the associate level, a far higher percentage than at the bachelor's or more advanced levels of higher education. At the advanced levels, the percentage of S&E degrees earned by underrepresented minorities drops off,

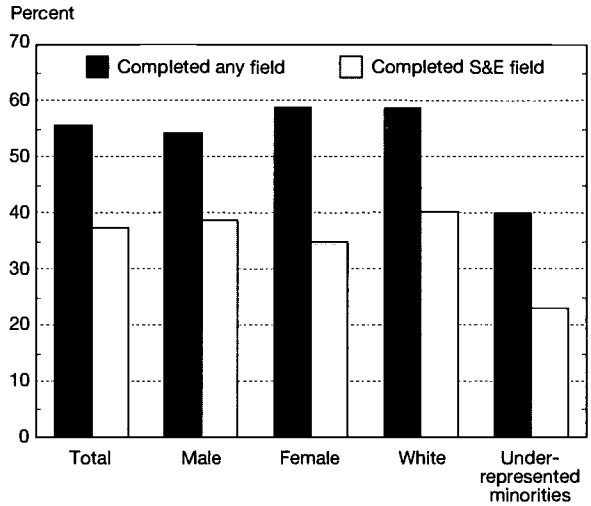
Retention and Graduation Rates

The Center for Institutional Data Analysis and Exchange (C-IDEA 2000) at the University of Oklahoma recently released a report of its longitudinal study, conducted from 1992 to 1998, of a cohort of college students. The study aimed to gather benchmark statistics on retention rates in science, mathematics, engineering, and technology disciplines. The study surveyed 119 colleges and universities ranging from small to large, liberal admission to highly selective admission, and bachelor's degree–only to doctorate-granting institutions.

In 119 colleges and universities, about 25 percent of all entering first-time freshmen in 1992 declared their intention to major in a science and engineering (S&E) field. By their second year, 33 percent of these students had dropped out of an S&E program. After six years, 38 percent had completed an S&E degree. Women and underrepresented minorities dropped out of S&E programs at a higher rate than men and nonminority students. Consequently, degree completion rates in S&E fields were lower for women (35 percent) and underrepresented minorities (24 percent). (See figure 2-9.)

The study found that retention rates of S&E majors also differ by institution. Specifically, retention rates are higher at more selective institutions, institutions with fewer part-time undergraduate students, and research institutions that also award postgraduate (master's and doctoral) degrees.

Figure 2-9.
Graduation rates and S&E completion rates of 1992 freshmen intending S&E major, by sex and race/ethnicity



NOTES: Study covers first-time college freshmen with intentions to major in S&E fields entering in 1992 and completing bachelor's degree by 1998. Underrepresented minorities include black, Hispanic, and American Indian/Alaskan Native.

SOURCE: Center for Institutional Data Exchange and Analysis, *1999–2000 SMET Retention Report*, University of Oklahoma (2000).

Science & Engineering Indicators – 2002

particularly in natural sciences and engineering (NS&E). In contrast, the decline in the percentage of degrees earned by underrepresented minorities at the advanced levels is smaller in social sciences and non-S&E fields. (See figure 2-10.)

Bachelor's Degrees

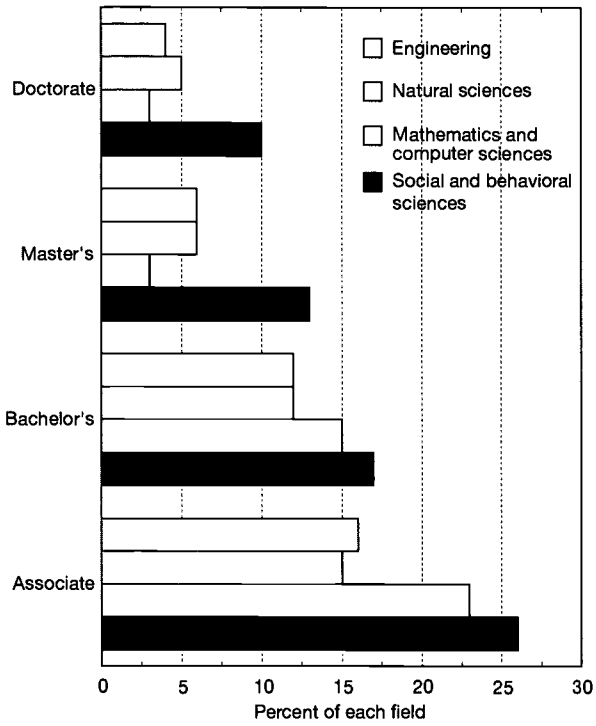
Percentage of Bachelor's Degrees in S&E Fields

Are college students earning the same percentage of bachelor's degrees in S&E fields as in the past, or have more students switched to non-S&E fields? From 1975 to 1998, the ratio of overall S&E degrees to total degrees remained approximately 33 percent. The percentages in fields within S&E, however, shifted during this period. In 1986, the year in which most S&E degrees were earned, engineering represented 8 percent of all bachelor's degrees earned, followed by a long, slow decline to 5 percent in 1998 (NSF/SRS 2001c). Since 1986, the percentage of bachelor's degrees earned by undergraduates has also declined slightly in physical sciences, mathematics, and computer sciences. In contrast, since 1986, the percentage of bachelor's degrees awarded in social and behavioral sciences and in biological sciences has increased. (See text table 2-7.)

Degree Trends

The number of overall S&E bachelor's degrees increased in the past two decades and leveled off in the late 1990s. However, the composite rise represents divergent trends in various fields. Biological and agricultural sciences are the only fields that show continuous increases in the number of degrees earned throughout the 1990s. Trends in biological sciences show a long, slow decline in the number of degrees earned in the 1980s but indicate a reversal of this trend in the early 1990s, which continued throughout the decade. The number of degrees earned in psychology increased in the 1990s but leveled off in 1997. In all other S&E fields, the number of degrees earned was either stable or declined. For two decades, students earned a relatively stable number of degrees in the physical sciences and mathematics, with slight declines in mathematics in the past few years. The number of degrees earned in computer sciences peaked in 1986, declined until the early 1990s, and then fluctuated in that decade, with a slight increase in 1997–98. The number of degrees earned in social sciences strongly increased in the 1980s, peaked in 1993, and then declined and leveled off. The number of engineering degrees earned peaked in 1986, declined sharply until 1990, fluctuated within that decade, and declined again in 1998. (See NSF/SRS 2001c and figure 2-11.)

Figure 2-10.
S&E degrees earned by underrepresented minorities within each field, by level: 1998–99



NOTES: Doctoral-level degrees are 1999 data; all other levels use 1998 data. Natural sciences include physics, chemistry, astronomy, and earth, atmospheric, ocean, biological, and agricultural sciences. Underrepresented minorities include black, Hispanic, and American Indian/Alaskan Native.

See appendix tables 2-15, 2-17, 2-23, and 2-25.

Science & Engineering Indicators – 2002

Text table 2-7.
Bachelor's degrees earned in S&E fields: various years
(Percentages)

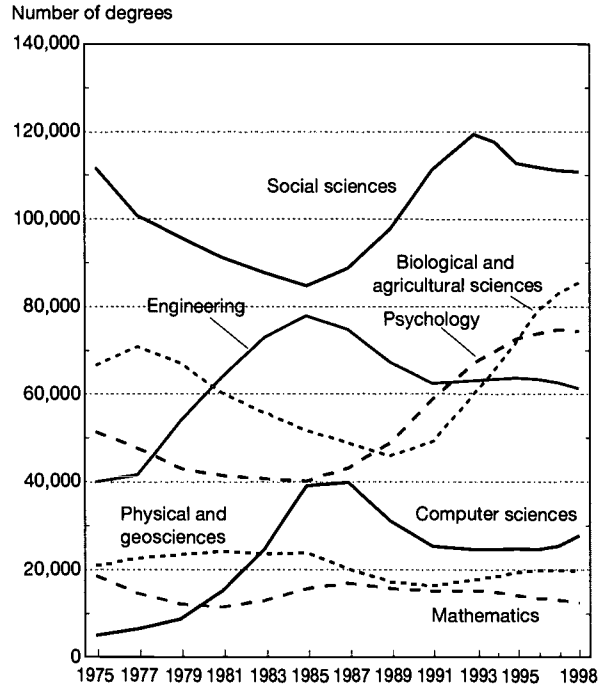
Field	1975	1985	1998
All S&E[a]	33.7	33.5	32.6
NS&E	16.1	20.9	17.1
Physical sciences	1.7	1.6	1.3
Earth, atmospheric, and ocean sciences	0.5	0.8	0.4
Biological and agricultural sciences	7.1	5.2	7.1
Mathematics	2.0	1.6	1.0
Computer sciences	0.5	3.9	2.3
Engineering	4.3	7.8	5.1
Social and behavioral sciences	17.5	12.6	15.4

NS&E = natural science and engineering

[a]Percentage of all bachelor's degrees.

See appendix table 2-16. *Science & Engineering Indicators – 2002*

Figure 2-11.
Bachelor's degrees earned in selected S&E fields: 1975–98



NOTE: Geosciences include earth, atmospheric, and ocean sciences.

See appendix table 2-16. *Science & Engineering Indicators – 2002*

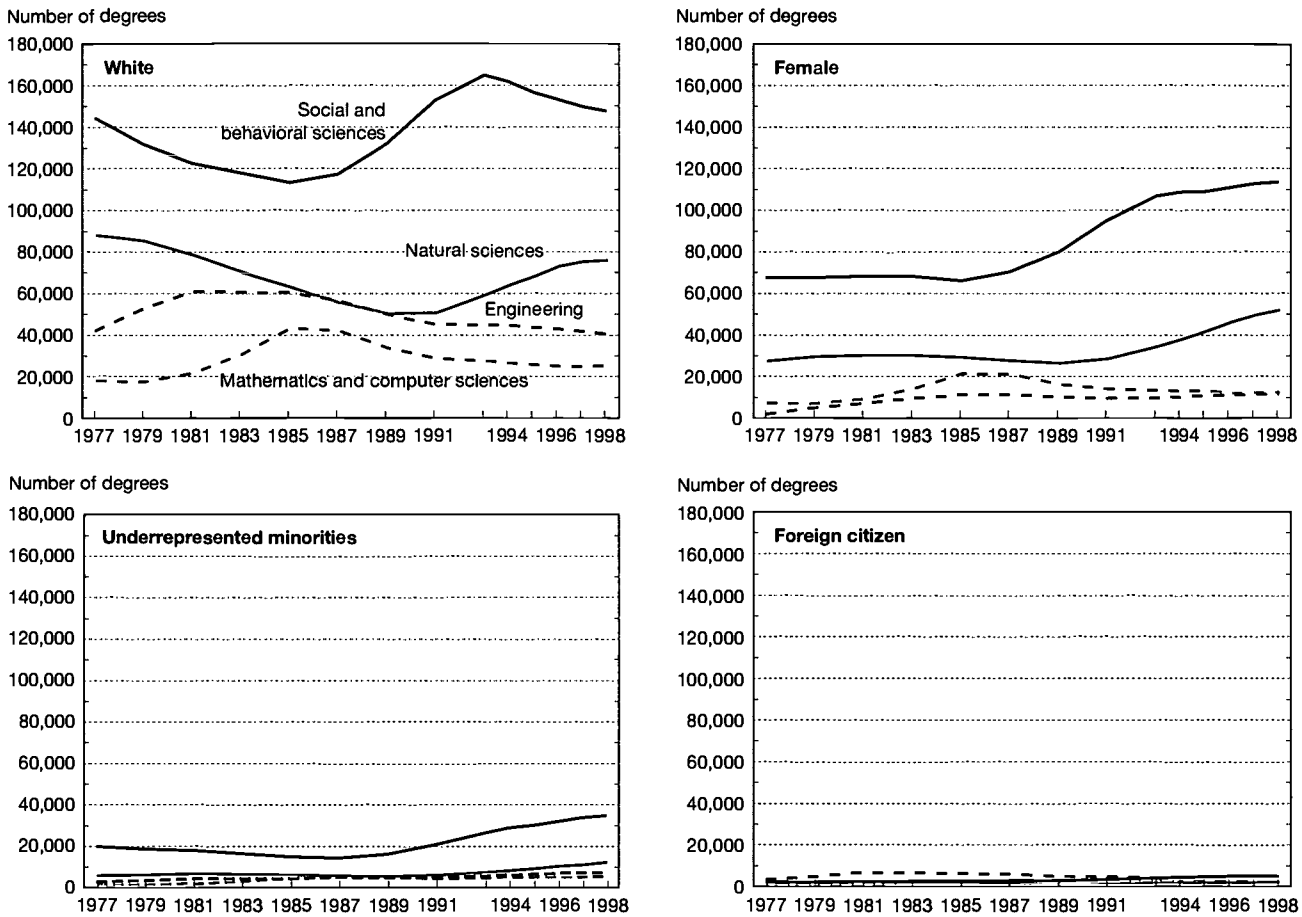
Bachelor's Degrees by Sex

The rise in the number of degrees earned in biological sciences and psychology in the 1990s reflects a high proportion of women entering these fields (48 percent in biological sciences and 72 percent in psychology in 1998), thus offsetting the decline expected from the shrinking college-age cohort. The declining number of degrees earned in most other S&E fields is influenced by both the shrinking college-age cohort and an underrepresentation of women and minorities in these fields. Women and minorities continue to be underrepresented in engineering and computer sciences. (See appendix table 2-16.) The sharp decline in the number of degrees earned in computer sciences is probably a combination of demographics and other readily available (non-degree-granting) modes of acquiring skills in this field, such as workplace training, certificate programs, and on-line courses. See sidebars, "New Horizons in Science and Engineering Education" and "Certificate Programs." (See appendix table 2-1.)

Bachelor's Degrees by Race/Ethnicity

In contrast to overall trends, all minority groups showed an increasing or stable number of degrees earned in most S&E fields in the 1990s. The number of degrees earned by Asians/Pacific Islanders increased in all S&E fields except mathematics. Underrepresented minority groups show a stable number of degrees earned in physical sciences, mathematics, and computer sciences and decade-long increases in degrees earned in social and behavioral sciences, biological sciences, and engineering. In 1998, their number of degrees earned lev-

Figure 2-12.
Bachelor's degrees in S&E fields, earned by selected groups



NOTES: Data for 1983 are estimated. Natural sciences include physics, chemistry, astronomy, and earth, atmospheric, ocean, biological, and agricultural sciences. Underrepresented minorities include black, Hispanic, and American Indian/Alaskan Native. White and underrepresented minorities include U.S. citizens and permanent residents. Foreign citizen includes temporary residents.

See appendix tables 2-16 and 2-17.

Science & Engineering Indicators – 2002

eled off only in engineering, after a decade-long increase. (See appendix table 2-17 for data by field and figure 2-12 for degree trends of selected groups.)

Bachelor's Degrees by Citizenship

Foreign students earn a small percentage (3.6 percent) of S&E bachelor's degrees, a number barely visible on a graph. (See figure 2-12.) Trends in degrees earned by foreign students show increases in the number of bachelor's degrees in social sciences, with slight increases in biological sciences and psychology; fluctuating and declining degrees in engineering; and declining degrees in physical sciences, mathematics, and computer sciences. Foreign students in U.S. institutions earn approximately 7–8 percent of bachelor's degrees awarded in mathematics, computer sciences, and engineering—somewhat lower than the proportion of degrees earned by foreign students in U.K. institutions. In 1999, foreign students in U.K. universities earned almost 30 percent of the bachelor's degrees awarded in engineering and 12 percent of those awarded in mathematics and computer sciences. (See text table 2-8.)

U.S. Participation Rates in Bachelor's Degrees and S&E Degrees by Sex and Race/Ethnicity

Traditionally, the United States has been among the leading nations of the world in providing broad access to higher education. The ratio of bachelor's degrees earned in the United States to the population of the college-age cohort is relatively high: 35 per 100 in 1998. The ratio of natural science and engineering (NS&E) degrees to the population of 24-year-olds in the United States has been between 4 and 5 per 100 for the past several decades and reached 6 per 100 in 1998. Several Asian and European countries have higher participation rates. (See appendix table 2-18 and "International Comparison of Participation Rates in University Degrees and S&E Degrees.")

Text table 2-8.
Bachelor's degrees earned by foreign students in S&E fields, United Kingdom and United States

Field	Degrees		Percent
	All students	Foreign students	foreign
United Kingdom (1999)			
Total S&E degrees	89,520	12,584	14.1
Natural sciences	32,226	2,223	6.9
Mathematics and computer sciences	14,630	1,708	11.7
Social and behavioral sciences	20,652	2,082	10.0
Engineering	22,012	6,571	29.9
United States (1998)			
Total S&E degrees	411,286	14,728	3.6
Natural sciences	104,852	2,391	2.3
Mathematics and computer sciences	39,404	2,585	6.6
Social and behavioral sciences	206,160	5,109	2.5
Engineering	60,870	4,643	7.6

NOTES: U.S. data on foreign students include temporary residents only. Natural sciences include physics, chemistry, astronomy, and earth, atmospheric, ocean, biological, and agricultural sciences.

SOURCES: United Kingdom—Higher Education Statistics Agency, unpublished tabulations (2001); and United States—appendix table 2-17.

Science & Engineering Indicators – 2002

National statistics on participation rates in S&E fields, however, are not applicable to all minority groups in the United States. The gap in educational attainment between whites and racial/ethnic minorities continues to be wide, particularly in participation rates in S&E fields. In 1998, the ratio of college degrees earned by underrepresented minorities to their college-age populations was 18 per 100, and the ratio of NS&E degrees was 2.6 per 100. Comparison of participation rates in 1980 and 1998 shows considerable progress for underrepresented minority groups in earning bachelor's degrees, but their rate of earning NS&E degrees is still less than one-half the rate of the total population. (See text table 2-9.) In contrast, Asians/Pacific Islanders have considerably higher-than-average achievement: the ratio of bachelor's degrees earned to the college-age population is 47 per 100 and that of NS&E degrees to the college-age population is 14.7 per 100.

One partial explanation given for this gap in educational attainment is that the cost barrier for students from low-income families to attend college is increasing; the needs-based system of financial aid for college students has shifted to a greater reliance on loans, tuition tax credits, and merit-based scholarships (The College Board 2000). The cost of higher education to the middle and upper income groups of the population in terms of percentage of their income consumed has not changed appreciably, whereas the percentage of income necessary for people in the lower income group to earn a college degree has risen considerably (National Governors Association (NGA) 2001).

Recommended Reforms

Recommendations have been offered for meeting the challenges of S&E higher education. They are outlined succinctly in recent studies by the National Research Council (Committee on Undergraduate Science Education 1999; CSMTP 2001) and NSF (*Shaping the Future* 1998). The recommendations relate to both institutionwide and departmental reforms:

- **Take an institutional approach to change.** The undergraduate education responsibilities of the university should be given high priority by accrediting agencies, discipline and higher education professional organizations, faculty, departments, and university administrators.
- **Give all students math and science literacy.** Postsecondary institutions should provide all students with the strong foundation in mathematics and sciences needed to function in an increasingly technologically complex world and prepare students for careers in S&E.
- **Help faculty improve their teaching.** Faculty and future faculty need to be aware of the latest research in teaching and learning, such as the benefits of incorporating student inquiry and teamwork into their regular classroom practices, collaborative and active learning, discovery- and inquiry-based courses, and incorporating real-world problems into the classroom by asking students to help frame problems and contribute solutions.
- **Increase undergraduate research.** Develop opportunities for all students to engage in undergraduate S&E-related research with particular attention to students majoring in S&E fields, students from groups traditionally underrepresented in these fields, and students preparing to be teachers. Faculty should bring the excitement of new research findings into both lower and upper division courses.
- **Expand interdisciplinary teaching.** Increase multidisciplinary perspectives in science and mathematics undergraduate programs to reflect the increased workplace

Text table 2-9.
Ratio of total bachelor's degrees and S&E bachelor's degrees to the 24-year-old population, by sex and race/ethnicity: 1980 and 1998

Race/ethnicity and sex	Total 24-year-old population	Total bachelor's degrees	Natural science degrees	Social and behavioral science degrees	Engineering degrees	Ratio to 24-year-old population: Bachelor's degrees	NS&E degrees	Social and behavioral science degrees
1980								
Total	4,263,800	946,877	110,468	132,607	63,717	22.2	4.1	3.1
Sex								
Male	2,072,207	474,336	70,102	64,221	56,654	22.9	6.1	3.1
Female	2,191,593	472,541	40,366	68,386	7,063	21.6	2.2	3.1
Race/ethnicity								
White	3,457,800	807,509	100,791	122,519	60,856	23.4	4.7	3.5
Asian/Pacific Islander	64,000	18,908	3,467	2,499	3,066	29.5	10.2	3.9
Underrepresented minority	892,000	97,539	8,915	22,782	4,464	10.9	1.5	3.9
Black	545,000	60,779	4,932	16,352	2,449	11.2	1.4	3.0
Hispanic	317,200	33,167	3,646	5,748	1,820	10.5	1.7	1.8
American Indian/Alaskan Native	29,800	3,593	337	682	195	12.1	1.8	2.3
1998								
Total	3,403,039	1,199,579	144,441	185,263	60,914	35.3	6.0	5.4
Sex								
Male	1,714,571	525,714	78,906	71,740	49,575	30.7	7.5	4.2
Female	1,688,468	673,865	65,535	113,523	11,339	39.9	4.6	6.7
Race/ethnicity								
White	2,251,292	878,018	101,967	147,707	40,533	39.0	6.3	6.6
Asian/Pacific Islander	149,413	69,988	15,001	12,565	7,002	46.8	14.7	8.4
Underrepresented minority	1,002,334	181,709	18,424	34,836	7,396	18.1	2.6	3.5
Black	473,402	95,878	9,713	18,667	3,018	20.3	2.7	3.9
Hispanic	497,620	78,125	7,881	14,719	4,125	15.7	2.4	3.0
American Indian/Alaskan Native	31,312	7,706	830	1,450	253	24.6	3.5	4.6

NS&E = natural science and engineering

NOTES: Natural sciences include physics, chemistry, astronomy, and earth, atmospheric, ocean, biological, and agricultural sciences, as well as mathematics and computer sciences. The ratios are the number of degrees to the 24-year-old population. Population data are for U.S. residents only and exclude members of the Armed Forces living abroad.

SOURCES: U.S. Bureau of the Census, Population Division, *U.S. Population Estimates by Age, Sex, Race, and Hispanic Origin: 1980 to 1999* (Washington, DC, 2000); National Science Foundation, Science Resources Studies (NSF/SRS), *Science and Engineering Degrees 1966–1998*, NSF 01-325 (Arlington, VA, 2001); and appendix table 2-17.

Science & Engineering Indicators – 2002

emphasis on interdisciplinary approaches, such as computational chemistry and bioengineering.

- **Increase partnerships.** Include appropriate industry and other potential employers in planning curricular changes.

Several organizations have made recommendations regarding their responsibilities for preparing high-quality K–12 teachers in science and mathematics, including institutions of higher education (Association of American Universities 1999; American Association of State Colleges and Universities 1999), business groups (National Alliance of Business 2001), and professional societies (CSMTP 2001). Although the strategies to meet their responsibilities differ, their goals to establish exemplary models of teacher preparation whose success can be widely replicated and to find ways to attract additional qualified candidates to teaching are similar.

Strategies offered by research universities and state colleges and universities include the following:

- Make teacher education a top campus priority and a joint endeavor between faculty in education programs and faculty in other academic disciplines.
- Create and sustain partnerships with schools, state departments of education, informal education providers such as zoos and museums, and local businesses and industries.
- Offer undergraduate research experience to future elementary and secondary mathematics and science teachers.
- Create sound alternatives for mathematics and science majors to obtain teacher certification.

National agencies such as the Department of Education and NSF have begun funding various support programs to

Meeting the Challenge of Teacher Preparation

In 1998, the Department of Education established Teacher Quality Enhancement grants to encourage comprehensive approaches in improving the quality of teacher preparation programs. Many of these grants are five-year awards with cumulative multimillion-dollar funding. Twenty-five awards were made in fall 1999, and eight awards were made in 2000. Six of these awards were given to institutions that had already begun the process of reform under the National Science Foundation's Collaboratives for Excellence in Teacher Preparation (CETP) program, which was initiated in 1992.

The 32 systemic (regional in scope) and institutional (concentrated in one or a few related institutions) CETP projects awarded as of fiscal year 2000 included 250 institutions of higher education (13 percent of the projects related to doctoral degrees, 30 percent to two-year degrees, 31 percent to master's or bachelor's degrees) and 89 to public high schools.

Data collected in spring 2000 by the systemic projects reveal that 4,050 faculty and 4,979 teachers were involved in the CETP projects' efforts to produce teachers who are prepared to teach mathematics and science and to teach and use information technology. The institutions involved in the CETP program are distributed within 22 states and produce 38 percent of the teachers in the states in which they operate. Of the 15,896 1999 CETP graduates who have been tracked, 72.4 percent entered the teaching profession, and 17.7 percent were still attending school—most presumably in postbaccalaureate programs necessary for certification in their state (NSF/EHR 2000).

Evaluation of these programs has shown that, generally, the concerted efforts to improve teacher education in mathematics and science have been effective:

- Higher student achievement was measured in schools served by the Philadelphia CETP (Temple University). From 1996 to 1999, the Stanford Achievement Test (SAT-9) math and science average test scores and gains for 4th-grade classes in which CETP undergraduates taught during their practica exceeded the citywide average.
- Retention of new teachers in the Montana CETP Early Career Support project improved. The attrition rate from teaching for the more than 120 beginning teachers in the Early Career program was approximately 3 percent, far below the national average of 30 percent.
- An increase in minority teachers resulted from the efforts of the Montana CETP. In 1992, before CETP was instituted, 5 of the 1,500 mathematics and science teachers in the state of Montana were Native American. By the end of the project in 1999, 11 American Indians had graduated certified to teach mathematics or science, and 77 more were in the pipeline, attending tribal colleges or university campuses for secondary mathematics or science certification.

catalyze efforts to improve teacher preparation. See sidebar, "Meeting the Challenge of Teacher Preparation." Alternative certification programs to increase the nation's supply of math and science teachers are aimed at those already in S&E careers or S&E majors who would like to enter K–12 teaching (Feistritzer and Chester 2000; Urban Institute 2000). See sidebar, "Alternative Certification for K–12 Teachers."

National data are scarce with regard to how students go through higher education, the extent of participation, and learning outcomes. See sidebar, "Special New Programs," for information about some funding programs and institutions attempting to implement recommended reforms. Changes include focusing on learning outcomes in undergraduate education, increasing diversity of the S&E workforce, incorporating recent advances in teaching and learning into the undergraduate classroom, and augmenting research experiences for undergraduates.

Graduate S&E Students and Degrees in the United States

Overall Trends in Graduate Enrollment

Is the United States educating an adequate number of bachelor-level S&E majors who are willing and able to pursue advanced degrees in S&E? Has access to graduate programs improved for women and underrepresented minorities? This section presents trends in graduate enrollment: strong growth in foreign student enrollment until 1992 and declining enrollment for both U.S. and foreign citizens from 1993 to 1998. Enrollment of foreign students turned up considerably in 1999, increasing their proportion of the graduate population.

The long-term trend of increasing enrollment in graduate S&E programs in the United States persisted for several decades, peaked in 1993, declined for five years, and then increased in 1999. Trends differ somewhat across S&E fields. For example, enrollment in mathematics and computer sciences peaked in 1992, declined for three years, and then increased from 1995 onward. In contrast, the number of graduate students in engineering declined for six consecutive years (1993–98) before increasing slightly in 1999. (See appendix

Alternative Certification for K–12 Teachers

The use of alternative routes to teaching certification is controversial. Although some experts point out the benefits of more traditional programs such as the use of fifth-year certification programs as a route to alternative certification, they also question the value of short-term alternative certification programs. According to a report from the National Commission on Teaching and America's Future, evaluations of truncated alternative certification programs reveal that students of these teachers learn less than those taught by traditionally prepared teachers (Darling-Hammond 2000). In addition, the report shows that approximately 60 percent of individuals who enter teaching through such programs leave the profession by their third year compared with approximately 30 percent of traditionally trained teachers and only about 10–15 percent of teachers prepared in extended, five-year teacher education programs.

A contrasting view is that alternative routes attract a significantly higher proportion of minority candidates who are more willing to teach mathematics and science in urban and rural environments. Two examples are Troops-to-Teachers and Teach for America. Troops-to-Teachers enables military retirees to prepare to be teachers through existing teacher preparation programs (approximately 50 percent have entered through an alternative teacher preparation and certification program and 50 percent through traditional college-based programs). Since 1994, this program has brought 3,000 military retirees into the teaching profession. According to a recent survey conducted by the National Center for Education Information, Troops-to-Teachers graduates are more likely than the general teaching population to teach mathematics or science (respectively, 29 versus 13 percent teach mathematics and 16 versus 8 percent teach science), be members of minority groups (30 versus 10 percent), or teach in inner-city schools (24 versus 16 percent) (Troops-to-Teachers 2001).

Teach for America enlists liberal arts graduates directly out of college to teach in poor urban and rural schools for at least two years after a summer training period and an induction period at the beginning of the teaching experience. The program has recruited and placed more than 6,000 individuals in teaching positions; 58 percent of the alumni are still in education, of whom 40 percent are full-time teachers. In 1997, 17 percent of matriculants were mathematics and science majors, and 33 percent were African American or Hispanic (Teach for America 2001).

table 2-19.) The favorable job market in the nation after 1992 may account for some of the decline in graduate enrollment. For general workforce conditions that may influence enrollment in higher education, see chapter 3, "Science and Engineering Workforce." The increase in 1999 is mainly accounted for by the increased percentage of foreign students enrolling in U.S. graduate S&E programs. (See appendix table 2-20.)

Graduate Enrollment by Sex, Race/Ethnicity, and Citizenship

The long-term trend of women's increasing proportion of enrollment in all graduate S&E fields has continued during the past two decades, with significant differences by field. By 1999, women constituted 59 percent of the graduate enrollment in social and behavioral sciences and 43 percent of the graduate enrollment in natural sciences. In the same year, women constituted 37 percent of the graduate students in mathematics, 30 percent of the graduate students in computer sciences, and only 20 percent of the graduate enrollment in engineering. However, men are not as prevalent among underrepresented minority groups in NS&E fields; women in underrepresented minority groups have a higher proportion of graduate enrollment than women in other groups. For example, one-third of black graduate students in engineering and more than one-half of the black graduate students in natural sciences are women. (See text table 2-10.)

Graduate enrollment trends also differ by race and ethnicity. The proportion of total enrollment represented by white (majority) students in graduate S&E programs declined from 65 percent in 1975 to less than 53 percent in 1999. In contrast, the number of underrepresented minority students in graduate S&E programs has increased during the past two decades. However, the rate of increase has slowed from 6.5 percent in the 1986–92 period to 4.1 percent in the 1992–99 period. Underrepresented minorities, which make up almost 25 percent of the U.S. population, represent 9.3 percent of the students in graduate S&E programs in U.S. higher education. Asians/Pacific Islanders are well represented in advanced S&E education, constituting 4 percent of the U.S. population and 6.7 percent of the graduate students in S&E programs. (See appendix table 2-20.)

After a four-year decline (1993–96), the number of foreign students enrolling in U.S. graduate S&E programs turned around in 1997 and 1998 and increased sharply in 1999. The decline in foreign students from 1993 to 1996 (and the subsequent decline in foreign doctoral degree recipients in 1997–99) is partly explained by fewer Chinese students coming to the United States during the few years after Tiananmen Square and the Chinese Student Protection Act. Chinese student enrollment in the U.S. S&E graduate programs declined from 28,823 in 1993 to 24,871 in 1995 and then continued to increase in subsequent years. However, the number of graduate S&E students from India, South

Special New Programs

Some programs and institutions of higher education have supported recommended reforms.

Focusing on Learning Outcomes

Newly adopted accreditation guidelines for both the Accreditation Board of Engineering and Technology (2001) and the National Council for Accreditation of Teacher Education are based on outcome rather than simply on courses of study and admission criteria (Wise 2001).

Recent surveys of higher education institutions have included specific questions related to employer and general public satisfaction and student perception of their experience in terms of the number and quality of their contact with faculty, level of academic challenge, internships and study abroad projects, frequency of student group and community projects, signs of active and collaborative learning, and other factors (NGA Center for Best Practices 2001; PEW Forum on Undergraduate Learning 2000).

Increasing the Diversity of the S&E Workforce

The production of minority science and engineering bachelor's degrees from the first set of institutions involved in an NSF program aimed at increasing minority S&E students has increased from 3,900 in 1990 to 7,200 in 2000 (Dale 2001).

Incorporating Recent Advances in Teaching and Learning Into the Undergraduate Classroom

Many institutions are experimenting with creating learning communities to encourage S&E students to understand the basic concepts of the phenomena they are studying and to help each other learn. For example, on a single-course basis, a consortium of nearly 60 institutions has added student-led discussion workshops to their organic chemistry classes. Students meet in workshops, are handed observations from a specific chemical technique (e.g., infrared spectroscopy), and are asked to jointly analyze the results. They work in teams and are encouraged to engage everyone on the team in devising solutions. At one participating institution, the University of Rochester, where only 67 percent of organic chemistry students in the early 1990s earned the "C" necessary to enroll in more advanced chemistry courses, 79–82 percent of the students now earn a "C" or better. These results are mirrored throughout the consortium (Cox 2001).

One effort involving a related series of courses is aimed at increasing the retention of entering prescience and preengineering students at the University of Texas at El Paso. Students are assigned to a block of three linked courses (an English course, a mathematics course, and a seminar course with a science or engineering theme) featuring cooperative learning teaching techniques. Twelve percent more of the students in the cluster groups remained S&E majors (80 percent retained) compared with nonclustered students (68 percent retained) (Rothman and Narum 1999).

In response to the findings of research on learning and teaching, numerous efforts have been initiated to more actively involve students in classes. Examples range from course-specific efforts such as those of Eric Mazur, a physics professor at Harvard, to more universal approaches such as the adoption of problem-based learning techniques in all basic science courses at the University of Delaware. As much as one-third of Mazur's physics classroom time is devoted to consideration of conceptual questions related to the subject of the day. Mazur poses a challenging question to the class, students record their answers via computer, and the results are discussed, resulting in increased student interest and participation and an opportunity for the faculty to correct misconceptions as they occur. The University of Delaware finds that problem-based learning promotes active learning and connects concepts to applications. A real-life science-related problem is presented to students, who then work in groups to gather information from appropriate sources and develop a reasonable solution (The Boyer Commission on Educating Undergraduates 1998).

Augmenting Research Experiences for Undergraduates

Numerous universities are incorporating research experiences for either a distinct subset or all of their S&E majors. Summer opportunities for research included approximately 400 NSF Research Experiences for Undergraduates projects in the nation in 2000, serving about 4,000 undergraduates (NSF/EHR 2001b); research opportunities for students preparing to be teachers initiated as a joint project of the Department of Energy and the National Science Foundation (NSF/EHR 2001c); and programs supported by the Howard Hughes Medical Institute (2001).

To encourage a research-based approach to education in S&E, Rensselaer Polytechnic Institute has redesigned its large introductory courses, replacing lecture, recitation, and laboratory with a studio format taught in a specially designed facility by a single faculty member assisted by one graduate student and several undergraduates (The Boyer Commission on Educating Undergraduates 1998).

The University of Arizona is attempting to make research opportunities an integral part of each student's undergraduate experience through the introductory biology course, serving about 1,800 students per year. In addition, two undergraduate laboratory research experiences are offered, one in faculty laboratories at the University of Arizona and a followup experience in biomedical research abroad.

Text table 2-10.
Female enrollment in U.S. graduate S&E programs among racial/ethnic groups and foreign students, by discipline: 1999
(Percentages)

Race/ethnicity and citizenship	Total S&E	Natural sciences	Mathematics	Computer sciences	Social and behavioral sciences	Engineering
Total	41	43	37	30	59	20
White	44	44	37	25	60	19
Asian/Pacific Islander	42	49	44	38	63	25
Black	58	58	45	45	66	33
Hispanic	50	50	39	24	63	24
American Indian/Alaskan Native	52	49	60	32	62	28
Foreign students	30	37	35	30	45	18

NOTES: Foreign students include those on temporary visas only. Values are percentages of total enrollment for each subgroup within each field. Natural sciences include physics, chemistry, astronomy, and biological, agricultural, earth, atmospheric, and ocean sciences.

SOURCE: National Science Foundation, Science Resources Studies (NSF/SRS), *Graduate Students and Postdoctorates in Science and Engineering: Fall 1999*, NSF 01-315 (Arlington, VA, 2001).

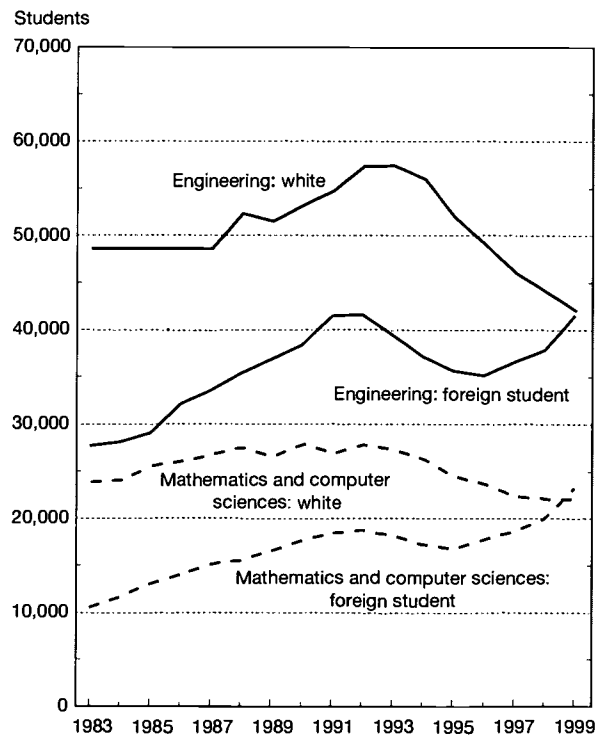
Science & Engineering Indicators – 2002

Korea, Taiwan, Indonesia, and Malaysia also declined in various years in the 1990s because of expanded opportunities for graduate education within their own countries or regional economies. (See appendix table 2-21.)

Despite the four-year decline, the longer term trend shows increasing enrollment of foreign graduate students in S&E fields in U.S. institutions. Evidence shows that foreign student enrollment also is increasing in other major host countries (the United Kingdom and France) and to other host countries (Germany and Japan). See "International Comparison of Foreign Student Enrollment in S&E Programs." The international trend may be driven by the desire for advanced training in S&E fields and employment opportunities in S&E careers. In 1999, this increasing foreign enrollment, coupled with a declining number of U.S. white (majority) students, resulted in an approximately equal number of white and foreign students in the U.S. graduate programs in mathematics, computer sciences, and engineering. (See figure 2-13.)

The NSF 1999 Survey of Graduate Students and Postdoctorates in Science and Engineering (NSF/SRS 2001a) shows that more than 100,000 foreign students were enrolled in U.S. S&E graduate programs. They represent a significant proportion of engineering (41 percent) and math and computer science (39 percent) students. Except for Canada, the 10 top countries of origin of foreign students to the United States are in the Asian region. Trends in enrollment from particular Asian countries and economies show a decline through most of the 1990s for students from Taiwan, a leveling off of students from South Korea, and an increasing number of students from China and India after a temporary drop. (See figure 2-14, appendix table 2-21, and "International Comparisons of Foreign Student Enrollment in S&E Programs" at the end of the chapter.)

Figure 2-13.
Trends in graduate enrollment in mathematics and computer sciences and in engineering: 1983–99



NOTE: White includes U.S. citizens and permanent residents; foreign student includes temporary residents only.

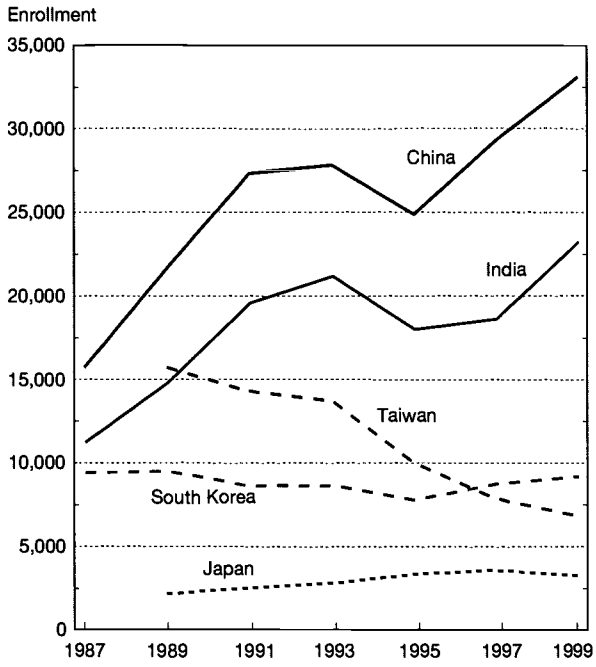
See appendix table 2-20. *Science & Engineering Indicators – 2002*

Master's Degrees

Overall Trends

Declining S&E degree trends at the master's level resemble those at the bachelor's level. The number of degrees earned in engineering, the most attractive major at the master's level, increased rapidly for more than a decade, peaked in 1994, declined for three consecutive years, and leveled off. The number of degrees earned in social sciences, psychology, and biological/agricultural sciences increased strongly in the 1990s

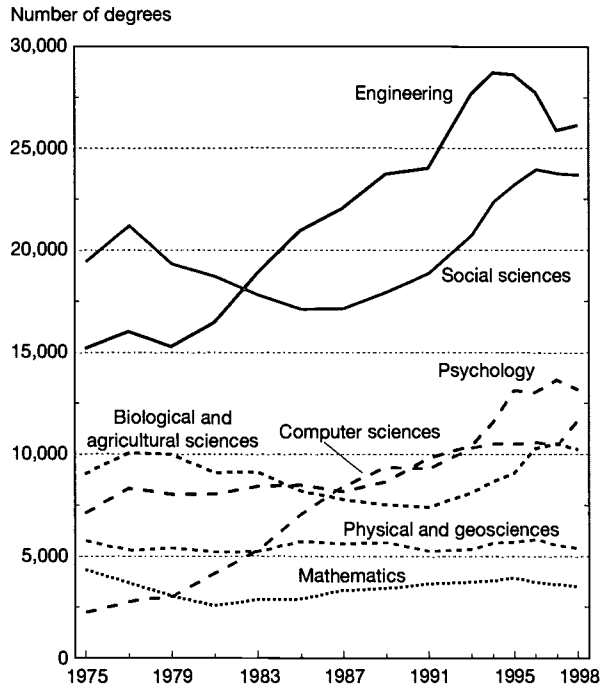
Figure 2-14.
Foreign student enrollment in U.S. S&E graduate programs, by selected countries and economies: 1987–99



NOTES: Data for 1999 are estimated based on the previous percentages of graduate students from each country who enrolled in S&E fields. Foreign students include only those on temporary visas.

See appendix table 2-21. *Science & Engineering Indicators – 2002*

Figure 2-15.
Master's degrees awarded in S&E, by field: 1975–98



NOTE: Geosciences include earth, atmospheric, and ocean sciences.

See appendix table 2-22. *Science & Engineering Indicators – 2002*

and leveled off in the past few years. The corresponding statistics for mathematics, physical sciences, and geosciences have remained stable during the past few decades. The number of degrees earned in computer sciences remained essentially flat for most of the 1990s; computer sciences is one of the few S&E fields that exhibited an increase in degrees earned in 1998. (See figure 2-15.)

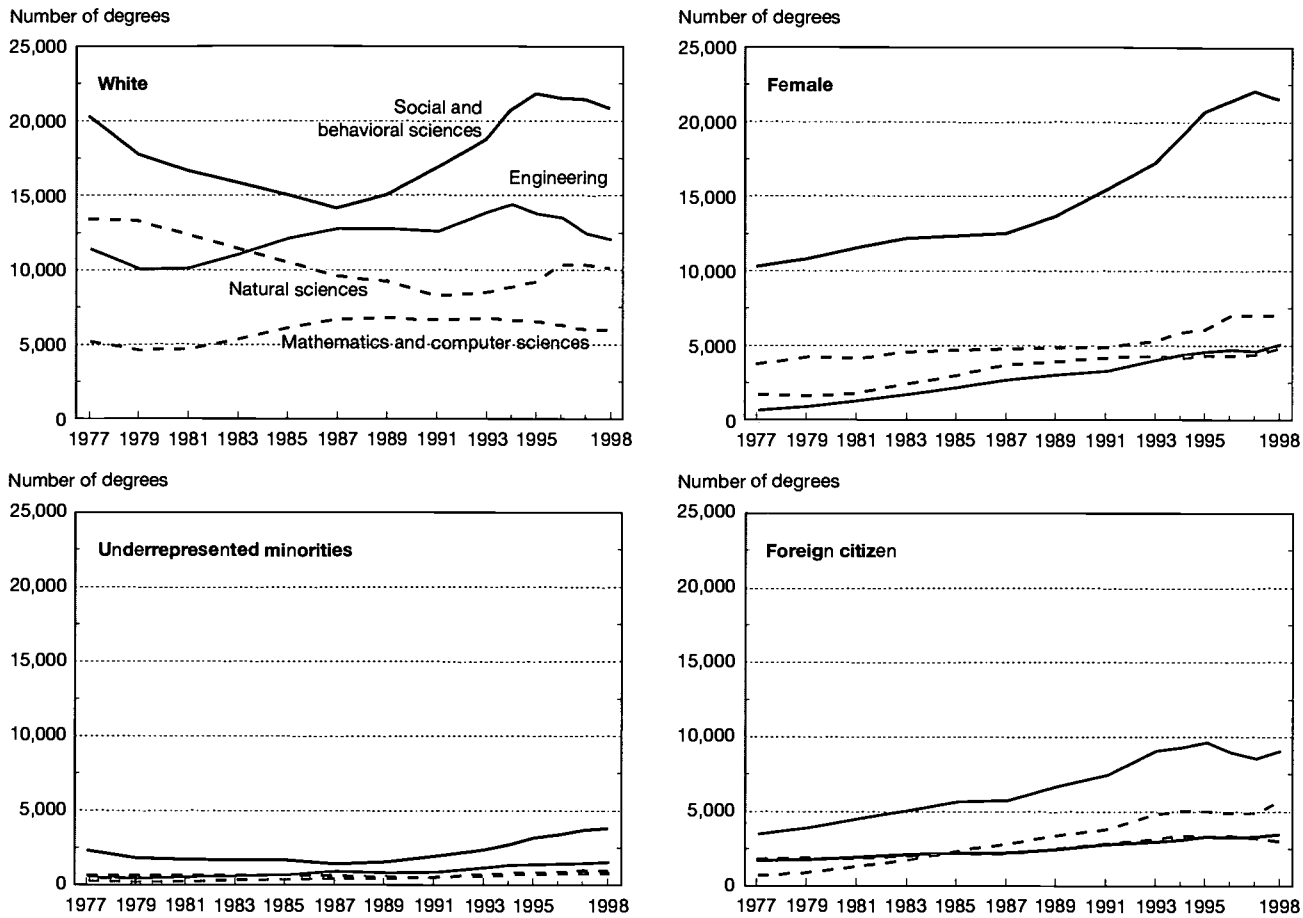
Master's Degrees by Sex, Race/Ethnicity, and Citizenship

Trends for men earning master's degrees differ slightly from trends for women. For men, growth in the number of degrees earned in biological and social sciences and psychology was more modest, and growth in computer sciences was stronger until 1996, when the number of degrees earned declined. Trends for women show continuously strong increases during the past two decades in biological and social sciences and psychology, modest increases in computer and physical sciences, and constant levels in mathematics, with a slight downturn in mathematics and physical sciences after 1996. (See appendix table 2-22.)

Trends also differ by race/ethnicity and citizenship. White students follow the overall trends, with increases in biological and social science, psychology, and computer science degrees earned in the 1980s, followed by steady decreases throughout the 1990s. In contrast, trends for Asian/Pacific Islander students show an increasing number of degrees earned in all S&E fields, particularly in computer sciences. S&E trends for blacks at the master's level show strong growth in the number of degrees earned in social sciences and psychology and modest growth in biological and computer sciences. Hispanic students also show strong growth in the number of degrees earned in social sciences and psychology, modest growth in biological sciences, and minor fluctuations in computer sciences. American Indians/Alaskan Natives earned an increasing number of degrees in social sciences and psychology, but the number of degrees earned in all other fields fluctuated around a low base. The number of degrees earned by foreign students increased in all S&E fields, particularly computer sciences, until 1993 and then leveled off or declined. Trends in broad fields are shown for selected groups in figure 2-16.

Among the new directions in graduate education are the creation of the new "terminal" master's degrees and the proliferation of professional certificate programs. Terminal master's programs provide the skills (often interdisciplinary) needed by professionals working in emerging S&E fields. Professional certificates that are approved by graduate programs include a coherent set of courses for a specialty, such as engineering management. The latter are amenable to distance delivery at corporate sites. See sidebar, "Terminal Master's Degree Programs."

Figure 2-16.
Master's degrees in S&E fields earned by selected groups: 1977–98



Underrepresented minorities = black, Hispanic, and American Indian/Alaskan Native

NOTES: Data are estimated for 1983. Natural sciences include physics, chemistry, astronomy, and earth, atmospheric, ocean, biological, and agricultural sciences. White and underrepresented minorities include U.S. citizens and permanent residents. Foreign citizen includes temporary residents.

See appendix tables 2-22 and 2-23.

Science & Engineering Indicators – 2002

Doctoral Degrees

Overall Doctoral Trends

After a steady upward trend during the past two decades, the overall number of doctoral degrees earned in S&E fields declined in 1999. Trends differ by field. Degrees in biological sciences followed the overall pattern and declined for the first time in 1999. The number of degrees earned in engineering peaked in 1996 and declined for the next three years. This decrease in the number of engineering degrees earned is accounted for mainly by the decrease in the number of degrees earned by foreign students from 1996 to 1999. See "Doctoral Degrees by Citizenship." The number of degrees earned in psychology and social sciences increased slightly in the 1990s and leveled off in 1998–99. The number of degrees earned in the physical sciences and geosciences, mathematics, and computer sciences was stable in the 1990s and declined slightly in 1999. (See figure 2-17.)

Doctoral Degrees by Sex

At the doctoral level, the proportion of S&E doctoral degrees earned by women has risen considerably in the past three decades, reaching a record 43 percent in 1999. (See figure 2-18.) However, dramatic differences by field exist. In 1999, women earned 23 percent of the doctoral degrees awarded in physical sciences, 18 percent of those in computer sciences, and 15 percent of those in engineering. However, they earned more than 41 percent of the degrees awarded in biological and agricultural sciences and 42 percent of those awarded in social sciences. Women earned most of the degrees (66 percent) awarded in psychology.[4] (See appendix table 2-24.) The long-term trend of an increasing number of doctoral degrees earned by women halted in 1999, with slight decreases in biological and physical sciences and a leveling off in other S&E fields (NSF/SRS 2001d). (See appendix table 2-24.)

[4]See National Science Foundation, Division of Science Resources Studies, *Science and Engineering Doctorate Awards: 1999*, table 2, for percentages of doctoral degrees earned by women for detailed S&E fields in 1990 and 1999.

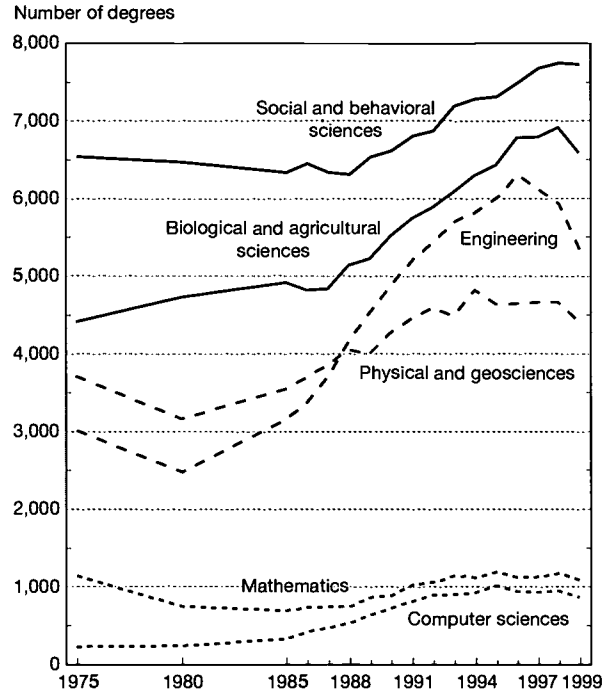
Terminal Master's Degree Programs

Terminal master's degree programs might be viewed as the science equivalents of master's degree programs in business administration (Littman and Ferruccio 2000). Although these programs have existed for many years, industrial and academic interest is growing in programs that prepare students to enter emerging science and engineering (S&E) fields (e.g., bioinformatics and computational chemistry) as skilled professionals. These programs tend to be broader than just one field and require skills in various disciplines.

The Sloan and Keck Foundations are supporting development of such programs to supply the growing S&E technical needs of industry, government agencies, and academic researchers and to answer the needs of students who do not want to go into clinical medicine or research careers but want to remain in science or mathematics (Tobias 2000). National data concerning how many of these programs exist or how many students participate in them will not emerge for several years. In 2000, the Sloan Foundation supported 17 such programs distributed among five universities, and at least 7 more programs distributed among three new university participants are planned for 2001.*

*For more information, see <http://www.sciencemasters.com>.

Figure 2-17.
Doctoral S&E degrees earned in U.S. universities, by field: 1975–99



NOTES: Data are in five-year increments for 1975–85, and one-year increments for 1985–99. Geosciences include earth, atmospheric, and ocean sciences.

See appendix table 2-24. *Science & Engineering Indicators – 2002*

Doctoral Degrees by Race/Ethnicity

In the past decade, the white (majority) population earned a slightly increasing number of doctoral degrees across most S&E fields, followed by a downturn in most fields in 1998–99. In the same period, underrepresented minorities also earned an increasing number of doctoral degrees across all fields, mainly in social, behavioral, and natural sciences. Their increases were from such a low base, however, that the number of doctoral degrees awarded to underrepresented minorities is barely visible on a graph that compares S&E degrees earned by various groups. (See figure 2-19.) The modest gains in the number of degrees earned in engineering, mathematics, and computer sciences continued in the 1990s until 1998, when the number of degrees earned in these fields turned slightly downward. Among Asians/Pacific Islanders who were citizens and permanent residents, the steep increases in the mid-1990s mainly reflect the Chinese foreign students on temporary visas shifting to permanent resident status from the 1992 Chinese Student Protection Act. The number of degrees earned by Asians/Pacific Islanders has since leveled off. (See appendix table 2-25.)

Doctoral Degrees by Citizenship

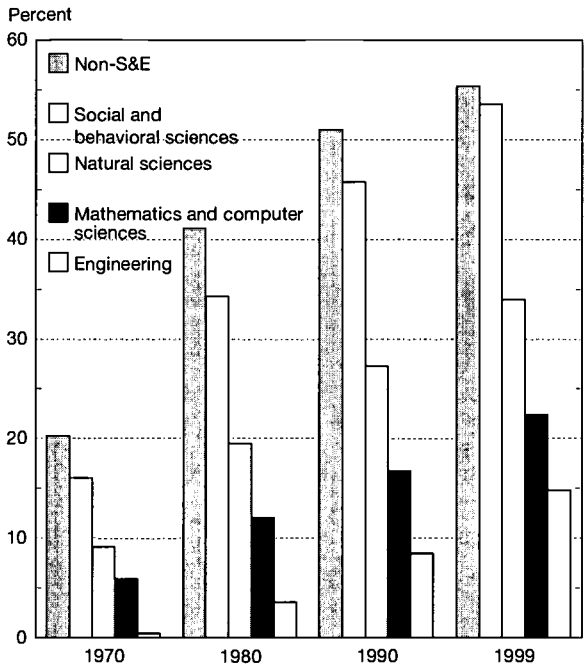
Each year from 1986 to 1996, the number of foreign students earning S&E doctoral degrees at universities in the United States increased; after that, this number of earned degrees dropped off. The number of such degrees earned by foreign students increased much faster (7.8 percent annually) than the number earned by U.S. citizens (2 percent annually). (See appendix table 2-26.) For example, the number of foreign students earning doctoral degrees in S&E increased from 5,000 in 1986 to almost 11,000 in the peak year of 1996, with declines each succeeding year.[5] During the 1986–99 period, foreign students earned 120,000 doctoral degrees in S&E fields. China is the top country of origin of these foreign students; almost 24,000 Chinese students earned S&E doctoral degrees at universities in the United States during this period (NSF/SRS 2001d).

The decline in S&E doctoral degrees earned by foreign students mirrors their declining enrollment in graduate S&E programs from 1993 through 1996. (See appendix table 2-20.) After this four-year drop-off in enrollment, the number of foreign graduate students stabilized in 1997 and increased in 1998 and 1999. (The number of foreign doctoral recipients may increase within the next few years if their graduate enrollment in U.S. institutions continues to increase.)

Foreign students earn a larger proportion of degrees at the doctoral level than any other degree level, more than one-third of all S&E doctoral degrees awarded. (See figure 2-20.)

[5]Numbers include students on both temporary and permanent visas but not naturalized citizens.

Figure 2-18.
Doctoral degrees earned by women in U.S. institutions, by field: 1970–99



NOTE: Natural sciences include physics, chemistry, astronomy, and earth, atmospheric, ocean, biological, and agricultural sciences.

See appendix table 2-24. *Science & Engineering Indicators – 2002*

Their proportion in some fields is considerably higher: in 1999, foreign students earned 47 percent of doctoral degrees awarded in mathematics and computer sciences and 49 percent of those awarded in engineering.

Doctoral Reform

The need for reform of doctoral education has been widely noted and discussed. In 1995, the Committee on Science, Engineering, and Public Policy (COSEPUP) recommended broadening the education of doctoral students beyond research training. Because more than one-half of all doctoral recipients obtain nonacademic employment, COSEPUP recommended that doctoral students acquire an education in the broad fundamentals of their field, familiarity with several subfields, the ability to communicate complex ideas to nonspecialists, and the ability to work well in teams (COSEPUP 1995). Subsequently, professional societies and leading educators encouraged the expansion of COSEPUP recommendations beyond physical sciences and engineering to include all graduate education.

NSF responded to COSEPUP's recommendations by funding universities to establish Integrative Graduate Education and Research Traineeship (IGERT) programs. Such awards enable universities to offer stipend support to graduate students to engage in research in emerging multidisciplinary areas of S&E (NSF/EHR 2001a). From 1997 to 2000, NSF granted university faculties a total of 57 awards in the IGERT program.

Current research on doctoral education shows that doctoral students' high level of interest and belief in the possibility of a faculty career persist even though the number of doctoral degrees granted far exceeds available tenure-track positions. See sidebar, "At Cross Purposes."

Current efforts focus on how to "re-envision the Ph.D." to meet the needs of society in the 21st century and how to effect reforms without lengthening the time to achieve a degree. The re-envisioning project provides a forum for national dialog on doctoral reforms among key stakeholders: research- and teaching-intensive institutions, doctoral students, agencies that fund and hire doctoral recipients, disciplinary societies, and education associations. A recent workshop composed of many such stakeholders agreed on six themes for doctoral reforms:

- shorten time to degree acquisition,
- increase underrepresented minorities among doctoral recipients,
- improve the use of technology for research and instructional purposes,
- prepare students for a wider variety of professional opportunities,
- incorporate understanding of the global economy and international scientific enterprise, and
- provide doctoral students with an interdisciplinary education.

The project also collects and disseminates promising practices for doctoral education that are submitted by individual departments (Nyquist and Woodford 2000). See also chapter 3 on "Science and Engineering Workforce" for employment prospects of doctoral recipients by field and the sidebar, "International Efforts in Doctoral Reform," at the end of this chapter.

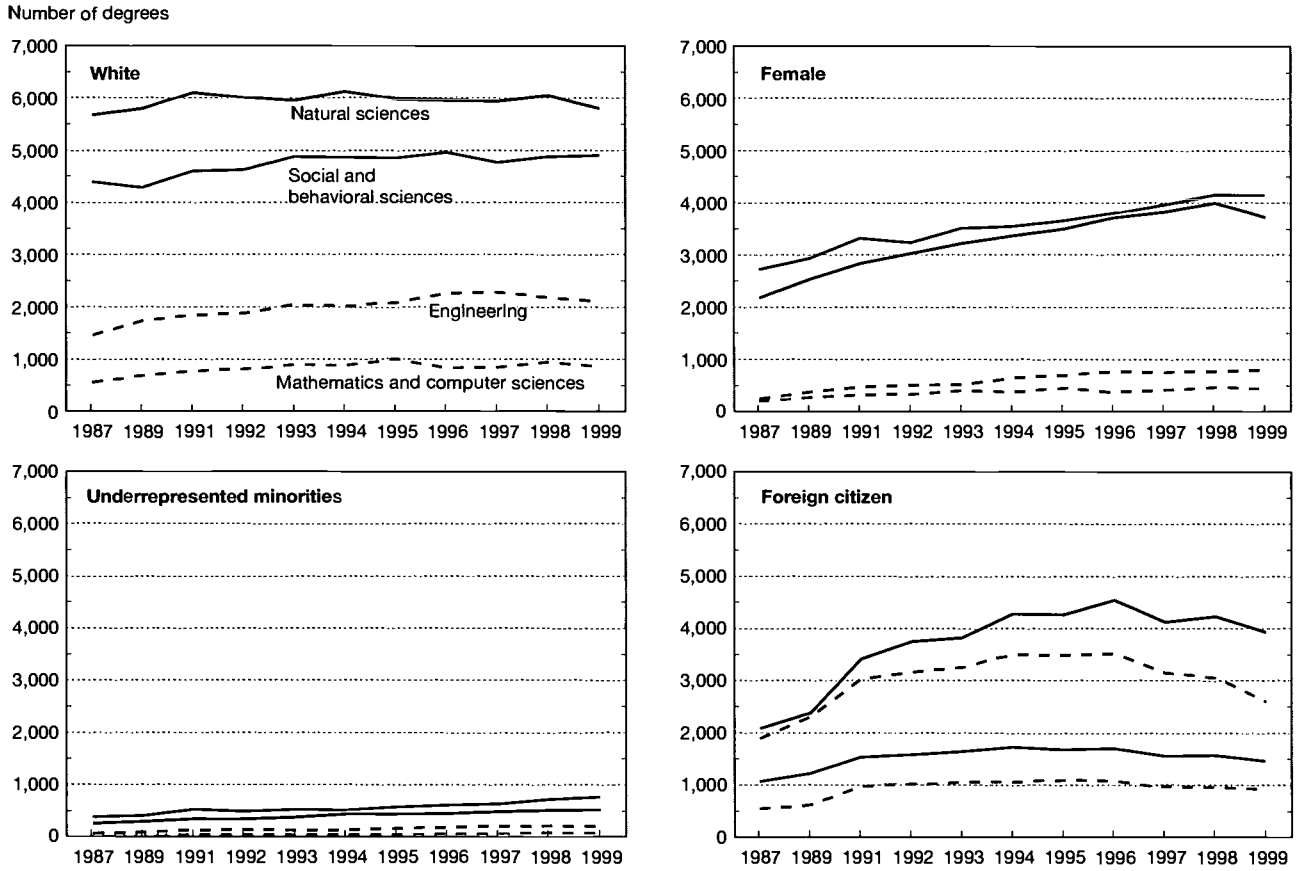
Financial Support for S&E Graduate Education

U.S. higher education in S&E fields has traditionally coupled advanced education with research. This coupling is reflected by the various forms of financial support for S&E graduate students, particularly those pursuing doctoral degrees. Support mechanisms include fellowships, traineeships, research assistantships (RAs), and teaching assistantships (TAs).

Sources of support include Federal agency support, non-Federal support, and self-support. See sidebar, "Definitions and Terminology," for fuller descriptions of both mechanisms and sources of support. Most graduate students, especially those who pursue doctoral degrees, are supported by more than one source and one mechanism during their time in graduate school; some graduate students may even receive support from several different sources and mechanisms in any given academic year.

This section describes both sources and mechanisms of financial support. During the 1990s, the distribution of different mechanisms of support stabilized after the importance of RAs increased during the 1980s. The increase was offset

Figure 2-19.
Doctoral degrees in S&E fields earned by selected groups



NOTES: Natural sciences include physics, chemistry, astronomy, and earth, atmospheric, ocean, biological, and agricultural sciences. Underrepresented minorities include black, Hispanic, and American Indian/Alaskan Native. White and under-represented minorities include U.S. citizens and permanent residents. Foreign citizen includes those on either permanent or temporary visas.

See appendix tables 2-24, 2-25, and 2-26.

Science & Engineering Indicators – 2002

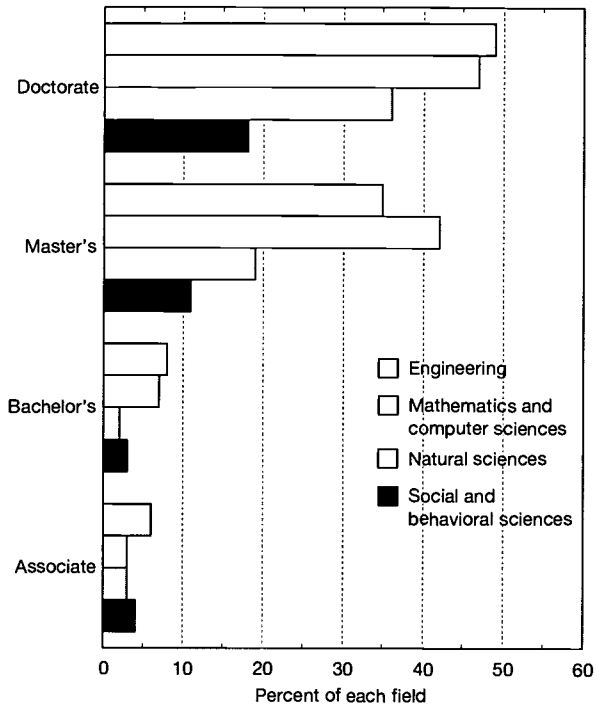
by a reliance on traineeships and self-support. The relative stability in the proportion of different mechanisms of support in the 1990s holds for both federally and nonfederally supported students. Federal support is found predominantly in the form of RAs, which represent 66 percent of all Federal support. However, Federal support through fellowships increased slightly in the 1990s, from 9 percent in 1989 to 11 percent in 1999. For students supported through non-Federal sources, TAs are the most prominent mechanism (41 percent), followed by RAs (30 percent). (See appendix table 2-27.)

Primary mechanisms of support differ widely by S&E fields of study. For example, students in physical sciences are supported mainly through RAs (42 percent) and TAs (41 percent). RAs also are important in engineering (42 percent) and earth, atmospheric, and ocean sciences (41 percent). In mathematics, however, primary student support is through TAs (57 percent) and self-support (17 percent). Students in social sciences are mainly self-supporting (41 percent) or receive TAs (22 percent). (See appendix table 2-28.)

The Federal Government plays a significant role in supporting S&E graduate students in some selected fields and mechanisms and an insignificant role in others. For example, Federal traineeships represent approximately two-thirds of all such support, almost one-half of all RAs, and one-quarter of all fellowships. The percentage of Federal traineeships is even greater in physical and biological sciences and in chemical engineering, and the Federal Government supports most RAs in physical sciences. In contrast, the Federal Government is not a significant source of support for graduate education in social sciences, psychology, and mathematics. (See appendix table 2-29.)

The National Institutes of Health (NIH) and NSF support most of the S&E graduate students whose primary support comes from the Federal Government, 17,000 and 14,000 students, respectively. Trends in Federal agency support of graduate students show a considerable increase in the proportion of students supported primarily by NIH, from less than 22 percent in 1980 to 29 percent in 1999. The proportion of graduate students receiving Federal support primarily by NSF has

Figure 2-20.
S&E degrees earned by foreign students within each field, by level: 1998–99



NOTES: Doctoral degree data are for 1999; all others are 1998 data. At the doctoral level, foreign students include both permanent and temporary residents; all other levels include only temporary residents. Natural sciences include physics, chemistry, astronomy, and earth, atmospheric, ocean, biological, and agricultural sciences.

See appendix tables 2-15, 2-17, 2-23, and 2-26.

Science & Engineering Indicators – 2002

At Cross Purposes

A recent survey of doctoral programs queried students in three areas: their goals, the effectiveness of doctoral programs in preparing students for careers within and outside academia, and the level of student satisfaction with their programs (Golde and Dore 2001).

The findings revealed that most students interviewed were interested in a faculty job in the future. When questioned about preparation for various aspects of their future career, 65 percent of the students indicated that they were prepared by their program to conduct research; fewer felt prepared to publish their research findings (43 percent) or collaborate in interdisciplinary research (27 percent). Relatively few students (38 percent) reported that they were encouraged to take part in nonacademic job search workshops.

More than half of all doctoral students had opportunities to improve their teaching skills, but these opportunities varied greatly among the disciplines surveyed. Training courses for teaching assistants were least likely in chemistry (28 percent) and molecular biology (30 percent).

Overall, students reported being satisfied with their decision to pursue doctoral degrees; however, they were less certain about the details of pursuing a doctoral education in regard to their daily lives. They entered the program without having a good idea of the time, money, clarity of purpose, and perseverance that doctoral study requires. Once enrolled, they received little guidance on how to complete the process successfully.

increased from 18 to 21 percent in the past two decades. In contrast, the Department of Defense provided primary support for a declining proportion of students funded primarily by Federal sources: 17 percent in 1988 and 12 percent in 1999. (See appendix table 2-30.)

Support Mechanisms for Doctoral Students

For doctoral students, support mechanisms can be classified by sex, race/ethnicity, and citizenship. For men, the leading support mechanism is RAs, followed by personal sources. For women, the leading support mechanism is personal sources, followed by fellowships. Foreign doctoral students serve as S&E research and teaching assistants and are more likely to have RAs and TAs as their primary sources of support. For example, more than 80 percent of the Chinese doctoral degree recipients in the United States from 1988 to 1996 reported in the U.S. Survey of Earned Doctorates (SED) that they were supported by university RAs,[6] and more than 50 percent reported financial support from TAs (NSF/SRS 2001a). U.S. citizens are more likely to have personal sources of support. For underrepresented minorities, however, fellowships are the primary source of support. (See appendix table 2-31.)

Stay Rates of Foreign Doctoral Recipients

Historically, approximately 50 percent of foreign students who earned S&E degrees at universities in the United States reported that they planned to stay in the United States, and a smaller proportion had firm offers to do so (NSF/SRS 1998). In 1990, for example, 45 percent of all foreign S&E doctoral degree recipients planned to remain in the United States after completing their degree, and 32 percent had received firm offers. As a result of the strong economy and employment opportunities of the 1990s, however, these percentages increased significantly. By 1999, more than 72 percent of foreign doctoral recipients in S&E fields planned to stay in the United States, and 50 percent accepted firm offers to do so. (See figure 2-21 and appendix table 2-32.)

The number of S&E doctoral degrees earned by foreign students declined after 1996, but the number of students who had firm plans to remain in the United States declined only slightly from its 1996 peak. Each year from 1996 to 1999,

[6] Much of the funding for university RAs is derived from Federal grants to universities.

Definitions and Terminology

Fellowships are competitive awards (often from a national competition) given to students for financial support of their graduate studies.

Traineeships are educational awards given to students selected by the institution.

Research assistantships are given to students whose assigned duties are devoted primarily to research.

Teaching assistantships are given to students whose assigned duties are devoted primarily to teaching.

Other mechanisms of support include work-study programs, business or employer support, and support from foreign governments that is not in the form of a previously mentioned mechanism.

Self-support is derived from any loans obtained (including Federal loans) or from personal or family contributions.

Federal support comes from Federal agencies; examples are the GI bill and tuition paid by the Department of Defense for members of the Armed Forces.

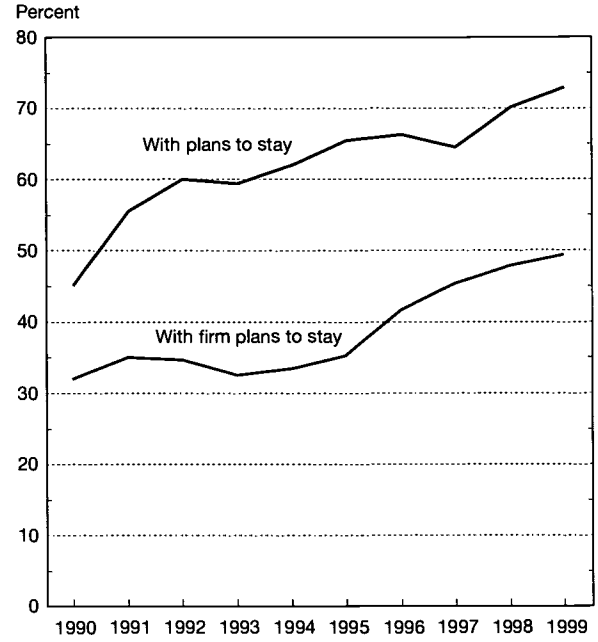
Non-Federal support comes from the student's institution of higher education, state and local government, foreign sources, nonprofit institutions, or private industry.

more than 4,000 foreign doctoral recipients had firm offers to remain in the United States at the time of degree conferral. (See figure 2-22.) These firm offers were mainly for postdoctorate appointments and industrial employment in research and development (R&D).

Foreign doctoral students' plans to stay in the United States differ by region of origin. Those from East and South Asia receive the highest number of doctoral degrees by far and constitute the highest percentage of students who plan to stay in the United States. (See text table 2-11.) Countries within regions also differ significantly. In Asia, China and India have higher-than-average firm stay rates in the United States, and South Korea and Taiwan have lower-than-average firm stay rates. In North America, Mexico has a far lower stay rate than Canada. The United Kingdom has the highest stay rate among European countries; in 1999, 79 percent planned to stay in the United States after earning their doctorate in S&E fields, and 62 percent had firm offers to do so. (See figure 2-23.)

After 1996, the number of foreign doctoral degree recipients from China, Taiwan, and India with plans to stay in the United States declined slightly, even though the proportion that planned to stay increased. Because the number of S&E doctoral degrees earned by these groups decreased after 1996, the net result was that fewer remained in the United States. (See figure 2-24.)

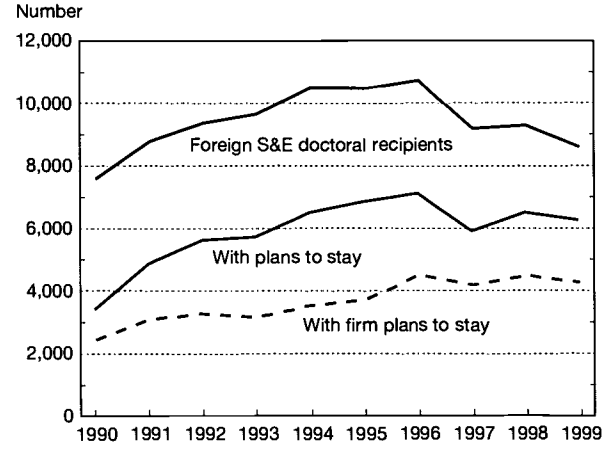
Figure 2-21.
Percentage of foreign S&E doctoral recipients with plans to stay in United States: 1990–99



NOTE: Data include foreign doctoral recipients with either permanent or temporary visas.

See appendix table 2-32. *Science & Engineering Indicators – 2002*

Figure 2-22.
Foreign S&E doctoral recipients with plans to stay in United States: 1990–99



NOTE: Foreign doctoral recipients include those with either permanent or temporary visas.

See appendix table 2-32. *Science & Engineering Indicators – 2002*

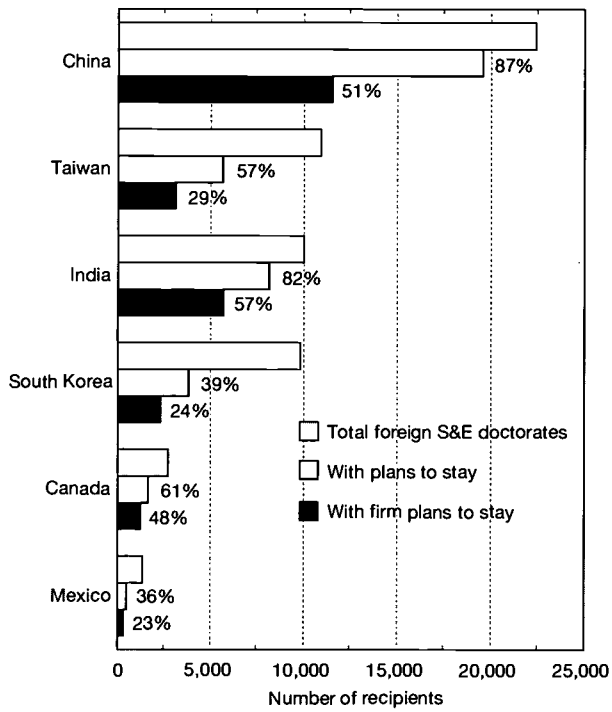
The SED data on stay rates can be used to indicate immediate reverse flow of foreign doctoral recipients. Those with no plans to stay in the United States may be planning an immediate return to their home country or to another country in the region. For example, Chinese doctoral recipients with no plans to stay in the United States may be hired by a research

Text table 2-11.
Foreign S&E doctoral recipients with plans to stay in the United States, by region: 1990–99

Region	Total	With plans to stay		With firm plans to stay	
		Number	Percent	Number	Percent
All regions	93,682	58,553	62.5	36,327	38.8
East/South Asia	57,609	39,154	68.0	23,932	41.5
West Asia	8,757	4,676	53.4	2,548	29.1
Pacifica/Australia	2,075	986	47.5	627	30.2
Africa	4,464	2,100	47.0	967	21.7
Europe	11,698	7,260	62.1	5,191	44.4
North/South America	9,079	4,377	48.2	3,062	33.7

See appendix table 2-32 for countries within each region. *Science & Engineering Indicators – 2002*

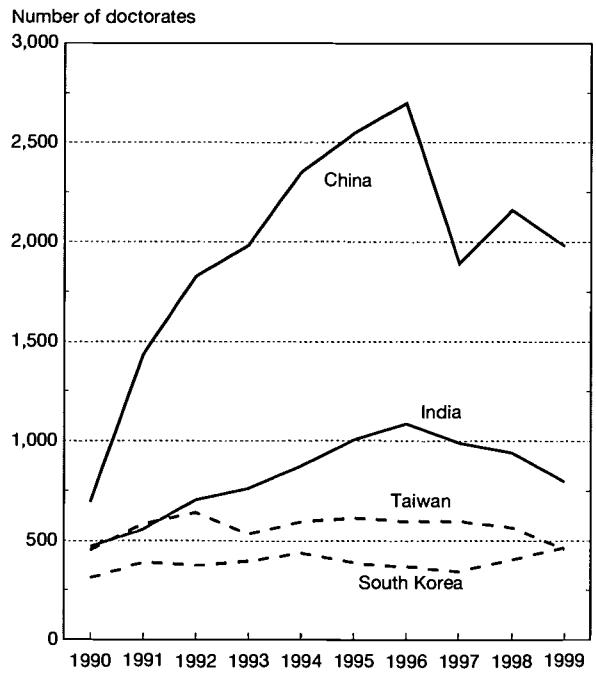
Figure 2-23.
Foreign S&E doctoral recipients with plans to stay in the United States, by place of origin: 1990–99



NOTE: Foreign doctoral recipients include those with either permanent or temporary visas.

See appendix table 2-32. *Science & Engineering Indicators – 2002*

Figure 2-24.
U.S. S&E doctoral recipients from selected Asian countries and economies with plans to stay in the United States: 1990–99



NOTE: Foreign doctoral recipients include those with either permanent or temporary visas.

See appendix table 2-32. *Science & Engineering Indicators – 2002*

institute in China or Singapore. The rate of return of S&E doctoral recipients from universities in the United States differs by country of origin. Mexico and Brazil have the highest reverse flow; India and China have the lowest. (See text table 2-12.)

Recently, the Social Science Research Council surveyed the rates of return of African Ph.D. recipients trained in U.S. and Canadian universities between 1986 and 1996. The survey found that 63 percent of these recipients were employed in their home country or a neighboring African country by 1999.[7] The factors that correlated with returning home were the home country of the degree holder, field of study, and type of funding for

[7]SED shows that 64 percent of African doctoral recipients planned to stay in the United States; however, because many were in biological sciences, they may have stayed for a postdoctorate for a few years and then returned to Africa. SSRC findings are relatively consistent with Finn's research on stay rates several years after Ph.D. attainment (Finn 1999). Finn's work shows that about 44 percent of African doctoral recipients were working in the United States several years after receiving their Ph.D.

Text table 2-12.
Foreign S&E doctoral recipients who returned home, by place of origin, selected countries and economies

Location of origin	Total recipients	Percentage who returned home
United Kingdom (1998)		
China	208	59
Malaysia	145	99
Germany	146	57
Greece	118	64
Iran	127	89
United States	80	75
Turkey	124	100
Canada	59	71
Taiwan	82	95
Ireland	61	45
United States (1999)		
China	2,187	10
India	888	10
South Korea	738	37
Taiwan	732	38
Canada	283	28
Turkey	186	41
Germany	179	35
Mexico	158	69
Brazil	156	69
United Kingdom	141	21

NOTES: U.S. data are foreign students with no plans to stay in the United States. Foreign students include those on either permanent or temporary visas.

SOURCES: Higher Education Statistics Agency, First Destination Survey of 1998 Doctoral Recipients, unpublished tabulations, 2001; and appendix table 2-32. *Science & Engineering Indicators – 2002*

graduate study. Economic opportunities, political stability, and institutional conditions for establishing a professional career correlated with high return rates. The fields of agricultural and biological sciences, which receive high funding priorities in some African countries, also correlated with high return rates (Pires, Kassimir, and Brhane 1999).

Foreign doctoral recipients in S&E who remain in the United States represent a potential "brain drain" from their country of origin, but they also have an opportunity for enhanced research experience before returning home. Reverse flow back home is increasing for countries with increasing S&E employment in higher education and research institutes. Little is known of the broader diffusion of S&E knowledge by foreign doctoral recipients who remain in the United States through activities such as cooperative research, short-term visits, and networking with scientists at home and abroad. See sidebar, "Reverse Flow."

Increasing Global Capacity in S&E

This section places data from the United States in an international context, including comparisons of bachelor's (first university) degrees, participation rates in S&E degrees, doctoral degrees, the level of foreign student enrollment, and the percentage of foreign students earning S&E doctoral degrees in major host countries. Information is provided on reforms to improve the quality of expanded doctoral programs in Europe and Asia and the stay rate and return flow of foreign doctoral recipients in a few other major host countries (the United Kingdom and France).

In regard to doctoral degrees, the proportion of S&E degrees earned outside the United States is shifting, which may eventually translate into a corresponding shift in research capacity, scientific output, and innovative capacity. See chapter 4, "U.S. and International Research and Development: Funds and Alliances," and chapter 5, "Academic Research and Development." The United States needs to devise effective forms of collaboration and information exchange to benefit from, and link to, the expanding scientific capabilities of other countries and regions. For example, increased international coauthorship may indicate that the United States is staying in touch with expanded research abroad. See "Scientific Collaboration" in chapter 5.

International Comparison of First University Degrees in S&E Fields

In 1999, more than 2.6 million students worldwide earned a first university degree in science or engineering.[8] (Note that the worldwide total includes only countries for which recent data are available, primarily the Asian, European, and American regions, and is therefore an underestimation.) Approximately 900,000 degrees were earned in fields within each of the broad categories of natural sciences, social and behavioral sciences, and engineering. (See appendix table 2-18.)

From among reporting countries, more than 1.1 million of the 2.6 million S&E degrees were earned by Asian students at Asian universities. Students across Europe (including Eastern Europe and Russia) earned almost 800,000 first university degrees in S&E fields. Students in North America earned more than 600,000 S&E bachelor's degrees. Students in Asia and Europe generally earn more first university degrees in natural science and engineering (NS&E) than in social sciences, whereas the converse is true for students in North America. (See figure 2-25.)

Trend data for bachelor's degrees show that the number earned in the United States remained stable or declined in the 1990s in all fields except psychology and biology. The number of engineering degrees earned in the United States declined from 1986 to 1991, remained nearly stable at the 1991 level for several years, and declined again in 1998. The number of computer science degrees declined from 1986 to 1990, remained essentially flat throughout the 1990s, and increased in 1998. In contrast, trend data available for selected Asian countries show strong growth in degree production in all S&E

[8]A first university degree refers to the completion of a terminal undergraduate degree program. These degrees are classified as level 5A in the International Standard Classification of Education, although individual countries use different names for the first terminal degree (for example, *laureata* in Italy, *diplome* in Germany, *maitrise* in France, and *bachelor's degree* in the United States and in Asian countries).

Reverse Flow

Systematic data are not available on the contributions that returning Ph.D.-holding scientists and engineers make to the science and technology (S&T) infrastructure of their home countries. Evidence suggests that they fill prominent positions in universities and research institutes. For example, college catalogs of universities in developing countries show the location of the doctoral education of science and engineering (S&E) faculty. Senior academic staff and directors of research centers typically receive their doctoral education from research universities in the United States, the United Kingdom, or France.* The following are four broad categories of reverse flow that contribute to the circulation of S&T knowledge. They are distinguished by location and duration. The first two categories relate to actually moving back home for permanent or temporary positions. The last two categories relate to short- and long-term activities conducted with the home country while employed abroad.

Employment Offers to Scientists and Engineers Trained Abroad

Taiwan and South Korea have been the places most able to immediately absorb Ph.D.-holding scientists and engineers trained abroad who contribute through teaching and research in universities and research parks (NSF/SRS 1998). Research and development (R&D) centers of foreign businesses in these countries also employ returning scientists and engineers, e.g., Motorola Korea Software Research Center and the South Korea International Business Machines (IBM) Tivoli Software Development Center (*The Korean-American Science and Technology News* 1998). Multinational R&D centers are also being established in China by Microsoft, Hewlett-Packard, and IBM (*China Daily* 2001a). A relatively small percentage of South Korean and Taiwanese doctoral recipients from universities in the United States plan to stay in the United States. (See appendix table 2-32.) Many of those who remain in the United States to pursue academic or industrial research experience eventually return to their home country.

In contrast, China and India can offer S&T employment to only a small fraction of their students who earn advanced degrees in S&E fields at universities in the United States. Most of these students remain in the United States, initially for postdoctoral research or for research in industry (NSF/SRS 1998). Those who do return later are usually recruited for a national research priority; for example, the recently established Brain Research Center in New Delhi hired top Indian scientists from home and abroad (American Association for the Advancement of Science 1999). The human genome center at the Chinese Academy of Science's Institute of Genetics in China attracted top young Chinese microbiologists and geneticists for 20 research groups formed in Beijing and Shanghai to sequence part of the human genome (Li 2000). More programs are being created in China to attract outstanding scientists and engineers to top faculty positions and to lead research programs in their disciplines (Guo 2001).

Besides immediate or delayed returns, reverse flow to a home country sometimes occurs after a long, distinguished scientific career abroad. Incidents of prominent scientists returning to their countries are noted in science journals. For example, Yuan T. Lee earned a doctorate in chemistry at the University of California–Berkeley, headed a top laboratory, and eventually earned a Nobel Prize for his research. Many years later, he returned home to head Taiwan's Academia Sinica, a collection of 21 research institutes (Nash 1994).

Temporary Positions for Scientists and Engineers Trained or Working Abroad

Besides various permanent positions, reverse flow can be the result of an offer for an attractive temporary S&E position or for access to high-technology parks with desirable conditions. For example, the government of Ireland's Science and Technology Agency (FORFAS) is funding basic science with five-year grants that are attempting to draw Irish scientists and engineers back to establish laboratories in Irish universities. (Previously educated in Ireland, the graduates left for employment in the United Kingdom or the United States.) Although not offered permanent positions, they would have funding to lead a research area for five years.† A different type of temporary arrangement is China and Taiwan's use of preferential status (no taxes for two to three years) for those who will try to start up a company within an industrial park (*China Daily* 2001b). Another example of a temporary position is transferring to an R&D position within a multinational firm operating in the home country or accepting a two- to three-year appointment in the home country while maintaining ties in the United States. For example, in 2001, Hong Kong University of Science and Technology hired Dr. Paul Chu of the University of

*See, for example, the international academic credentials of the S&E faculty in recent college catalog of Bilkent University, Ankara, Turkey, and Hong Kong University of Science and Technology.

†Personal communication with Rhona Dempsey, Manager, S&E Indicators, Science & Technology Division, The National Policy and Advisory Board for Enterprise, Trade, Science, Technology and Innovation (FORFAS), NSF, Arlington, VA, March 2001.

Houston as its new president for a three-year appointment, but he maintains his laboratory on High Temperature Superconductivity in Houston (Cinelli 2000).

Long-Term Collaborative Research Arrangements

Some scientists remain abroad but establish and maintain a long-term relationship with researchers in their home country through periodic visits, international conferences and workshops, short courses and workshops at their home institutions, and collaborative research. For example, Samuel Ting, Nobel laureate in physics, Professor at the Massachusetts Institute of Technology (MIT), and member of Taiwan's Academia Sinica, encourages collaboration of teams of scientists in 16 countries and Taiwan. As chairman of the Alpha Magnetic Spectrometer (AMS) research program under the Department of Energy and National Aeronautics and Space Administration, Ting established international collaboration with Taiwanese researchers to manufacture all AMS electronics (*Taipei Update* 2001). In addition, U.S. cooperative science programs with China and India funded by the National Science Foundation often provide grants to Chinese and Indian scientists in the United States collaborating with a home-country scientist.†

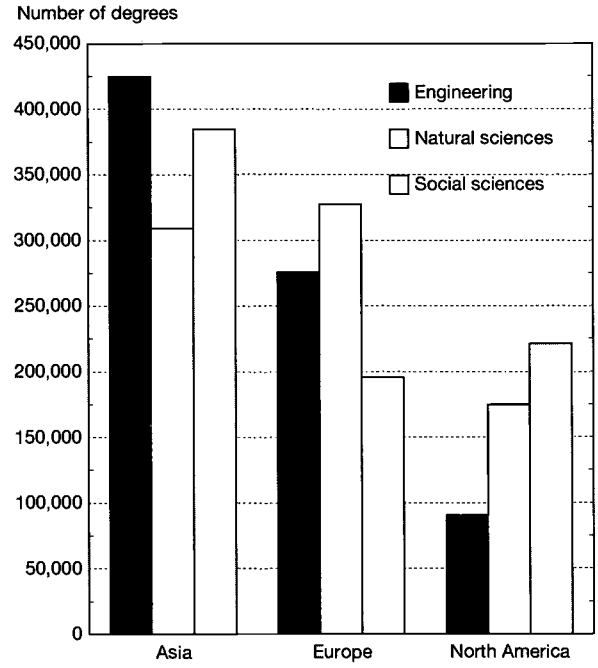
Intermittent Networking

Another mechanism for scientific information flow is networking of scientists abroad with scientists in their home country. Because of economic and political crises, several Latin American countries have lost scientists and engineers to other countries in the region or outside Latin America. Colombia was the first to attempt to link to these "lost" scientists and engineers working abroad and to reframe the concept from "brain drain" to "brain gain." In the early 1990s, the Caldas program in Colombia linked all expatriate Colombian scientists to advise on scientific and economic development schemes (Charum and Meyer 1998). Approximately 40 countries have since devised such networking schemes, and others are working to implement programs (Meyer 2001).

Some countries are able to use all types of reverse flow, absorbing their scientists and engineers in temporary or permanent positions and promoting links through international collaboration or visits.

†See abstracts of awards for grants and workshops with China and India at the NSF website: <http://www.nsf.gov>.

Figure 2-25.
First university degrees in S&E fields in selected countries, by region: 1999 or most recent year



NOTES: Natural sciences include physics, chemistry, astronomy, and earth, atmospheric, ocean, biological, and agricultural sciences, as well as mathematics and computer sciences. Social sciences include sociology, psychology, and other social sciences.

See appendix table 2-18 for countries and economies included within each region.

Science & Engineering Indicators – 2002

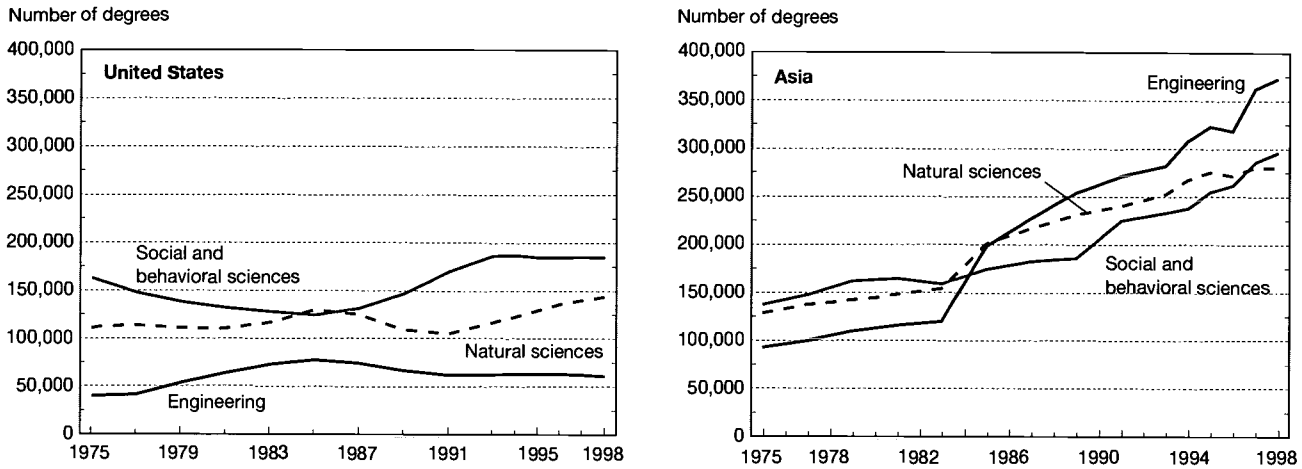
fields. At the bachelor's level, institutions of higher education in Asian countries produce approximately six times as many engineering degrees as do institutions in the United States. (See figure 2-26.) The number of degrees earned in NS&E fields in a country is reflected in the skill level of the labor force and may explain some of Asia's increased capacity in high-technology manufactures and exports. See chapter 6, "Industry, Technology, and the Global Marketplace."

For the past three decades in the United States, overall S&E degrees awarded represented about one-third of the total number of bachelor's degrees. Among some Asian countries and economies, S&E degrees represent a considerably higher proportion of total degrees. In 1999, S&E degrees represented 73 percent of total bachelor's degrees earned in China, 45 percent of total bachelor's degrees earned in South Korea, and 40 percent of total bachelor's degrees earned in Taiwan.

International Comparison of Participation Rates in University Degrees and S&E Degrees

Most countries agree with the notion that a shift to a technology-based economy brings national advantage and that the ability to do so depends on highly educated citizens. Especially important are people educated in science, mathematics, and engineering (Greenspan 2000). A high ratio of the college-age population earning university degrees correlates with better public understanding of science, and a high proportion of the college-age population earning NS&E degrees correlates with the technical skill level of those entering the workforce.

Figure 2-26.
Bachelor's S&E degrees in the United States and selected Asian countries and economies, by field: 1975–98



NOTES: Asian countries and economies include China, India, Japan, South Korea, and Taiwan. Natural sciences include physics, chemistry, astronomy, biological, and earth, atmospheric, ocean, agricultural sciences, as well as mathematics and computer sciences. Data for China are included after 1983.

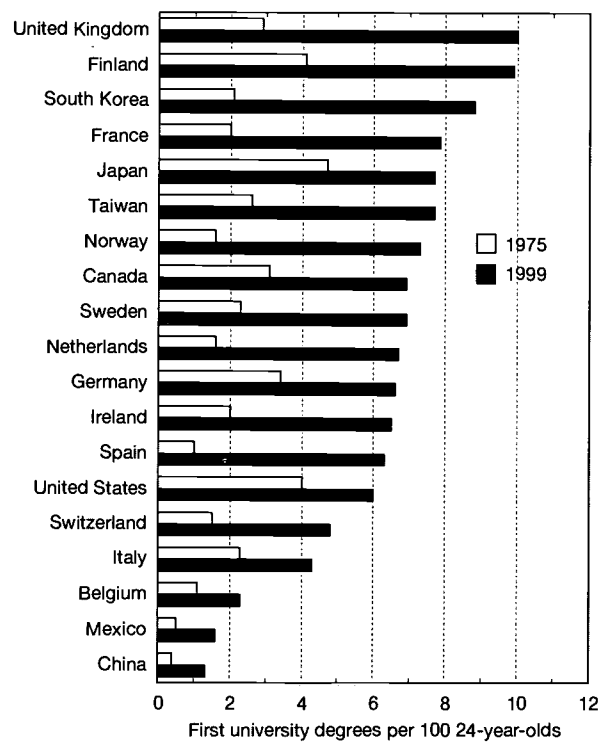
See appendix table 2-33. *Science & Engineering Indicators – 2002*

Traditionally, the United States has been a world leader in providing broad access to higher education. The ratio of bachelor's degrees earned in the United States to the college-age cohort is relatively high—35 per 100 in 1998. However, other countries have expanded their higher education systems, and the United States is now 1 of 10 countries providing a college education to approximately one-third or more of their college-age population. In more than 16 countries, the ratio of natural science and engineering (NS&E) first university degrees to the college-age population is higher than that in the United States. The ratio of these degrees to the population of 24-year-olds in the United States has been between 4 and 5 per 100 for two decades and reached 6 per 100 in 1998. South Korea and Taiwan dramatically increased ratios of NS&E first university degrees earned by 24-year-olds, from 2 per 100 in 1975 to 9 per 100 in South Korea and almost 8 per 100 in Taiwan in 1999. At the same time, several European countries have doubled and tripled the ratio of young people earning NS&E first university degrees to between 8 and 10 per 100. (See figure 2-27.)

International Comparison of Participation Rates by Sex

Among Western countries for which degree data are available by sex, the United Kingdom, Canada, and the United States show relatively high participation rates for both men and women in first university degrees. Among these countries, women in the United Kingdom have the highest participation rate in first university degrees. In 1999, the ratio of women-earned first university degrees to the female 24-year-old population was 41 per 100, slightly higher than the ratio in the United States and Canada (38–40 per 100). Women in the United Kingdom and Canada also show high participa-

Figure 2-27.
Ratio of natural science or engineering first university degrees to 24-year-old population, by country or economy



NOTES: Natural sciences include physics, chemistry, astronomy, and earth, atmospheric, ocean, biological, agricultural, as well as mathematics and computer sciences. The ratio is the number of natural science and engineering degrees to the 24-year-old population. China's data are for 1985 and 1999. Other countries' data are for 1975 and 1998 or 1999.

See appendix table 2-18. *Science & Engineering Indicators – 2002*

tion rates of NS&E bachelor's degrees earned. In 1999, the ratio of NS&E first university degrees earned by women in the United Kingdom to the female 24-year-old population was 7.5 per 100, still far less than the rate for U.K. men. Participation rates for men and women in Canada are more similar. (See text table 2-13 and appendix table 2-34.)

In Asian countries, women earn first university degrees at a rate similar to or higher than those in many European countries. However, only in South Korea do women have high participation rates in first university NS&E degrees. In 1998, the ratio of women-earned degrees in these fields to the female 24-year-old population was 4.9 per 100, higher than the participation rate of women in other Asian countries, Germany, or the United States. (See text table 2-13.) Among all reporting countries, women earned the highest proportion of their S&E degrees in natural and social sciences. (See appendix table 2-34.)

International Comparison of Foreign Student Enrollment in S&E Programs

Despite a decline in foreign graduate student enrollment in the United States from 1994 through 1996, the current flow of foreign S&E students to the United States and other industrialized countries is increasing. Some of the factors that have fostered this flow to advanced countries are an increasing focus on academic research and declining college-age populations. See "Demographics and Higher Education." The policies of the European Union (EU) to foster comparable degrees and transferable credits augment the inter-European mobility of students and faculty (Koenig 2001b). The group of traditional host countries for many foreign students (United States, France, and United Kingdom) is expanding to include Japan, Germany, Canada, and Australia. This section compares foreign student enrollment in S&E programs in some of these countries.

The United Kingdom has traditionally educated numerous foreign students, many of whom have come from Britain's former colonies in Asia and North America (particularly India, Malaysia, and Canada). In the 1990s, the proportion of foreign students studying S&E fields in the United Kingdom increased at both the graduate and undergraduate levels. From 1995 to 1999, foreign undergraduate students in S&E increased from 8.8 to 11.6 percent. Engineering received a higher concentration of foreign students as undergraduate enrollment in engineering in U.K. universities declined from 113,000 in 1995 to 100,000 in 1999. At the same time, the enrollment of foreign students in engineering rose from 16,000 in 1995 to 21,000 in 1999, representing 21 percent of all undergraduate engineering students in U.K. universities in 1999, up from 14 percent in 1995. (See text table 2-14 and appendix table 2-35.)

During the same period, U.K. universities also increased enrollment of foreign students within their graduate S&E departments. Foreign S&E graduate student enrollment rose from 28,848 in 1995 to 36,631 in 1999, an increase of 27 percent. Concurrently, U.K. universities increased the percentage of foreign S&E students at the graduate level from 28.9 to 31.5 percent. Percentages of foreign students differ by field. In 1999, foreign student graduate enrollment reached 37.6 percent in engineering and 40 percent in social and behavioral sciences. (See figure 2-28 and appendix table 2-35.)

European countries are receiving more students from within EU countries. By 1999, at U.K. universities, the number of foreign graduate students from other EU countries was three times higher than the number of foreign students from Britain's former colonies (Malaysia, Hong Kong, and India). (See text table 2-15 and appendix table 2-35.) Graduate students from EU countries represent approximately 7 percent of the graduate students in sciences in U.K. universities and approximately 11 percent of the graduate engineering students. Chinese students, who represent about one-third of foreign S&E graduate students at universities in the United States, make up only 4 percent of S&E graduate students at U.K. universities. (See appendix tables 2-21 and 2-35.) Students from Greece have traditionally attended other European universities and universities in the United States for graduate education. After Greece, however, German students account for the second highest number of foreign graduate students at U.K. universities.

Text table 2-13.
Ratio of NS&E degrees to 24-year-old population, by country and sex: 1998–99

Country	Female	Male
Japan	2.3	12.8
United Kingdom	7.5	12.5
South Korea	4.9	12.4
Canada	5.7	7.9
Germany	4.3	7.7
United States	4.6	7.5
Mexico	0.9	2.4

NS&E = natural science and engineering

NOTES: Natural sciences include physics, chemistry, astronomy, and earth, atmospheric, ocean, biological, agricultural, as well as mathematics and computer sciences. The ratio is the number of NS&E degrees to the 24-year-old population.

See appendix table 2-34.

Science & Engineering Indicators – 2002

Text table 2-14.
Enrollment of foreign students in undergraduate engineering, selected countries: 1998–99

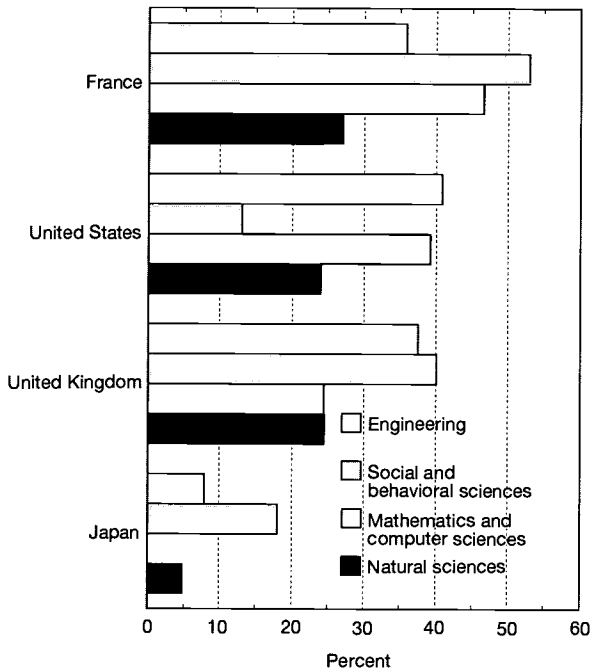
Country	Total engineering enrollment	Foreign enrollment	Percent foreign
United Kingdom	99,900	20,811	20.8
United States	366,991	21,110	5.8
Japan	471,310	3,322	0.7

NOTE: U.S. data are 1998; U.K. and Japan data are 1999.

SOURCES: American Association of Engineering Societies, Engineering Workforce Commission, *Engineering and Technology Enrollment, Fall 1999* (Washington DC, 2000) and appendix tables 2–35 and 2–37.

Science & Engineering Indicators – 2002

Figure 2-28.
Foreign graduate student enrollment in selected countries, by field: 1999



NOTES: French data include foreign doctoral students only; Japanese data include mathematics in natural sciences and computer sciences in engineering. Natural sciences include physics, chemistry, astronomy, and earth, atmospheric, ocean, biological, and agricultural sciences.

See appendix tables 2-20, 2-35, 2-36, 2-37, and 2-38.

Science & Engineering Indicators – 2002

Text table 2-15.
Foreign graduate students in S&E fields in U.K. universities, by region of origin: 1999

Region	Number
Total	36,000
Europe	15,000
Asia	10,000
Africa	3,000
Middle East	3,000
North America	3,000
South America	1,000
Central America	600

SOURCE: Higher Education Statistics Agency, unpublished tabulations (2001).

Science & Engineering Indicators – 2002

Foreign students also are attracted to France for graduate programs in S&E. French universities have a long tradition of educating foreign students and have a broad base of countries of origin of foreign doctoral students (more than 150), primarily developing countries in Africa, Latin America, and Asia. Approximately 15 percent of the foreign students in French doctoral programs come from neighboring European countries. In 1998, most of the 17,000 foreign doctoral students who entered French universities enrolled in S&E fields. (See appendix table 2-36.) Foreign students enrolled in S&E doctoral programs represent about 26 percent of S&E doctoral enrollment, somewhat smaller than the proportion of foreign students in U.S. graduate enrollment. (See figure 2-28.)

Japan and Germany also are attempting to bolster their enrollment of foreign students in S&E. Japan's goal of 100,000 foreign students, promulgated in the 1980s, has never been met but is once again being discussed as a serious target. In 1999, 55,000 foreign students enrolled in Japanese universities, mainly at the undergraduate level (34,000) and concentrated in social sciences (13,000) and engineering (3,000). In that year, about 22,000 foreign students enrolled in graduate programs in Japan, mainly from China and South Korea, representing 10 percent of the graduate students in S&E fields. (See appendix table 2-37.) Germany is also recruiting foreign students from India and China to fill its research universities, particularly in engineering and computer sciences (Grote 2000; Koenig 2001a).

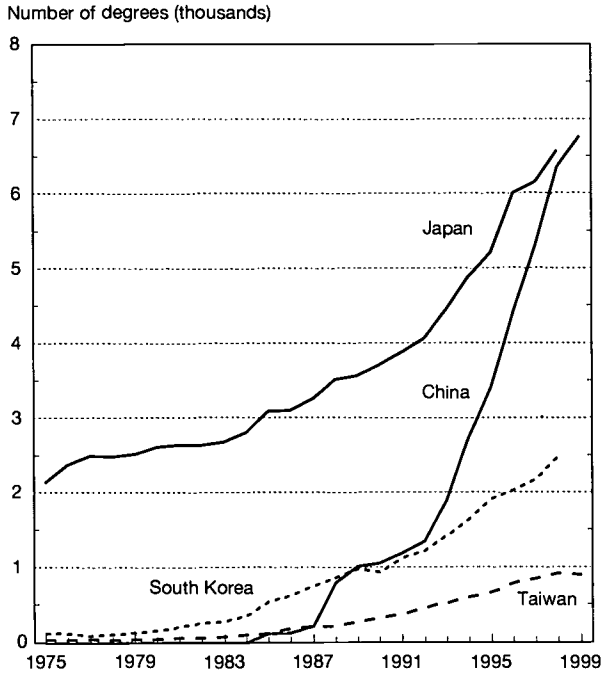
International Comparison of Doctoral Degrees in S&E Fields

The development of increasing institutional capacity to provide advanced S&E education through the highest levels is indicated in trend data for earned doctorates in selected countries of Europe and Asia. Japan has doubled its S&E doctoral degree production within the past decade. Developing Asian countries, starting from a very low base in the 1970s and 1980s, have increased their S&E doctoral education by several orders of magnitude. China, Japan, South Korea, and Taiwan have established new institutions for graduate education in S&E and expanded their S&E graduate programs in existing national universities. China now has the largest capacity for S&E doctoral degree production in the Asian region (see figure 2-29) and ranks fifth in the world. In Europe, France, Germany, and the United Kingdom have almost doubled their S&E doctoral degree production in the past two decades, with slight declines in 1998. (See figure 2-30.) All of these countries are engaged in reforms to improve the quality of doctoral research programs. See sidebar, "International Efforts in Doctoral Reform."

The growing capacity of some developing Asian countries and economies (China, South Korea, and Taiwan) for advanced S&E education decreases the proportion of doctoral degrees earned by their citizens in the United States. (See figure 2-31.) For example, in the past five years, Chinese and South Korean students earned more S&E doctoral degrees in their respective countries than in the United States. Taiwanese students have also become less dependent on the United States for advanced training; in 1999, for the first time, they earned more S&E doctoral degrees at Taiwanese universities than at universities in the United States.

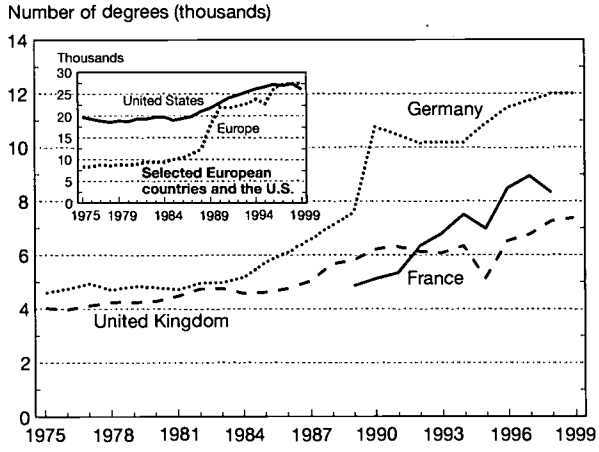
In 1999, Europe produced far more S&E doctoral degrees (54,000) than the United States (26,000) or Asia (21,000). Considering broad fields of science, most of the doctorates earned in natural sciences, social sciences, and engineering are earned at European universities. The United States awards

Figure 2-29.
Doctoral S&E degrees earned in selected Asian countries and economies: 1975–99



See appendix table 2-39. *Science & Engineering Indicators – 2002*

Figure 2-30.
Doctoral S&E degrees in selected industrialized countries: 1975–99



NOTES: The peak in the data from Germany in 1990 reflects the inclusion of degrees from former East Germany. The inset combines the three European countries.

See appendix table 2-40. *Science & Engineering Indicators – 2002*

more doctoral degrees in natural and social sciences than Asian countries. (See figure 2-32.)

Trend data for NS&E doctoral degrees (excluding social sciences) show that Asian universities educated more students at the doctoral level in these fields than universities in the United States in the late 1990s. (See figure 2-33.) In 1999, Asian universities awarded more engineering doctoral degrees but fewer natural science degrees than universities in the United States. (See appendix tables 2-39 and 2-40.)

Considering the proportion of S&E doctoral degrees by sex, women in Europe and the United States earn a higher proportion of such degrees than women in Asia. Women in France and the United States earned more than a third of S&E doctoral degrees in their respective countries in 1999. Women in Japan, Taiwan, and South Korea earned about 10 percent of such degrees. (See appendix table 2-43.)

International Comparison of Foreign Doctoral Recipients

Like the United States, the United Kingdom and France have a large percentage of foreign students in their S&E doctoral programs. In 1999, Germany was the top country of origin of foreign S&E doctoral degree recipients in the United Kingdom, China was the top country earning S&E doctoral degrees in the United States, and Algeria was the top country of origin of foreign students studying for S&E doctoral degrees in France. (See appendix tables 2-32, 2-36, and 2-44.) In 1999, foreign students earned 44 percent of the doctoral engineering degrees awarded by U.K. universities, 30 percent of those awarded by French universities, and 49 percent of those awarded by universities in the United States. In that same year, foreign students earned more than 31 percent of the doctoral degrees awarded in mathematics/computer sciences in France, 38 percent of those awarded in the United Kingdom, and 47 percent of those awarded in the United States. (See figure 2-34.) In addition, Japan and Germany have a modest but growing percentage of foreign students among their S&E doctoral degree recipients. (See appendix table 2-45.)

International Comparison of Stay Rates

Data similar to the data on "plans to stay" in the annual SED are available on the first destination of foreign doctoral students in the United Kingdom and France after earning their degree. Data from the U.K. Higher Education Statistics Agency show that, in 1998, most foreign S&E doctoral degree recipients at U.K. universities returned home after earning their degree. In fact, among the 10 top countries of origin, all doctoral recipients from Malaysia and Turkey returned to their home country. Ireland is the only exception, with 45 percent of doctoral recipients returning to Ireland as their first destination after receiving their degree. (See text table 2-12.)

Doctoral survey data from the French Ministry of Education, Research, and Technology show that the return rate for foreign S&E doctoral recipients is lower in France than in the United Kingdom. Data are not available on the return rates of French foreign doctoral recipients by countries of origin, but return rates are available by S&E field of study. In 1998, the overall return rate of foreign doctoral recipients from France to their countries of origin was 28 percent in natural sciences and 20 percent in engineering fields. (See text table 2-16.)

International Efforts in Doctoral Reform

Doctoral reforms in European and Asian countries are strengthening the university sector to become an explicit component of national innovation systems. The goals are to develop the capacity for breakthrough research leading to innovative products and successful markets, to stem "brain drain," and to attract top scientists to the country (NSF/INT 2000). Doctoral reforms also include providing national universities with more autonomy in hiring faculty and governance of academic programs and providing additional funds. International networks of universities share curriculum development and distance education.

Asian countries are using various mechanisms to improve the quality of doctoral programs and to upgrade equipment and facilities for academic research. World-class facilities often require international partnerships (Bagla 2000). For example, the Indian Institute of Technology (IIT) in Delhi is partnering with the International Business Machine research center on its campus for graduate research opportunities and exchange of faculty. In China, Shanghai's Fudan University and Bell Labs have a joint laboratory for software development and information technology (IT) (*China Daily* 2001b). In addition, research parks throughout Asia are concentrating high-technology industries next to top universities to attempt to create a "Silicon Valley." For example, Beijing's research park includes Peking University, the Chinese Academy of Sciences, and 4,000 high-technology enterprises (*China Daily* 2001a).

European countries are experimenting with doctoral reforms that prepare students not only to increase the store of basic science but also to apply knowledge to innovative technologies and find solutions to the problems confronted by society (Carlson 2001). Doctoral reform in France brings university research programs closer with the network of national laboratories (CNRS). For example, the CNRS Laboratory of Material Physics and two university labs are forming a Materials Center to be part of a large research complex outside Rouen (Carlson 1999).

Doctoral reforms in Europe also include international partnerships to create centers of excellence, some through the EU and some trans-Atlantic centers. The centers of excellence are designed both to improve the quality of research and to stem brain drain to other countries. For example, the University of Cambridge in Cambridge, England, and the Massachusetts Institute of Technology (MIT) in Cambridge, Massachusetts, are collaborating on the Cambridge-MIT Technology Institute. These two leading research universities will develop common courses and exchange faculty and students (Tugend 1999). A second MIT partnership, the MIT MediaLabEurope in Dublin, will build on Ireland's strength in computer sciences to become a center of excellence in IT for Europe (Birchard 2001).

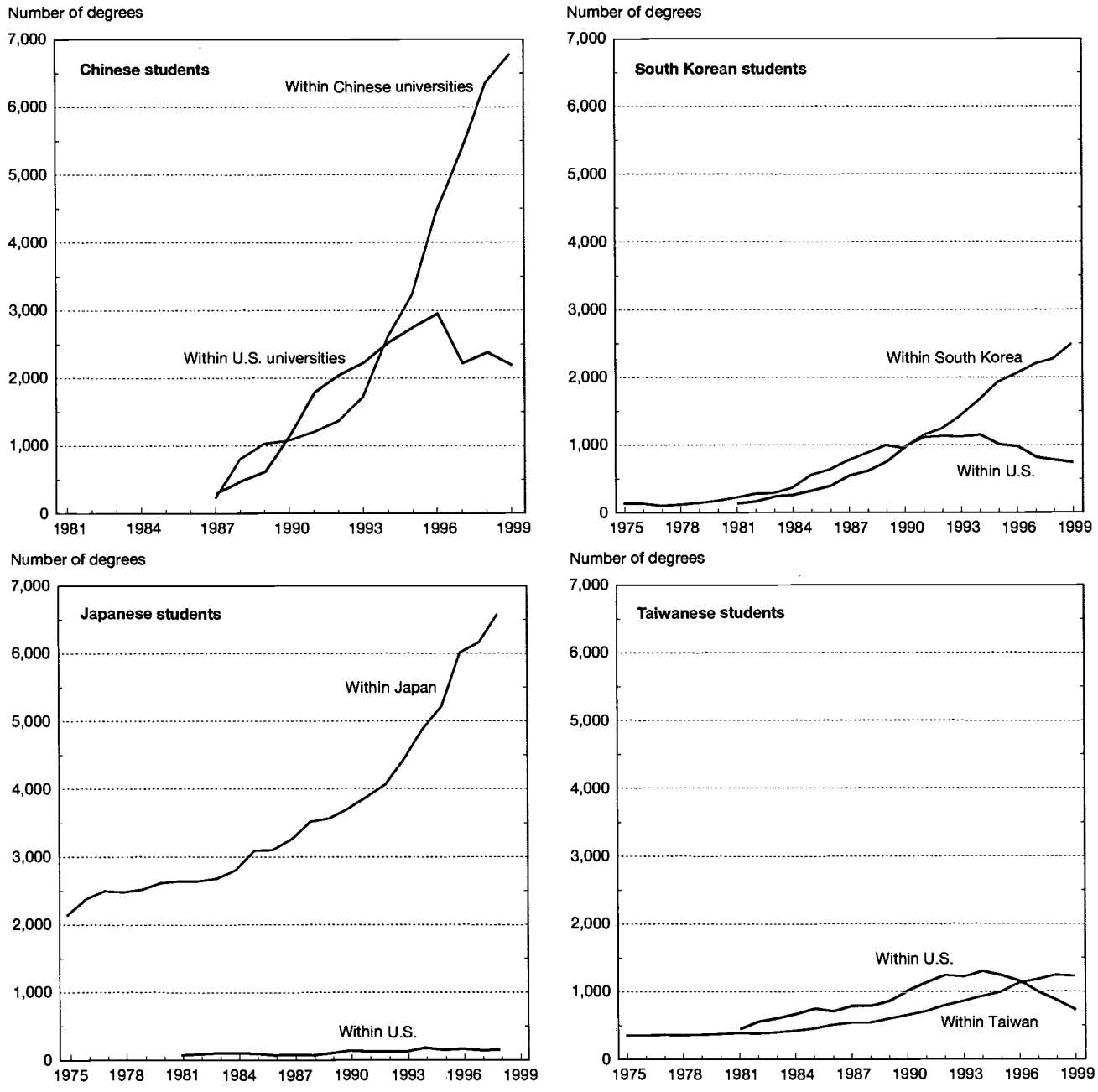
Countries and other places are using various funding sources, either public or private, to upgrade equipment and facilities. For example, Taiwan is publicly funding infrastructure improvements, as are industrialized countries such as Japan and those within the European Union. The U.K. government has recently committed large funds to improve deteriorating facilities and to raise stipends for doctoral students (Stone 2000; Urquhart 2000). China has used international funding sources to improve higher education (Hayhoe 1989) and is assisting the top universities in becoming financially independent through their partnerships with high-technology industries (China Daily 2001b). Hong Kong and South Korea have built science and technology (S&T) universities with business donations. The philanthropy of Indian scientists and engineers in the United States with successful companies is upgrading the IIT's facilities and creating new S&T universities in India (Goel 2000; Bagla 2000).

Conclusion

Students in the United States are as interested in studying some fields of science as they were in the past, but the declining level of interest in engineering and physical sciences still raises national concern. From 1975 to 1998, approximately one-third of all bachelor's degrees were earned in S&E fields. However, the distribution among natural sciences, social sciences, and engineering has changed. The approximately 12 percent of degrees earned in natural sciences are not as evenly distributed across physical and biological sciences as in previous decades. The number of degrees earned in biological sciences continues to increase, whereas the number earned in other natural sciences is dropping off. Engineering degrees, which represented 8 percent of all bachelor's degrees awarded in 1986, slowly dropped to 5 percent of all bachelor's degrees awarded in 1998. In addition, other countries award a higher percentage of bachelor's degrees in S&E fields; among European and Asian countries, the average is about 40 percent and it is considerably higher for some emerging Asian countries.

The United States has programs to increase access to S&E education for groups that were formerly underrepresented in S&E fields. Because these groups represent the growing segment of the population in the United States, an adequate future workforce will require that minorities choose careers in S&E. To date, modest progress has been made toward increasing the proportion of these minority college-age populations earning NS&E degrees. In 1998, among whites, the ratio of

Figure 2-31.
Doctoral S&E degrees earned by Asian students at home universities and U.S. universities: 1981–99



NOTES: Chinese degree data not available for earlier years. U.S. data include foreign doctoral recipients on either permanent or temporary visas.

See appendix tables 2-39 and 2-41.

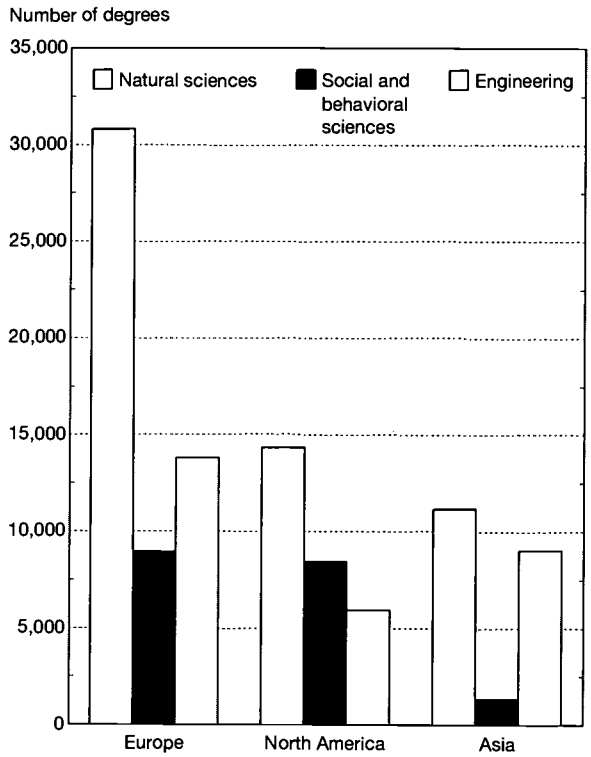
Science & Engineering Indicators – 2002

NS&E degrees to the college-age population was 6 per 100. Among underrepresented minorities, the ratio was less than half that of whites.

Further research is needed to quantify the increasing access to S&E education outside traditional higher education institutions. That is, what is the effect of nondegree programs in engineering and IT completed in the workplace through distance education and certificates?

This chapter discussed indicators of expanding access to S&E education in several world regions and modest expansion of access to minority groups within the United States. Many countries have significantly increased the proportion of their college-age population earning first university degrees in NS&E fields. In addition, they have expanded their institutional capacity for S&E graduate programs and doctoral education. This expansion indicates a share-shift in the proportion of S&E doc-

Figure 2-32.
Doctoral S&E degrees in Europe, North America, and Asia: 1999

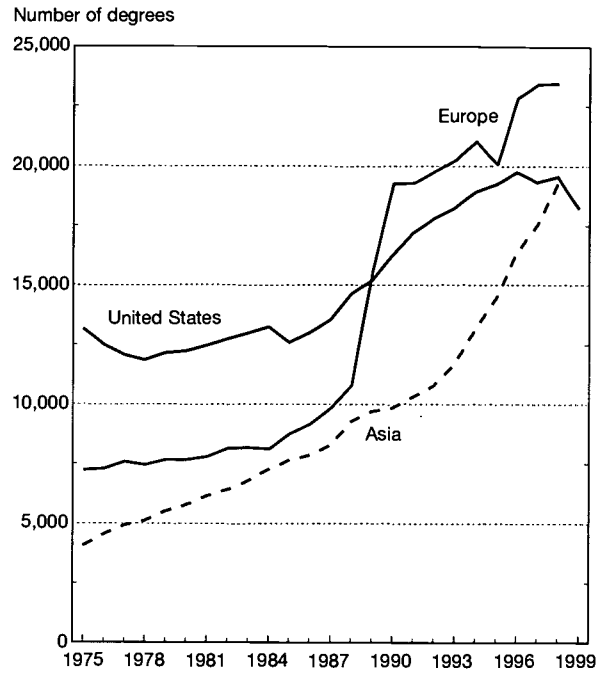


NOTE: Natural sciences include physics, chemistry, astronomy, and biological, agricultural, earth, atmospheric and ocean sciences, as well as mathematics and computer sciences.

See appendix table 2-42 for countries and economies included in Europe, North America, and Asia.

Science & Engineering Indicators – 2002

Figure 2-33.
Doctoral NS&E degrees in the United States, Europe, and Asia: 1975–99



NOTES: Natural sciences include physics, chemistry, astronomy, and biological, agricultural, earth, atmospheric and ocean sciences, as well as mathematics and computer sciences. Europe includes France, Germany, and the United Kingdom. Asia includes China, India, Japan, South Korea, and Taiwan.

See appendix tables 2-39, 2-40, and 2-24.

Science & Engineering Indicators – 2002

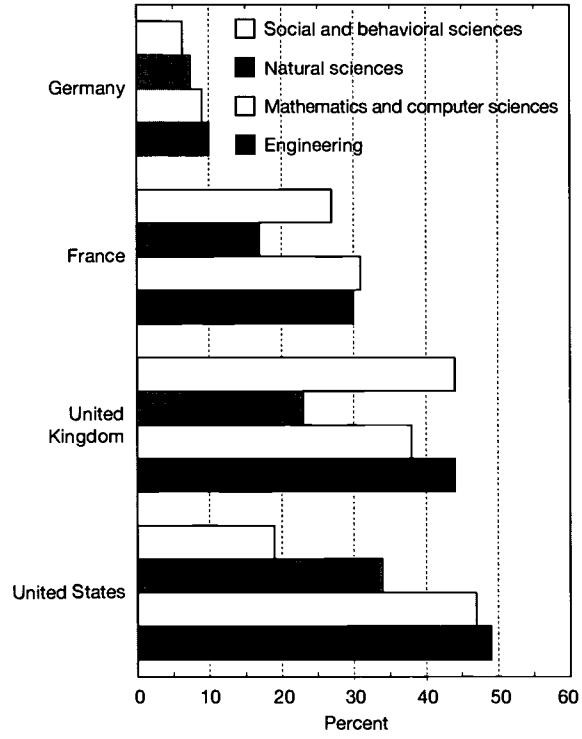
toral degrees earned outside the industrialized countries. The challenge to the scientific leadership of the United States and to corporate R&D[9] from this share-shift is to devise effective forms of collaboration and information exchange to benefit from, and link to, the expanding proportion of science performed abroad. Measures of collaboration in international coauthorship of scientific articles may be an important indicator for monitoring the globalization of science. For example, the degree to which international coauthorship increases or decreases could indicate how the United States is staying in touch with expanded research abroad.

Several advanced industrial countries are also expanding recruitment of foreign S&E graduate students to maintain and strengthen their academic R&D efforts, considered to be of increasing importance to innovation (Porter and Stern 1999). Little evidence suggests that other countries are competing with graduate schools in the United States in the recruitment of foreign S&E students. The number of foreign graduate students is increasing in universities in the United States and in several other countries. Small shifts in graduate students in Asia entering Japanese or Australian universities may occur because of proximity and active recruitment by those countries. There are also small downward shifts in the number of foreign graduate students to universities in the United States from some traditional feeder countries and economies that have expanded their graduate programs, such as South Korea and Taiwan.

Because mobility of people is the main mechanism for technology transfer, the flow of foreign students abroad and reverse flow of students back to their home countries provide an opportunity for S&T development. Whether S&E education abroad eventually contributes to the home country depends on its S&T policy and commitment to employing highly skilled professionals. China and many other developing countries have shown that they need not be able to offer employment to their scientists and engineers educated abroad to receive their scientific advice on development schemes or research directions (Meyer 2001). Research is needed on the appropriate mix of foreign S&E doctoral recipients who "stay abroad" and "return home" for mutual benefit to the host and sending countries. The beneficial mix of immediate and delayed returns and the variety of cooperative activities associated with reverse flow are likely to differ for individual countries, regions, and stages of development.

[9]See, for example, John E. Pepper, Chairman of the Board, The Procter & Gamble Company, "National Benefits from Global R&D," Industrial Research Institute Annual Meeting. Williamsburg, VA, May 26, 1999.

Figure 2-34.
Doctoral S&E degrees earned by foreign students in selected countries, by field: 1999



NOTES: U.S. data include those on permanent and temporary visas. Natural sciences include physics, chemistry, astronomy, and earth, atmospheric, ocean, biological, and agricultural sciences.

See appendix table 2-45. *Science & Engineering Indicators – 2002*

Text table 2-16.
Foreign S&E doctoral recipients in France who returned home, by field: 1998

Field	Total recipients	Percentage who returned
Natural sciences	672	28
Mathematics and computer sciences	262	17
Agriculture	37	5
Social sciences	262	44
Engineering	551	20

NOTE: Natural sciences include physics, chemistry, astronomy, and biological, agricultural, earth, atmospheric, and ocean sciences.

SOURCE: Government of France, Ministère de l'Éducation Nationale, de la Recherche, et de la Technologie, *Rapport sur les Études Doctorales* (Paris, 2000).

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Chapter 3
Science and Engineering Workforce

Highlights

- **The U.S. workforce in 1999 included 11 million college-educated individuals with either science and engineering (S&E) degrees or S&E occupations.** The vast majority (10.5 million) held at least one college degree in a science or engineering field. About 31 percent (3.3 million) of the 10.5 million S&E degree-holders in the workforce were also employed in S&E occupations. Regardless of occupation, more than three-quarters of those whose highest degree was in S&E said their work was related to their degree.
- **Since 1980, nonacademic S&E jobs grew at more than four times the rate of the U.S. labor force as a whole.** Nonacademic S&E jobs increased by 159 percent between 1980 and 2000—an average annual growth rate of 4.9 percent compared with 1.1 percent for the entire labor force.
- **The total number of retirements among S&E-degreed workers will increase dramatically over the next 20 years, barring large changes in retirement rates.** More than half of S&E-degreed workers are age 40 or older, and the 40–44 age group is nearly four times as large as the 60–64 age group.
- **Despite increasing retirements, the S&E labor force is likely to increase for some time, albeit at a slower rate.** The rate of S&E-degreed workers reaching retirement ages will remain less than the rate of S&E degree production for many years.
- **Labor market conditions for those with S&E degrees improved during the 1990s.** Holders of S&E bachelor's degrees had lower unemployment rates and were significantly more likely to be doing work related to their degree in 1999 compared with 1993.
- **Labor market conditions for new Ph.D. recipients have been good by most conventional measures.** S&E doctorate-holders are both employed and doing work relevant to their training. Employment gains have come in the nonacademic sectors. In most fields, a small percentage of recent Ph.D. recipients are obtaining tenure-track positions.
- **In April 1999, 27.0 percent of doctorate-holders in S&E in the U.S. labor force were foreign born.** The lowest percentage of foreign-born doctorate-holders was in psychology (7.6 percent), and the highest was in civil engineering (51.5 percent). About one-fifth (19.9 percent) of those with master's degrees in S&E and about one-tenth (9.9 percent) of those with bachelor's degrees in S&E were foreign born. The largest percentages of these degrees were in electrical engineering (18.3 percent), civil engineering (16.1 percent), and computer sciences (15.2 percent).
- **High-skill temporary-visa migration is becoming an important factor in many economies.** In 1999, 240,936 workers entered Japan in high-skill visa categories—a 75 percent increase since 1992. Germany has recently introduced a high-skill temporary visa program.
- **The Bureau of Labor Statistics forecasts faster growth in S&E occupations than in any others.** From 2000 to 2010, S&E occupations are projected to increase by 47 percent compared with 15 percent for all occupations. Although a projected 82 percent increase in computer-related S&E occupations will almost certainly dominate this expansion, most major S&E occupational groups are projected to show above-average growth.

Introduction

Chapter Overview

Within the U.S. civilian workforce, a group generically referred to as "scientists and engineers" consists of people educated in science (including life, physical, social, computer, and mathematical sciences) and engineering (S&E) and people who, although not educated in these fields, hold S&E occupations. This varied workforce includes technicians and technologists, researchers, educators, and managers of the S&E enterprise. Although these workers make up only a small fraction (less than 5 percent) of the total U.S. civilian workforce, their effect on society belies their number—scientists and engineers contribute enormously to technological innovation and economic growth, scientific and engineering research, and a greater understanding of S&E.

Chapter Organization

This chapter first presents a profile of the U.S. S&E workforce, including workforce size and various employment characteristics. Information on the sex and racial or ethnic composition of the S&E workforce is provided, followed by a description of labor market conditions for recent bachelor's, master's, and doctoral S&E degree recipients. Discussions on the effects of age and retirement on the S&E workforce and the projected demand for S&E workers over 2000–10 are presented. The chapter concludes by examining the global S&E workforce and the migration of scientists and engineers to the United States.

Profile of the U.S. S&E Workforce

Data in this section are from the National Science Foundation's (NSF's) Scientists and Engineers Statistical Data System (SESTAT), which is a unified database containing information on the employment, education, and demographic characteristics of scientists and engineers in the United States.[1]

How Large Is the U.S. S&E Workforce?

Estimates of the size of the U.S. S&E workforce vary based on the criteria used to define a scientist or engineer. See sidebar, "Who Is a Scientist or Engineer?" Education, occupation, field of degree, and field of employment are all factors that may be considered.[2] For example, should any employee with an S&E education be considered a member of the S&E workforce, or should only someone employed in an S&E occupation be considered? In 1999, more than 13 million people in the United States either had an S&E education or were working as scientists or engineers. (See appendix table 3-2.) The number of college-degreed individuals in S&E fields in 1999 exceeded the number of individuals working in S&E occupations because many S&E degree-holders were not working in S&E fields. Also, many individuals who held S&E occupations were educated in fields not considered science or engineering.

Basic Characteristics

Including those either trained or working as scientists or engineers, approximately 13 million[3] scientists and engineers were residing in the United States as of April 1999. However, only 84 percent (nearly 11 million) of these individuals were in the workforce. (See text table 3-1.) The remaining individuals were either unemployed but seeking work (193,200) or not in the workforce (1.86 million).

Of the nearly 11 million individuals trained or working as scientists and engineers in the United States in 1999, the vast majority (almost 10.5 million) had at least one college degree in an S&E field. About 30 percent (3.3 million) of the almost 10.5 million S&E degree-holders in the workforce were also employed in S&E occupations. The remaining one-half million individuals had college degrees in non-S&E fields but were currently or had been previously employed in S&E occupations. See sidebar, "Growth of the S&E Workforce."

What Do People Do With an S&E Education?

Many U.S. scientists and engineers have multiple S&E degrees or have degrees in both S&E and non-S&E fields. Many S&E-educated workers also routinely find S&E-related employment in occupations not included within traditional S&E classifications. In 1999, of the 10.5 million S&E degree-holders in the workforce, about three-fourths (almost 8 million) reported that their highest degrees were in S&E fields. (See text table 3-1.) However, many of these individuals (approximately 5 million) were not employed principally in a science or engineering occupation.

Although the majority of S&E degree-holders do not work in S&E occupations, their S&E training does not necessarily go to waste. Of the 5 million S&E degree-holders perform-

[1]SESTAT data are collected from three component surveys sponsored by NSF (*National Survey of College Graduates, National Survey of Recent College Graduates,* and *Survey of Doctorate Recipients*) and conducted periodically throughout each decade. SESTAT's target population is U.S. residents who hold bachelor's degrees or higher (in either an S&E or a non-S&E field) who, as of the study's reference period, were noninstitutionalized, not older than age 75, and either trained or working as a scientist or engineer (e.g., either had at least one bachelor's degree or higher in an S&E field or had a bachelor's degree or higher in a non-S&E field and worked in an S&E occupation during the reference week. For the 1999 SESTAT, the reference period was the week of April 15, 1999.

[2]For a detailed discussion of the S&E degree fields and occupations in SESTAT, see NSF 1999a. A list of S&E occupations and fields is contained in appendix table 3-1. In general, S&E occupations and fields in this report include those in the field of social sciences and exclude medical practitioners and technicians (including computer programmers). Thus, a physician with an M.D. will not be considered to be "S&E" either by occupation or by highest degree, but he is likely (but not certainly) to be included in statistics that incorporate those with S&E degrees based on their field of bachelor's degree.

[3]This number includes all those who received a bachelor's degree or higher in an S&E field plus those holding a non-S&E bachelor's degree or higher who were employed in an S&E occupation during either the 1993, 1995, 1997, or 1999 SESTAT surveys.

Who Is a Scientist or Engineer?

The terms "scientist" and "engineer" have many definitions—none of which are perfect. For a more thorough discussion of these complexities, see *SESTAT and NIOEM: Two Federal Databases Provide Complementary Information on the Science and Technology Labor Force* (NSF 1999e) and "Counting the S&E Workforce—It's Not That Easy" (NSF 1999b). Multiple definitions are used for analytic purposes in this report, and even more are used in reports elsewhere. Three main definitions used in this report are as follows:

- **Occupation.** The most common way to count scientists and engineers in the workforce is to include those having an occupational classification that matches some list of science and engineering (S&E) occupations. Although considerable questions can arise regarding how well individual write-ins or employer classifications are coded, the occupation classification comes closest to defining the work a person performs. An engineer, by occupation, may or may not have an engineering degree, but correct classification will show that worker as doing engineering work. One limitation of classifying by occupation is that it will not capture individuals using S&E knowledge, sometimes extensively, under occupational titles such as manager, salesman, or writer.* It is common for a person with a science or engineering degree in such occupations to report that his or her work is closely related to his degree and, in many cases, also report research and development (R&D) as a major work activity.
- **Highest degree.** Another way to classify scientists and engineers is to focus on the field of their highest (or most recent) degree. For example, classifying as "chemist" a person who has a bachelor's degree in chemistry but works as a technical writer for a professional chemists' society magazine—may be appropriate. Using this "highest degree earned" classification does not solve all problems, however. For example, should a person with a bachelor's degree in biology and a master's degree in engineering be included among biologists or engineers? Should a person with a bachelor's degree in political science be counted among social scientists if he also has a law degree? Classifying by highest degree earned in situations similar to the above examples may be appropriate, but one may be uncomfortable excluding an individual who has a bachelor's degree in engineering and also a master's degree in business administration from an S&E workforce analysis.
- **Anyone with an S&E degree or occupation.** Another approach is to classify by both occupation and education. National Science Foundation sample surveys of scientists and engineers attempt to include those residing in the United States who have either a science or an engineering degree or occupation.†

*In most collections of occupation data, a generic classification of postsecondary teacher fails to properly classify many university professors who would otherwise be included by most definitions of the S&E workforce. Scientists and Engineers Statistical Data System (SESTAT) data mostly avoids this problem.

†Individuals who lacked a U.S. S&E degree but who earned an S&E degree from another country are included in 1999 SESTAT data to the extent they were in the United States in 1990, 1993, 1995, 1997, and 1999, as were those who had at least a bachelor's degree in some field and who were working in an S&E occupation in 1993, 1995, 1997, and 1999.

ing non-S&E jobs in 1999, 67.3 percent indicated that they were employed in a field at least somewhat related to the field of their highest S&E degrees.[4] (See text table 3-2.) Almost 80 percent of those whose highest earned degrees were in mathematics or computer sciences and who were employed in non-S&E jobs were working in fields related to their degrees compared with 63 percent of those whose highest earned degrees were in social and physical sciences.

Of all employed individuals whose highest degrees were in S&E, 76.8 percent said their jobs were related to the fields of their highest degrees, and 45.7 percent said their jobs were closely related to their fields.[5] (See appendix tables 3-8 and 3-9.) The relatedness of a field of study to an individual's job varies in ways that are mostly predictable by level, years since earning, and field of degree.

In the one- to four-year period after receiving their degrees, 73 percent of S&E doctorate-holders say that they have jobs closely related to the degrees they received compared with 67.4 percent of master's recipients and 42 percent of bachelor's recipients. (See figure 3-2.) This relative ordering of relatedness by level of degree holds across all periods of years since the recipients received their degrees. However, at every degree level, jobs held by degree recipients generally are less closely related to the field of degree earned.[6] There may be good reasons for this: individuals may change their career interests over time, gain skills in different areas while working, take on general management responsibilities, and forget some of their original college training—or some of

[4]Refers to highest degree received.

[5]Although these self-assessments by survey respondents are highly subjective, they may capture associations between training and scientific expertise not evident through occupational classifications. For example, an individual with an engineering degree but an occupational title of salesman may still use or develop technology.

[6]Ph.D.-holders of more than 25 years are an exception; the percentage of those holding jobs closely related to their degrees increases. This disparity may reflect differences in retirement rates.

Text table 3-1.
Employed scientists and engineers, by S&E employment status and field of highest degree: 1999

Employee characteristic	Employment status Total	S&E	Non-S&E
Total employed	10,981,600	3,540,800	7,440,800
No S&E degree	501,800	282,000	219,800
S&E degree	10,479,800	3,258,800	7,221,000
S&E is highest degree	7,980,000	3,003,200	4,976,800
Computer sciences and mathematics	1,045,800	537,200	508,600
Life and related sciences	1,287,700	361,700	926,000
Physical and related sciences	621,700	343,000	278,700
Social and related sciences	3,088,400	458,000	2,630,400
Engineering	1,936,400	1,303,300	633,100
Non-S&E is highest degree	2,499,800	255,600	2,244,200

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

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Scientists and Engineers Statistical Data System (SESTAT), 1999.

Science & Engineering Indicators – 2002

their original college training may become obsolete. Given these possibilities, the career-cycle decline in the relevance of an S&E degree is modest.

When comparing 1993 data with 1999 data (see figure 3-3), each year demonstrates the same general pattern. However, given the better labor market conditions in 1999, a somewhat higher proportion of midcareer (10–24 years since receiving degree) S&E bachelor's degree-recipients and doctorate-holders said in 1999 that their jobs were closely related to their degrees. At the bachelor's degree level, an additional 11.5 percent of those who had received their degrees 15–19 years prior were in jobs closely related to their field of study. For Ph.D. recipients, the improvement was much smaller (4.7 percent) for those 20–24 years after receiving their degrees.

Differences in the percentages of those who said their jobs were closely related to their fields of degree are shown in figure 3-4 by level of degree and in figure 3-5 by major S&E disciplines for bachelor's recipients. Although mathematics and computer sciences are often combined into a single group, they are shown separately here because of their very different patterns. From one to four years after receiving their degrees, the percentage of S&E bachelor's degree-recipients who said their jobs were closely related to fields of degree earned ranged greatly—from 30.0 percent for those whose degree was in social sciences to 74.3 percent for those whose degree was in computer sciences. Between these extremes, most other S&E fields show similar percentages for recent graduates: 54.1 percent for physical sciences, 51.8 percent for mathematics, 54.9 percent for engineering, and 44.2 percent for life sciences.

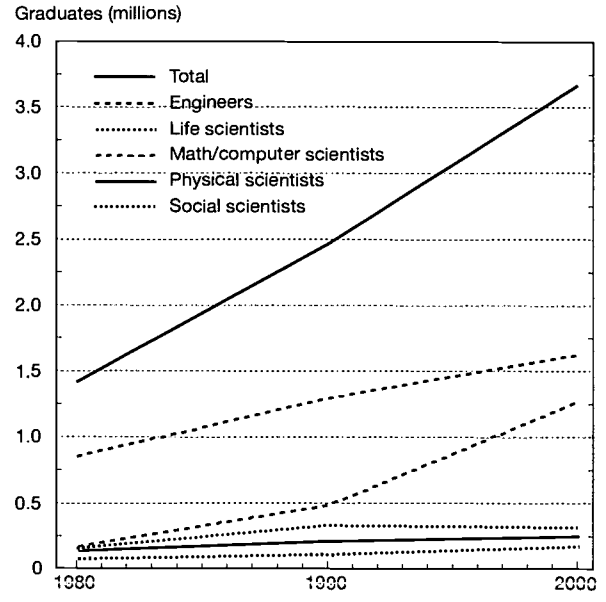
Growth of the S&E Workforce

Although Scientists and Engineers Statistical Data System data for the 1990s demonstrate limitations of using only occupation to measure the scope of the science and engineering (S&E) workforce, we depend on occupation classifications to examine S&E growth over extended time periods. By looking only at college graduates working in narrowly defined S&E occupations (excluding technicians and computer programmers) and employed outside academia,* S&E jobs increased by 159 percent between 1980 and 2000, totaling 3,664,000 nonacademic S&E occupations in 2000. (See figure 3-1.) This represents a 4.9 percent average annual growth rate, much more than the 1.1 percent average annual growth rate of the entire labor force.

Although every broad S&E occupational group grew between 1980 and 2000 (the lowest growth, 81 percent, occurred in physical sciences), the most explosive growth was in mathematics and computer sciences, which experienced a 623 percent increase (177,000 jobs in 1980 to 1,280,000 jobs in 2000).

*Another difficulty when using occupation to identify scientists and engineers in most data sources other than NSF/SRS's SESTAT is that many in academia are identified simply as "college professor" or by similar titles that do not indicate specialty. For that reason, the time trend examined here is only for those outside academic employment.

Figure 3-1.
College graduates in nonacademic S&E occupations



SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), tabulation of 1980 and 1990 U.S. Decennial Census Public Use Microdata Sample, March 2000 Current Population Survey.

Science & Engineering Indicators – 2002

Text table 3-2.
People with S&E degrees who are employed in non-S&E occupations, by highest degree and relation of degree to job: 1999

Highest degree	Total in non-S&E occupations	Highest degree related to job (percent)		
		Closely	Somewhat	Not
Total[a]	4,976,900	33.2	34.1	32.7
Bachelor's ...	4,092,800	29.9	34.7	35.5
Master's	724,800	48.7	31.2	20.1
Doctorate	155,200	46.0	35.6	18.5

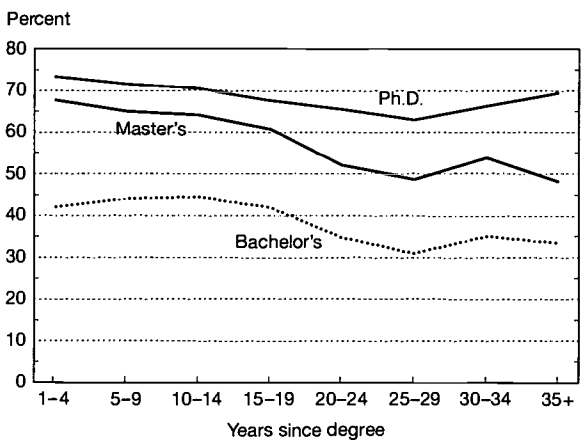
[a]Includes professional degrees.

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

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Scientists and Engineers Statistical Data System (SESTAT), 1999.

Science & Engineering Indicators – 2002

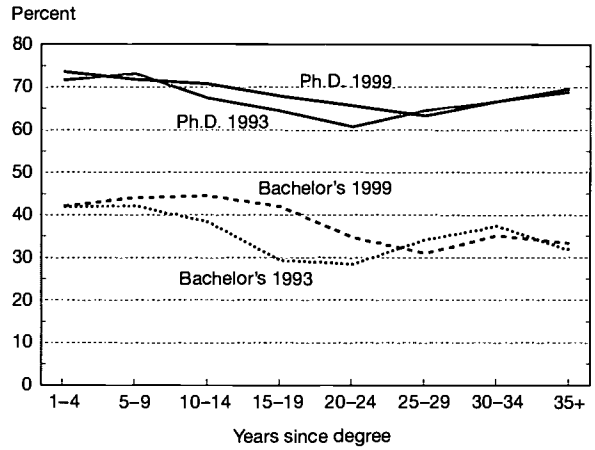
Figure 3-2.
Employed S&E degree-holders in jobs closely related to highest degree: 1999



SOURCE: National Science Foundation/Division of Science Resources Statistics (NSF/SRS), Scientists and Engineers Statistical Data System (SESTAT), 1999.

Science & Engineering Indicators – 2002

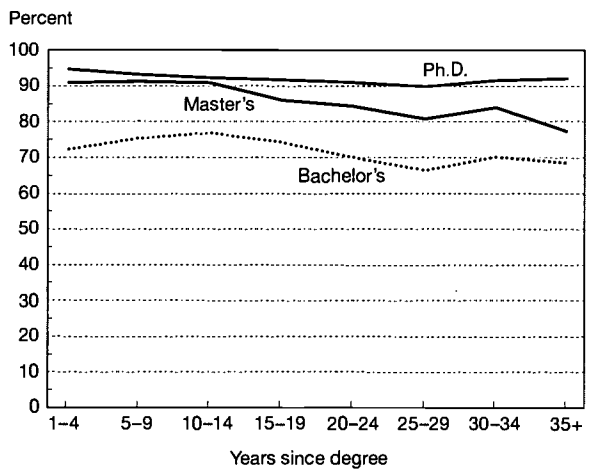
Figure 3-3.
Employed S&E degree-holders, in job closely related to highest degree, by years since degree: 1993 and 1999



SOURCE: National Science Foundation/Division of Science Resources Statistics (NSF/SRS), Scientists and Engineers Statistical Data System (SESTAT),1993 and 1999.

Science & Engineering Indicators – 2002

Figure 3-4.
Employed S&E degree-holders in jobs related to highest degree: 1999



SOURCE: National Science Foundation/Division of Science Resources Statistics (NSF/SRS), Scientists and Engineers Statistical Data System (SESTAT), 1999.

Science & Engineering Indicators – 2002

Employment in Non-S&E Occupations

Slightly more than one-half of the 5 million S&E degree-holders working outside S&E in 1999 held management or administrative occupations (28 percent), sales and marketing jobs (15 percent), or non-S&E-related teaching positions (9 percent). (See text table 3-3.) Almost 89 percent of non-S&E teachers said that their work was at least somewhat related to their S&E degrees compared with 73 percent of managers or administrators and almost 51 percent of those employed in sales and marketing jobs.

Almost 82 percent of the 5 million S&E degree-holders not working in S&E occupations in 1999 reported their highest degree to be a bachelor's degree; 15 percent listed a master's degree, and 3 percent listed a doctorate. Approximately two-thirds of those with a bachelor's degree reported their jobs to be closely related to their highest degree field compared with four-fifths of doctoral and master's S&E degree recipients.

Employment in S&E Occupations

Of the 8 million scientists and engineers in the workforce in 1999 whose highest degree earned was in an S&E field, slightly more than one-third (3 million) were principally em-

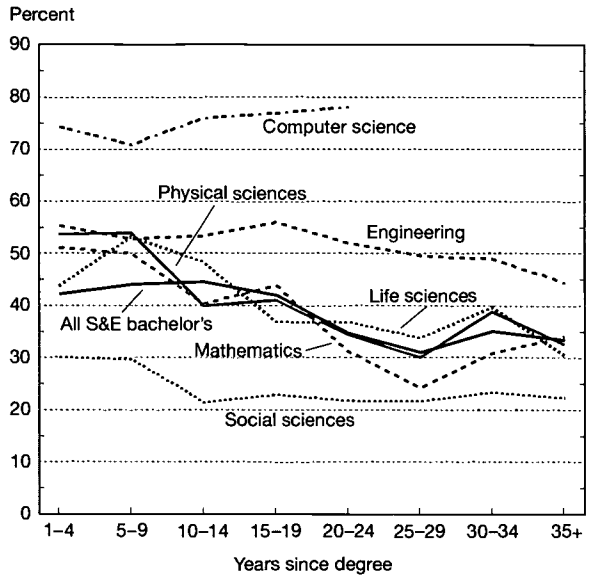
ployed in S&E jobs. Additionally, 256,000 people trained in S&E whose highest degree was in a non-S&E field were employed in S&E occupations. Also, 282,000 college-educated individuals were employed in S&E occupations yet held no degrees in an S&E field.

Altogether, approximately 3.5 million individuals held S&E occupations in 1999. (See appendix table 3-10.) Engineers represented 39 percent (1.37 million) of the S&E positions, and computer scientists and mathematicians represented 33 percent (1.17 million). Physical scientists accounted for less than 9 percent of those working in S&E occupations in 1999.

By subfield, electrical engineers made up about one-fourth (362,000) of all those employed as engineers, whereas biologists accounted for about three-fifths (206,000) of employment in life sciences. In physical and social science occupations, chemists (122,000) and psychologists (197,000) were the largest occupational subfields, respectively.

Almost 56 percent of those employed in S&E jobs reported their highest degree earned to be a bachelor's degree, whereas 29 percent listed a master's degree and 14 percent listed a doctorate. About 1 percent reported other professional degrees to be their highest degree earned. Almost one-half of bachelor's degree-recipients were engineers; slightly more than one-third were computer scientists and mathematicians. (See text table 3-4.) These occupations were also the most popular among those with master's degrees (approximately 37 and 34 percent, respectively). Most doctorate-holders were employed as social scientists (26 percent), life scientists (25 percent), and physical scientists (18 percent).

Figure 3-5.
Employed S&E bachelor's degree-holders in job closely related to degree: 1999



SOURCE: National Science Foundation/Division of Science Resources Statistics (NSF/SRS), Scientists and Engineers Statistical Data System (SESTAT). 1999.

Science & Engineering Indicators – 2002

Unemployment

Of the approximately 3.6 million individuals with S&E occupations in the labor force in 1999, only 1.6 percent (56,000) were unemployed.[7] (See text table 3-5.) This compares with 4.4 percent for the 1999 U.S. labor force as a whole and 1.9 percent for all professional specialty workers. Unemployment for those with S&E occupations has dropped steadily since 1993, when it stood at 2.6 percent. The highest unemployment rate in 1999 was for physical scientists (1.9 percent), and the lowest rate was for computer scientists and

[7] The unemployment rate is the ratio of those who are unemployed and seeking employment to the total labor force (i.e., those who are employed plus those who are unemployed and seeking employment). Those who are not in the labor force (those who are unemployed and not seeking employment) are excluded from the denominator.

Text table 3-3.
People with S&E as highest degree who are employed in non-S&E occupations, by occupation and relation of degree to job: 1999

Occupation	Number	Highest degree related to job (percent)		
		Closely	Somewhat	Not
Total non-S&E occupations	4,976,900	33.2	34.1	32.7
Managers and administrators	1,416,000	30.0	43.0	27.0
Health related	322,200	58.1	27.1	14.7
Non-S&E teachers	452,400	65.8	22.7	11.5
Non-S&E postsecondary teachers	50,000	68.1	23.7	8.2
Social services	291,500	61.2	28.7	10.0
Technologists and technicians	337,600	46.6	34.1	19.3
Sales and marketing	764,400	13.3	37.5	49.2
Arts and humanities	122,500	21.7	38.1	40.2
Other	1,220,400	20.0	29.2	50.8

NOTE: Details may not add to total because of rounding.

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Scientists and Engineers Statistical Data System (SESTAT), 1999.

Science & Engineering Indicators – 2002

Text table 3-4.
Distribution of individuals in S&E occupations, by level of highest degree: 1999
(Percentages)

Occupation	All degrees	Bachelor's	Master's	Doctorate	Professional
Total	100.0	100.0	100.0	100.0	100.0
Computer scientists and mathematicians	33.0	37.1	34.3	13.9	18.8
Life and related scientists	9.7	6.8	7.0	25.0	42.2
Physical and related scientists	8.4	7.0	7.1	17.5	1.4
Social and related scientists	10.3	3.6	15.1	26.2	30.4
Engineers	38.7	45.5	36.5	17.4	7.2

NOTE: Percentages may not add to 100 because of rounding.

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Scientists and Engineers Statistical Data System (SESTAT), 1999.

Science & Engineering Indicators – 2002

Text table 3-5.
Unemployment rates for individuals in S&E occupations: 1993 and 1999
(Percentages)

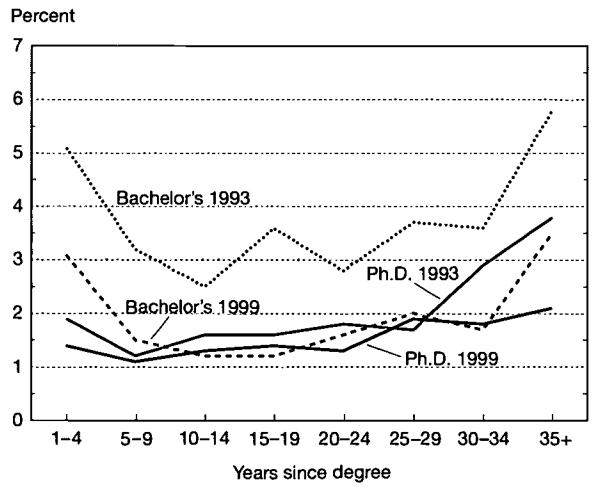
Occupation	1993	1999
All S&E occupations	2.6	1.6
Computer scientists and mathematicians	1.9	1.2
Life and related scientists	1.7	1.3
Physical and related scientists	2.8	1.9
Social and related scientists	1.6	1.4
Engineers	3.4	1.8

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Scientists and Engineers Statistical Data System (SESTAT), 1993 and 1999.

See appendix tables 3-10 and 3-11.

Science & Engineering Indicators – 2002

Figure 3-6.
Unemployment rates for S&E degree-holders by years since highest degree: 1993 and 1999



SOURCE: National Science Foundation/Division of Science Resources Statistics (NSF/SRS), Scientists and Engineers Statistical Data System (SESTAT),1993 and 1999.

Science & Engineering Indicators – 2002

mathematicians (1.2 percent). By degree level, 1.6 percent of the scientists and engineers whose highest degree earned was a bachelor's degree were unemployed compared with 1.6 percent of those with a master's degree and 1.2 percent of those with a doctorate.

Unemployment rates during S&E degree-holders' careers are shown in figure 3-6 and indicate 1993 and 1999 rates for bachelor's and doctorate degree-holders. The generally stronger 1999 labor market had its greatest effect on bachelor's degree-recipients: among them, unemployment dropped by about 2 percentage points between 1993 and 1999 for all career levels. Although labor market conditions affect Ph.D. unemployment rates much less, significant reductions in unemployment rates between 1993 and 1999 occurred for Ph.D.-holders at both the beginning and end of their careers.

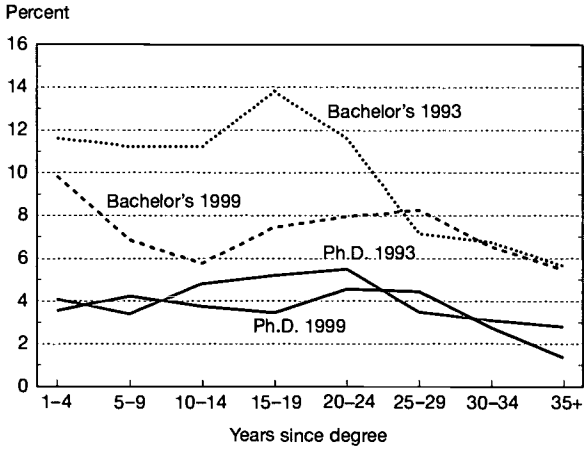
Similarly, labor market conditions from 1993 to 1999 had a greater effect on the portion of bachelor's degree-recipients who said they were working involuntarily outside their field of highest degree (involuntarily out of field, or IOF) than for Ph.D.-holders. (See figure 3-7.) However, the greatest differences in IOF rates for bachelor's degree-recipients occurs not at the beginning and end of one's career, but in midcareer. For Ph.D.-holders, few differences in IOF rates were noted between 1993 and 1999, and little change was noted during their careers.[8]

Sector of Employment

The private, for-profit sector is by far the largest provider of S&E employment. In 1999, approximately 74 percent of scientists and engineers with bachelor's degrees and 62 percent of those with master's degrees were employed in private, for-profit companies. (See appendix table 3-12.) The academic sector was the largest sector of employment for those with doctorates (48 percent). Sectors employing fewer S&E workers included educational institutions other than four-year colleges and universities, nonprofit organizations, and state or local government agencies.

[8] The decline in IOF rates for the oldest doctorate-holders may reflect in part lower retirement rates for those still working in their fields.

Figure 3-7.
Involuntarily out-of-field rates of S&E degree-holders, by years since highest degree: 1993 and 1999



SOURCE: National Science Foundation/Division of Science Resources Statistics (NSF/SRS), Scientists and Engineers Statistical Data System (SESTAT), 1993 and 1999.

Science & Engineering Indicators – 2002

For S&E occupations, the percentages of scientists and engineers employed in private, for-profit industry varied greatly. Although slightly more than three-fourths of both computer scientists and mathematicians and engineers (76 and 78 percent, respectively) were employed in this sector, only about one-fourth (27 percent) of life scientists and one-fifth (19 percent) of social scientists were so employed in 1999. Educational institutions employed the largest percentages of life scientists (48 percent) and social scientists (45 percent). See sidebar, "Educational Distribution of S&E Workers."

Who Performs R&D?

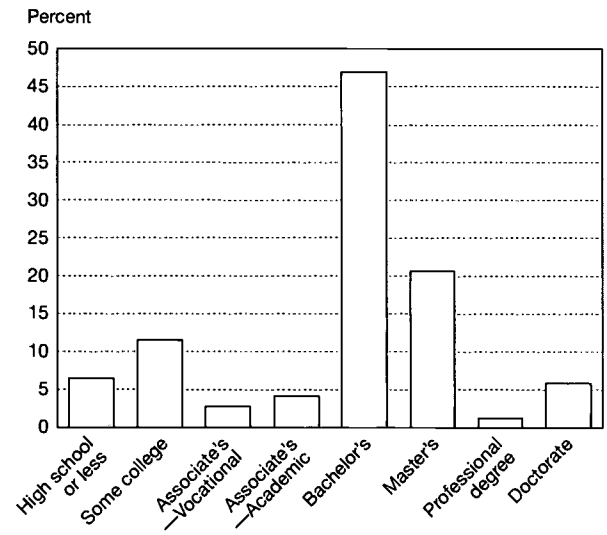
Although S&E-educated individuals use their acquired knowledge in various ways (e.g., teaching, writing, evaluating, and testing), they show a special interest in research and development (R&D). Figure 3-9 shows the distribution of individuals with S&E degrees by level of degree who report R&D as a major work activity. Those with doctorates make up only 5.6 percent of total S&E degrees achieved but represent 14.4 percent of those reporting R&D as a major work activity. Despite this, the majority of S&E degree-holders who report R&D as a major work activity have only bachelor's degrees (55.4 percent). An additional 27.4 percent have master's degrees, and 2.8 percent have professional degrees (mostly in medicine). Figure 3-10 shows the distribution of individuals with S&E degrees by field of highest degree who reported R&D as a major work activity. Those with engineering degrees constitute almost one-third (31.7 percent) of the total. Notably, 17.9 percent did not earn their highest degrees in S&E fields. In most cases, a person in this group has an S&E bachelor's degree and a higher degree in a professional field, such as business, medicine, or law.

Educational Distribution of S&E Workers

In 2000, more than two-thirds of those in nonacademic science and engineering (S&E) occupations had bachelor's degrees (47.0 percent) or master's degrees (20.7 percent). Discussions of the S&E workforce often focus on employees who hold doctorates. However, using United States Current Population Survey data to look at the educational achievement of those in S&E occupations outside academia in 2000, only 5.9 percent had doctorates. (See figure 3-8.)

In contrast, one-fourth of those in S&E occupations had not earned a bachelor's degree. Although technical issues of occupational classification may account for the size of the nonbaccalaureate S&E workforce, it is also true that many individuals who have not earned a bachelor's degree do enter the labor force with marketable technical skills. These skills come from technical or vocational school training (with or without earned associate degrees), college courses, and on-the-job training. In information technology (IT) (and to some extent in other occupations), employers are more frequently using certification exams to judge skills without reference to formal degrees.

Figure 3-8.
Educational distribution of those in nonacademic S&E occupations: 2000

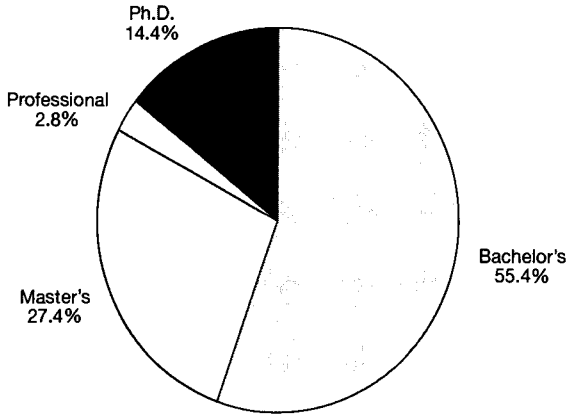


SOURCE: U.S. Department of Commerce/Bureau of the Census, Current Population Survey, March 2000

Science & Engineering Indicators – 2002

The percentages of S&E Ph.D.-holders reporting R&D as a major work activity are shown by field of degree and by years since receipt of Ph.D. in figure 3-11. The highest R&D rates over the career cycle are found in physical sciences and engineering; the lowest R&D rates are in social sciences. Al-

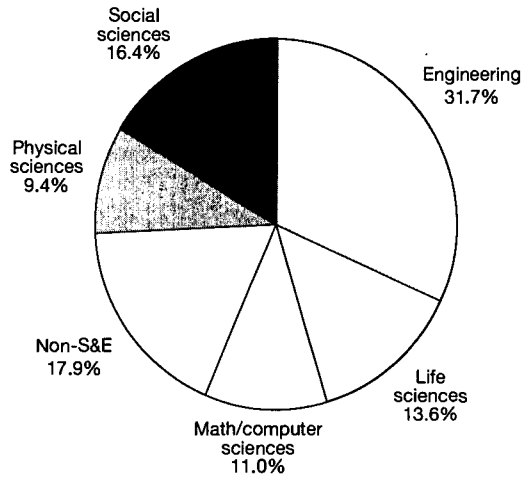
Figure 3-9.
Distribution of S&E R&D workers, by level of degree: 1999



SOURCE: National Science Foundation/Division of Science Resources Statistics (NSF/SRS), Scientists and Engineers Statistical Data System (SESTAT), 1999.

Science & Engineering Indicators – 2002

Figure 3-10.
Distribution of S&E R&D workers by field of highest degree: 1999

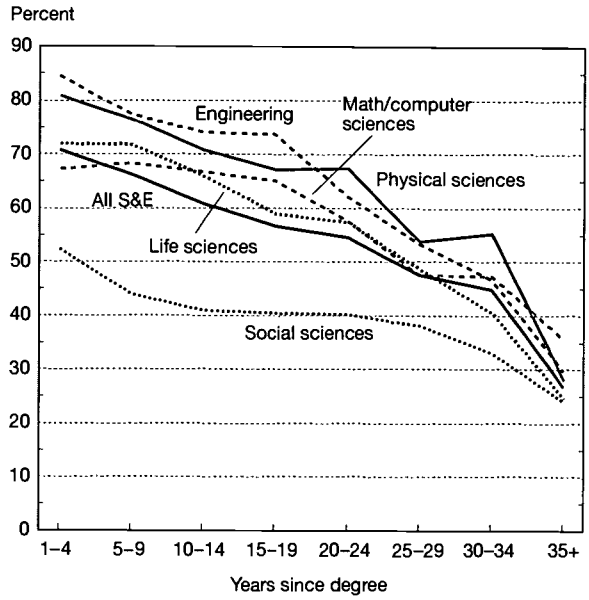


SOURCE: NSF/SRS 1999 Scientists and Engineers Statistical Data System file.

Science & Engineering Indicators – 2002

though the percentage of Ph.D.-holders engaged in R&D declines as years since receipt of degree increase, it remains greater than 50 percent in all fields except social sciences through 25 years since receipt of degree. The decline may reflect a normal career process of movement into management or other career interests.

Figure 3-11.
S&E Ph.D.-holders engaged in R&D as major work activity: 1999



SOURCE: National Science Foundation/Division of Science Resources Statistics (NSF/SRS), Scientists and Engineers Statistical Data System (SESTAT), 1999.

Science & Engineering Indicators – 2002

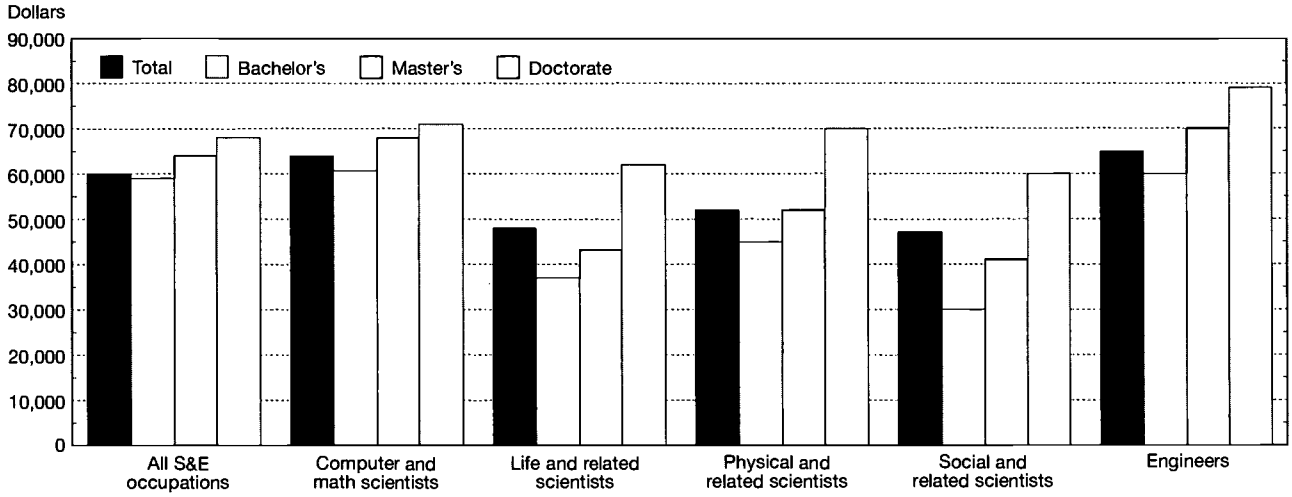
Salaries

In 1999, the median annual salary of employed bachelor's degree-recipients was $59,000; for master's recipients, it was $64,000; and for doctorate-holders, it was $68,000. (See figure 3-12 and appendix table 3-22.) Engineers commanded the highest salaries at the master's and doctorate levels, whereas computer scientists and mathematicians earned the highest salaries at the bachelor's level. The second highest salaries were earned by engineers at the bachelor's level, by computer scientists and mathematicians at the master's level, and by physical scientists at the doctorate level. The lowest median salaries reported were for social scientists at each degree level.

From 1993 to 1999, median salaries for those employed in S&E occupations rose about 25 percent. (See text table 3-6.) Computer scientists and mathematicians experienced the largest salary growth (37 percent), followed by engineers (30 percent). By degree level, median salaries for bachelor's degree-recipients rose by 31 percent, followed by master's degree-recipients (28 percent).

Median salaries for S&E job-holders also rise steadily as years pass from completion of the degree. For example, individuals who earned their bachelor's or doctoral degrees 5–9 years ago earned about $14,000 less in 1999 than those who received their degrees 15–19 years ago. For master's degree-recipients, the difference is $9,000. (See appendix table 3-26.)

Figure 3-12.
Median annual salaries of employed scientists and engineers by broad occupation and highest degree: 1999



See appendix table 3-22.

Science & Engineering Indicators – 2002

Text table 3-6.
Median annual salaries of individuals in S&E occupations, by highest degree attained: 1993–99
(Dollars)

Highest degree	1993	1995	1997	1999
Total S&E	48,000	50,000	55,000	60,000
Bachelor's	45,000	48,000	52,000	59,000
Master's	50,000	53,500	59,000	64,000
Doctorate	54,800	58,000	62,000	68,000

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Scientists and Engineers Statistical Data System (SESTAT), 1993 and 1999.

See appendix tables 3-22, 3-23, 3-24 and 3-25.

Science & Engineering Indicators – 2002

Women and Minorities in S&E

Demographic factors for women and minorities, such as age, time spent in the workforce, field of S&E employment, and highest degree level achieved, influence employment patterns.[9] To the extent that men differ from women and minorities differ from nonminorities on these factors, their employment patterns are also likely to differ. For example, the age distributions of women compared with men and of minorities compared with the majority are quite different. Because many women and minorities have entered S&E fields only recently, women and minority men generally are younger and have fewer years of experience. (See appendix table 3-34.) In turn, age and stage in career influence such employment-related factors as salary, rank, tenure, and work activity. In addition, employment patterns vary by field, and these field differences influence S&E employment, unemployment, salaries, and work activities. Highest degree earned, yet another important influence, particularly affects primary work activity and salary. This section examines the employment characteristics of representation in S&E, work experience, field of S&E, educational background, workforce participation, sectors of employment, and salaries for women and minorities in 1999.

Women Scientists and Engineers

Representation in S&E

Women made up almost one-fourth (24 percent) of the S&E workforce but close to one-half (46 percent) of the U.S. workforce in 1999. Although changes in NSF surveys do not permit analysis of long-term trends in employment, short-term trends reflect an increase in female doctorate-holders employed in S&E. In 1993, women made up 20 percent of the doctoral scientists and engineers in the United States; in 1995, they made up 22 percent; in 1997, they made up 23 percent; and in 1999, they made up 24 percent.[10] See sidebar, "Growth of Representation of Women, Minorities, and the Foreign Born in the S&E Workforce."

Work Experience

Many differences in employment characteristics between men and women are due in part to differences in time spent in the workforce. Women in the S&E workforce are younger on average than men; 50 percent of women and 36 percent of men employed as scientists and engineers in 1999 received their degrees within the past 10 years.

[9] Throughout this section, scientists and engineers are defined by field of employment, not by field of degree.

[10] For 1993 figures, see NSF 1996, p. 63; for 1995 figures, see NSF 1999b, p. 99.

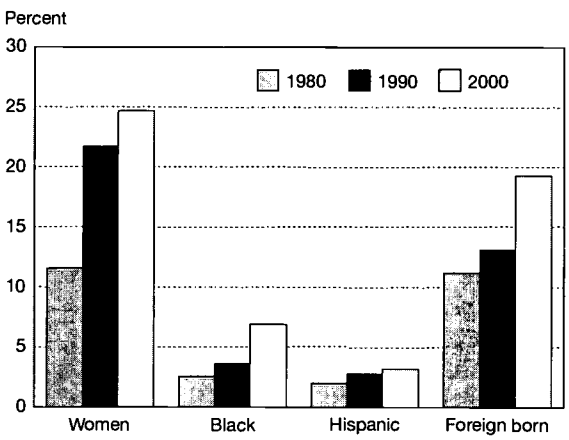
Growth of Representation of Women, Minorities, and the Foreign Born in the S&E Workforce

A longer view of the changes that have occurred in the sex and ethnic composition of the science and engineering (S&E) workforce can be achieved by examining data on college-educated individuals in nonacademic S&E occupations from the 1980 census, the 1990 census, and the March 2000 Current Population Survey. (See figure 3-13.) In 2000, the percentages of historically underrepresented groups in S&E occupations were still lower than the percentages of those groups in the total college-educated workforce:

- Women were 24.7 percent of the S&E workforce but 48.6 percent of the college-degreed workforce.
- Blacks were 6.9 percent of the S&E workforce but 7.4 percent of the college-degreed workforce.
- Hispanics were 3.2 percent of the S&E workforce but 4.3 percent of the college-degreed workforce.

However, these percentages are more than double of the shares of S&E occupations since 1980 for blacks (2.6 to 6.9 percent) and women (11.6 to 24.7 percent). Hispanic representation increased between 1980 and 2000, albeit at a lower rate (2.0 to 3.2 percent). Foreign-born college graduates also became a larger percentage of those in S&E jobs (11.2 percent in 1980 to 19.3 percent in 2000).

Figure 3-13.
College graduates in nonacademic S&E occupations: women and minorities



SOURCE: U.S. Department of Commerce, Bureau of the Census, 1980 and 1990 U.S. Decennial Census Public Use Microdata Sample, and March 2000 Current Population Survey.

Science & Engineering Indicators – 2002

Field of S&E Occupation

As is the case in degree fields, representation of men and women differ in field of occupation. Women are more represented in some S&E fields than in others. For example, in 1999, women made up more than one-half of social scientists but only 23 percent of physical scientists and 10 percent of engineers. (See figure 3-14.) Within engineering, women are represented more in some fields than in others. For example, women constituted 15 percent of chemical and industrial engineers but only 6 percent of aerospace, electrical, and mechanical engineers. Since 1993, the percentages of women in most S&E occupations have gradually increased; the exception is mathematics and computer sciences, in which the percentage of women declined about 4 percent between 1993 and 1999.

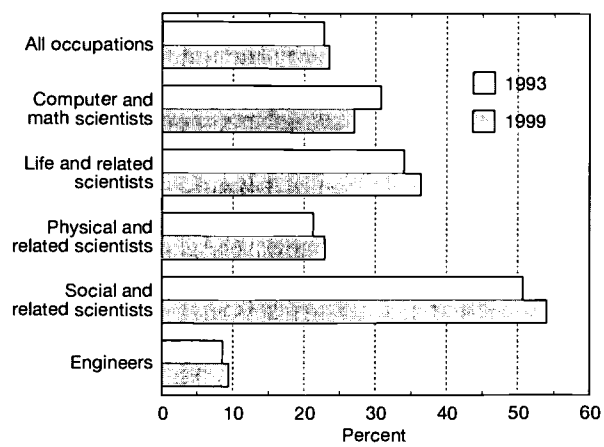
Educational Background

In many occupational fields, women scientists have a lower level of education than men. In the science workforce as a whole, 16 percent of women and 20 percent of men hold doctoral degrees. In biology, 26 percent of women and 40 percent of men hold doctoral degrees; in chemistry, 14 percent of women and 27 percent of men hold doctoral degrees; and in psychology, 22 percent of women and 42 percent of men hold doctoral degrees. Differences in highest degree achieved influence differences in type of work performed, employment in S&E jobs, and salaries. In engineering, the difference is much less: about 5 percent of women and 6 percent of men have doctoral degrees. (See NSF 1999f.)

Labor Force Participation, Employment, and Unemployment

Scientists and engineers who are men are more likely than women to be in the labor force, employed full time, and em-

Figure 3-14.
Women as proportion of S&E workforce, by broad occupation



See appendix tables 3-38 and 3-39.

Science & Engineering Indicators – 2002

ployed in fields of highest degree achieved. Women are more likely than men to be out of the labor force, employed part time, and employed outside their fields. Some of these differences are due to differences in age distributions of men and women, and some are due to family-related reasons, such as the demands of a spouse's job or the presence of children.

The labor force participation rates for men and women with current or former S&E occupations are similar: 88 percent of men and 86 percent of women are in the labor force; the remaining percentages are those not in the labor force (i.e., not working and not seeking employment). (See appendix table 3-38.) Among those in the labor force, unemployment rates for men and women scientists and engineers are similar: 1.5 percent of men and 1.8 percent of women were unemployed in 1999. By comparison, the unemployment rate in 1993 was 2.7 percent for men and 2.1 percent for women. (See text table 3-7.)

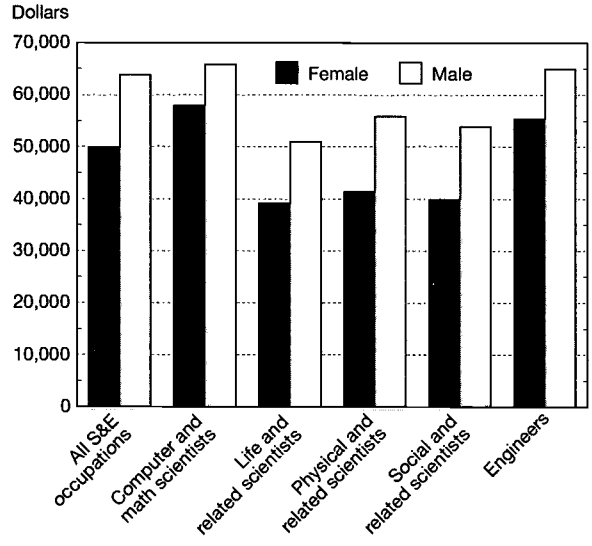
Sector of Employment

Within fields, women are about as likely as men to choose industrial employment. For example, among physical scientists, 55 percent of women and 54 percent of men are employed in business or industry. (See appendix table 3-40.) Among employed scientists and engineers as a whole, women are less likely than men to be employed in business or industry but are more likely to be employed in educational institutions: 51 percent of women and 68 percent of men are employed in for-profit business or industry, but 27 percent of women and 14 percent of men are employed in educational institutions. These differences in sector of employment, however, are due to differences in field of degree. Women are less likely than men to be engineers or physical scientists, who tend to be employed in business or industry.

Salaries

In 1999, the median annual salary for women scientists and engineers was $50,000, about 22 percent less than the median salary for men ($64,000). (See figure 3-15.) Between 1993 and 1999, salaries for women scientists and engineers increased by 25 percent compared with an increase of 28 percent for men. (See text table 3-8.) These salary differentials could be due in part to several factors. Women were more likely than men to be working in educational institutions and social science occupations, to be working in nonmanagerial positions, and to have less experience, all factors that con-

Figure 3-15.
Median annual salaries of employed scientists and engineers, by broad occupation and sex: 1999



See appendix table 3-26. *Science & Engineering Indicators – 2002*

Text table 3-7.
Unemployment rates for individuals in S&E occupations, by sex and race/ethnicity: 1993 and 1999
(Percentages)

Sex and race/ethnicity	1993	1999
S&E occupations, total	2.6	1.6
Sex		
Male	2.7	1.5
Female	2.1	1.8
Race/ethnicity		
White	2.4	1.5
Black	2.8	2.6
Hispanic	3.5	1.8
Asian/Pacific Islander	4.0	1.5
Other	4.8	0.9

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Scientists and Engineers Statistical Data System (SESTAT), 1993 and 1999.

See appendix tables 3-38 and 3-39.

Science & Engineering Indicators – 2002

Text table 3-8.
Median annual salaries of individuals employed in S&E occupations, by sex and race/ethnicity
(Dollars)

Sex and race/ethnicity	1993	1995	1997	1999
S&E occupations, total	48,000	50,000	55,000	60,000
Sex				
Male	50,000	52,000	58,000	64,000
Female	40,000	42,000	47,000	50,000
Race/ethnicity				
White	48,000	50,500	55,000	61,000
Black	40,000	45,000	48,000	53,000
Hispanic	43,000	47,000	50,000	55,000
Asian/Pacific Islander	48,000	50,000	55,000	62,000
Other	43,300	49,700	49,000	52,000

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Scientists and Engineers Statistical Data System (SESTAT), 1993 and 1999.

See appendix tables 3-26, 3-27, 3-28 and 3-29.

Science & Engineering Indicators – 2002

The NSB Task Force on National Workforce Policies for Science and Engineering

In October 2000, the National Science Board established the Task Force on National Workforce Policies for Science and Engineering to assess long-term national workforce trends and needs in S&E and their relationship to existing Federal policies and to recommend strategies that will address long-term S&E workforce needs. The task force will consider the following issues:

- how U.S. demographic trends, trajectories of S&E preparation and degree attainment, and availability of foreign scientists and engineers may affect the future S&E workforce;
- how data on industry demand—both for requisite skills and the numbers of workers who possess them—can better inform preparation, hiring, and retention of students at all levels for high-technology careers;
- how graduate training can be diversified to support aspirations that match opportunities, especially outside of research and of academia, while ensuring continued excellence in the traditional preparation of U.S. scientists and engineers; and
- how the mix of Federal law, such as immigration policy, Federal agency and state programs, higher education institution practices, and employer recruitment and other incentives affect student and worker choices related to S&E careers.

The report of the Task Force on National Workforce Policies For Science and Engineering is expected to be available in 2002. Further information about the work of the task force can be found on the Board's website at http://www.nsf.gov/nsb/.

tribute to salary differences. Among scientists and engineers in the workforce who have held their degrees for five years or less, the median annual salary for women was 83 percent of that for men in 1999.

Salary differentials varied by broad field. In computer science and mathematics occupations in 1999, women's salaries were approximately 12 percent less than men's salaries, whereas there was a 23 percent salary difference in life science occupations. In these respective occupations, women also reported the highest and lowest median salaries; their highest median salary was in computer science and mathematics occupations ($58,000), and their lowest was in life science occupations ($39,000).

Racial and Ethnic Minority Scientists and Engineers

Representation in S&E

With the exception of Asians, minorities make up a small portion of scientists and engineers in the United States.[11] Eleven percent of scientists and engineers in 1999 were Asian, although they constituted 4 percent of the U.S. population. Blacks, Hispanics, and American Indians as a group constituted 24 percent of the U.S. population but only 7 percent of the total S&E workforce in 1999.[12] Blacks and Hispanics each represented about 3 percent of scientists and engineers, and American Indians represented less than 0.5 percent. (See appendix tables 3-41 and 3-44.) Between 1993 and 1999, the portion of Asians in the S&E workforce increased by about 2 percent, whereas the portion of blacks, Hispanics, and American Indians remained virtually unchanged.

Work Experience

The work experience of minorities, including Asians, differs from that of white scientists and engineers. As noted earlier, such differences influence employment characteristics. About 33 percent of white scientists and engineers employed in 1999 had received their degrees within the previous 10 years compared with 46–52 percent of Asian, black, and Hispanic scientists and engineers.

Field of S&E Occupation

Asian, black, and American Indian scientists and engineers are concentrated in fields different from those for white and Hispanic scientists and engineers. Asians are less represented in social sciences than in other fields. In 1999, they were 4 percent of social scientists but more than 11 percent of engineers and computer scientists. Black scientists and engineers have higher representation rates in social sciences and in computer sciences and mathematics than in other fields. In 1999, they were 5 percent of social scientists, 4 percent of computer scientists and mathematicians, and approximately 3 percent of physical scientists, life scientists, and engineers. Although their representation is small, American Indians are concentrated in social sciences, making up 0.4 percent of social and life scientists and 0.3 percent or less of scientists in other fields in 1999. Hispanics are more proportionally represented among fields; they were approximately 2.5 to 4.5 percent of scientists and engineers in each field.

[11] The term "minority" includes all groups other than white; "underrepresented minorities" include three groups whose representation in S&E is less than their representation in the population: blacks, Hispanics, and American Indians/Alaskan Natives. In accordance with Office of Management and Budget guidelines, the racial and ethnic groups described in this section are identified as white and non-Hispanic, black and non-Hispanic, Hispanic, Asian/Pacific Islander, and American Indian/Alaskan Native. In text and figure references, these groups are identified as white, black, Hispanic, Asian, and American Indian.

[12] The S&E fields in which blacks, Hispanics, and American Indians earn their degrees influence participation in the S&E labor force. Blacks, Hispanics, and American Indians are disproportionately likely to earn degrees in social sciences (defined by NSF as degrees in S&E) and to be employed in social service occupations, such as social worker and clinical psychologist, which are defined by NSF as non-S&E occupations. See NSF 1999a for NSF's classification of S&E fields.

Educational Background

The educational achievement of scientists and engineers differs among racial and ethnic groups. On average, black and Hispanic scientists and engineers have a lower level of educational achievement than scientists and engineers of other racial and ethnic groups. A bachelor's degree is more likely to be the highest degree achieved for black and Hispanic scientists and engineers than for white or Asian scientists and engineers—in 1999, a bachelor's degree was the highest degree achieved for 61 percent of black scientists and engineers in the U.S. workforce compared with 56 percent of all scientists and engineers.

Labor Force Participation, Employment, and Unemployment

Labor force participation rates vary by race and ethnicity. Minority scientists and engineers are more likely than whites to be in the labor force (that is, employed or seeking employment). Between 89 and 93 percent of black, Asian, Hispanic, and American Indian scientists and engineers were in the labor force in 1999 compared with 86 percent of white scientists and engineers. (See appendix table 3-38.) Age somewhat explains these differences. On average, white scientists and engineers are older than scientists and engineers of other racial and ethnic groups: 28 percent of white scientists and engineers were age 50 or older in 1999 compared with 15–20 percent of Asians, blacks, and Hispanics. For those in similar age groups, the labor force participation rates of white and minority scientists and engineers are similar. (NSF 1999b.)

Although minorities are for the most part less likely than nonminorities to be out of the labor force, minorities in the labor force are more likely to be unemployed. In 1999, the unemployment rate of white scientists and engineers was somewhat lower than that of other racial and ethnic groups. (See text table 3-7.) The unemployment rate for whites was 1.5 percent compared with 1.8 percent for Hispanics, 2.6 percent for blacks, and 1.5 percent for Asians. In 1993, the unemployment rate for whites was 2.4 percent compared with 3.5 percent for Hispanics, 2.8 percent for blacks, and 4.0 percent for Asians.

The differences in 1999 unemployment rates are evident within fields of S&E as well as for S&E as a whole. For example, the unemployment rate for white engineers was 1.8 percent; for black and Asian engineers, it was 2.3 and 1.8 percent, respectively.

Sector of Employment

Racial and ethnic groups differ within employment sector due in part to differences in field of employment. Among employed scientists and engineers in 1999, 58 percent of blacks, 60 percent of Hispanics, and 56 percent of American Indians were employed in for-profit business or industry compared with 64 percent of white and 70 percent of Asians. (See appendix table 3-40.) Blacks and American Indians are concentrated in social sciences (a field that provides less opportunity for employment in business or industry) and are underrepresented in engineering (a field that provides greater opportunity for employment in business or industry). On the other hand, Asians are overrepresented in engineering; thus, they are more likely to be employed by private, for-profit employers.

Black, Hispanic, and American Indian S&E job-holders are also more likely than other groups to be employed in government (Federal, state, or local): 20 percent of black, 15 percent of Hispanic, and 18 percent of American Indian scientists and engineers were employed in government in 1999 compared with 12 percent of white and Asian scientists and engineers.

Salaries

Salaries for S&E job-holders vary among racial and ethnic groups. In 1999, for all scientists and engineers, the median salaries by racial and ethnic group were $61,000 for whites, $62,000 for Asians, $53,000 for blacks, $55,000 for Hispanics, and $50,000 for American Indians. (See figure 3-16 and text table 3-8.) These salary patterns are about the same as they were in 1993.

Within occupational fields and age categories, median salaries of scientists and engineers by race and ethnicity are not dramatically different and do not follow a consistent pattern. For example, in 1999, the median salary of 20- to 29-year-old engineers with bachelor's degrees ranged from $35,000 for American Indians to $46,000 for Hispanics. Among those between the ages of 40 and 49, the median salary ranged from $60,000 for Asians and Native Americans to $70,000 for whites. The median salary of engineers with bachelor's degrees in 1999 who had received their degrees within the past five years was $45,000 for all ethnicities. (See appendix table 3-26.) Among those who had received their degrees 20–24 years ago, the median salary was approximately $70,000 for all ethnicities. See sidebar, "Salary Differentials."

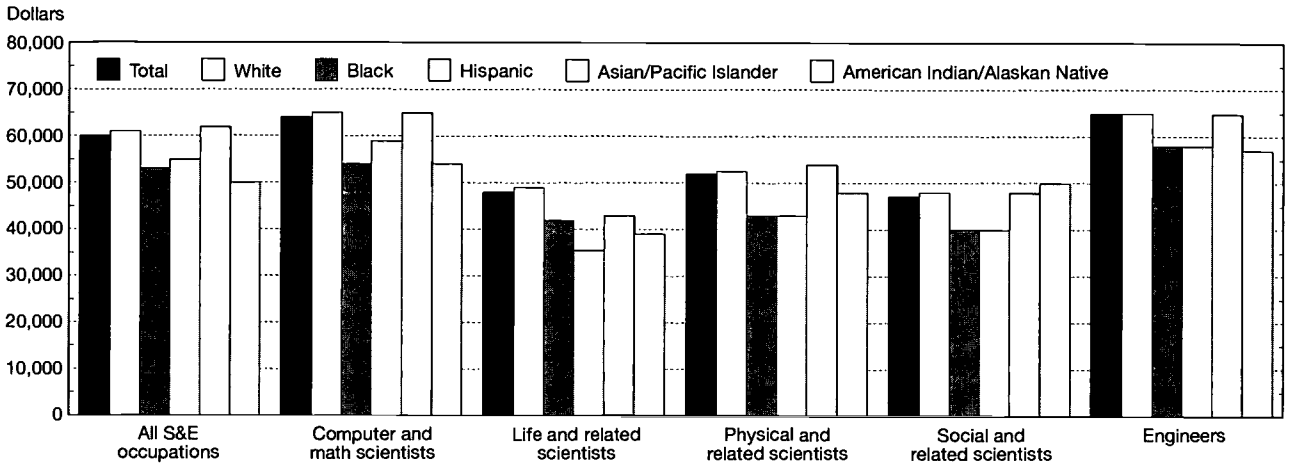
Labor Market Conditions for Recent S&E Degree-Holders

Recipients of Bachelor's and Master's Degrees

Recent recipients of S&E bachelor's and master's degrees form a key component of the U.S. S&E workforce: they account for almost one-half of the annual inflow to the S&E labor market (NSF 1990).[13] Recent graduates' career choices and entry into the labor market affect the supply and demand

[13] Data for this section are taken from the *1999 National Survey of Recent College Graduates*. This survey collected information on the 1999 workforce status of 1997 and 1998 bachelor's and master's degree recipients in S&E fields. Surveys of recent S&E graduates have been conducted biennially for NSF since 1978. For information on standard errors associated with survey data, see NSF (forthcoming b).

Figure 3-16.
Median annual salaries of scientists and engineers, by broad occupation and race/ethnicity: 1999



See appendix table 3-26.

Science & Engineering Indicators – 2002

for scientists and engineers in the United States. This section offers insight into the labor market conditions for recent S&E graduates in the United States. Topics examined include graduate school enrollment rates, employment by level and field of degree, employment sectors, and median annual salaries.

Employment Versus Graduate School

In 1999, approximately one-fifth of 1997 and 1998 graduates who earned bachelor's or master's degrees were enrolled full time in graduate school. Students who had majored in physical and life sciences were more likely to be full-time graduate school students than were graduates with degrees in computer and information sciences and engineering. (See appendix table 3-45.)

Employment Related to Level and Field of Degree

Success in the job market varies significantly by level and field of degree. One measure of success is the likelihood of finding employment directly related to a graduate's field of study. Almost one-half of master's recipients but only one-fifth of bachelor's recipients were employed in their fields of study in 1999. Among both master's and bachelor's recipients, students who had received their degrees in either engineering or computer sciences were more likely to be working in their fields of study than degree recipients in other S&E fields, whereas students in social sciences were less likely than their counterparts in other S&E fields to have jobs directly related to their degrees.

Sector of Employment

The private, for-profit sector is the largest employer of recent S&E bachelor's and master's degree- recipients. (See text table 3-10.) In 1999, 63 percent of bachelor's degree-recipients and 57 percent of master's degree-recipients found employment in private, for-profit companies. The academic sector is the second largest employer of recent S&E graduates. Master's degree-recipients were more likely to be employed in four-year colleges and universities (12 percent) than were bachelor's degree-recipients (8 percent). The Federal sector employed only 5 percent of S&E master's degree-recipients and 4 percent of S&E bachelor's degree-recipients in 1999. Engineering graduates are more likely than science graduates to find employment in the Federal sector. Other sectors employing small numbers of recent S&E graduates include educational institutions other than four-year colleges and universities, nonprofit organizations, and state and local government agencies. Very small percentages of engineering bachelor's and master's recipients were self-employed (1 and 2 percent, respectively).

Employment and Career Paths

Career-path jobs are those that will help graduates fulfill their future career plans. As one might expect, S&E master's degree-recipients are more likely than S&E bachelor's degree-recipients to report having a career-path job. Approximately three-fourths of all master's degree-recipients and three-fifths of all bachelor's degree- recipients found a career-path job in 1999. Graduates with degrees in computer and information sciences or in engineering are more likely to find career-path jobs than graduates with degrees in other fields; about four-fifths of bachelor's and master's degree graduates in computer and information sciences and in engineering reported that they had found career-path jobs.

Salaries

Of recent bachelor's degree-recipients in sciences, in 1999, those with degrees in computer and information sciences earned the highest median annual salaries ($44,000); for graduates with degrees in engineering, those with degrees in electrical/electronics, computer, and communications engi-

Salary Differentials

Differences in salaries of women and ethnic minorities are often used as indicators of progress that individuals in such groups are making in science and engineering (S&E). Indeed, as shown in text table 3-9, these salary differences are substantial when comparing all individuals with S&E degrees by the level of degree: in 1999, women with S&E bachelor's degrees had full-time mean salaries that were 35.1 percent less than those of men with S&E bachelor's degrees.* Blacks, Hispanics, and individuals in other underrepresented ethnic groups with S&E bachelor's degrees had full-time salaries that were 21.9 percent less than those of non-Hispanic whites and Asians with S&E bachelor's degrees.** These raw differences in salary are lower but still large at the Ph.D. level (−25.8 percent for women and −12.7 percent for underrepresented ethnic groups). In contrast, foreign-born individuals with U.S. S&E degrees have slightly higher salaries than U.S. natives at the bachelor's and master's levels, but their salaries at the Ph.D. level show no statistically significant differences from those of natives.

However, differences in average age, work experience, field of degree, and other characteristics make direct comparison of salary and earnings statistics difficult. Generally, engineers earn a higher salary than social scientists, and newer employees earn less than those with more experience. One common statistical method that can be used to look simultaneously at salary and other differences is regression analysis.† Text table 3-9 shows estimates of salary differences for different groups after controlling for several individual characteristics.

Although this type of analysis can provide insight, it cannot give definitive answers to questions about the openness of S&E to women and minorities for many reasons. The most basic reason is that no labor force survey ever captures all information on individual skill sets, personal background and attributes, or other characteristics that

* For consistency with the other salary differences shown in text table 3-9, these salary differences were generated from regressions of ln (full-time annual salary) on just a dummy variable for membership in the group being examined. This corresponds to differences in the geometric mean of salary, not to differences in median salary as reported elsewhere in this chapter.

** "Underrepresented ethnic group" as used here includes individuals who reported their race as black, Native American, or other or who reported Hispanic ethnicity.

† Specifically presented here are coefficients from linear regressions using the 1999 SESTAT data file of individual characteristics upon the natural log of reported full-time annual salary as of April 1999.

Text table 3-9.
Salary differentials controlling for individual characteristics: 1999
(Percentages)

Variable	Bachelor's	Master's	Doctorate
Female (compared with male)			
All with S&E degrees	−35.1	−28.9	−25.8
Controlling for			
Age and years since degree	−27.2	−25.5	−16.7
Plus field of degree	−14.0	−9.6	−16.7
Plus occupation and employer characteristics	−11.0	−8.0	−8.4
Plus family and personal characteristics	−10.2	−7.4	−7.4
Plus gender-specific marriage and child effects	−4.6	NS	−3.1
Black, Hispanic, and other (compared with non-Hispanic white and Asian)			
All with S&E degrees	−21.9	−19.3	−12.7
Controlling for			
Age and years since degree	−13.0	−14.6	−4.7
Plus field of degree	−8.6	−6.7	−2.2
Plus occupation and employer characteristics	−7.3	−4.2	NS
Plus family and personal characteristics	−5.7	−3.3	NS
Foreign born with U.S. degree (compared with native born)			
All with S&E degrees	3.7	9.5	NS
Controlling for			
Age and years since degree	6.7	12.4	7.8
Plus field of degree	NS	NS	NS
Plus occupation and employer characteristics	NS	−2.8	−2.8
Plus family and personal characteristics	NS	−3.1	−2.7

NS = not significantly different from zero at $P = .05$

NOTE: Linear regressions on ln(full-time annual salary).

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Scientists and Engineers Statistical Data System (SESTAT), 1999.

may affect compensation. In addition, even characteristics that are measurable are not distributed randomly among individuals. An individual's choice of degree field and occupation, for example, will reflect in part the real and perceived opportunities for that individual. The associations of salary differences with individual characteristics, not field choice and occupation choice, are examined here.

Effects of Age and Years Since Degree on Salary Differentials

Salary differences between men and women reflect to a large extent the lower average ages of women with degrees in most S&E fields. Controlling for differences in age and years since degree reduces salary differentials for women compared with men by about one-fourth at the bachelor's degree level (to –27.2 percent) and by about one-third at the Ph.D. level (to –16.7 percent).*

When controlling for differences in age and years since degree, even larger drops in salary differentials are found for underrepresented ethnic minorities. Such controls reduce salary differentials of underrepresented minorities compared with non-Hispanic whites and Asians by more than two-fifths at the bachelor's degree level (to –13.0 percent) and by nearly two-thirds at the Ph.D. level (to –4.7 percent).

Because foreign-born individuals in the labor force who have S&E degrees are somewhat younger on average than natives, controlling for age and years since degree moves their salary differentials in a positive direction—in this case, making an initial earnings advantage over natives even larger—to 6.7 percent for foreign-born individuals with S&E bachelor's degrees and to 7.8 percent for those with S&E Ph.D.s.

Effects of Field of Degree on Salary Differentials

Controlling for field of degree and for age and years since degree reduces the estimated salary differentials for women with S&E degrees to –14.0 percent at the bachelor's level and to –10.3 percent at the Ph.D. level.** These reductions generally reflect the greater concentration of women in the lower paying social and life sciences as opposed to engineering and computer sciences. As noted above, this identifies only one factor associated with salary differences and does not speak to why there are differences between males and females in field of degree or whether salaries are affected by the percentage of women studying in each field.

Field of degree is also associated with significant estimated salary differentials for underrepresented ethnic groups. Controlling for field of degree further reduces salary differentials to –8.6 percent for those with S&E bachelor's degrees and to –2.2 percent for those with S&E Ph.D.s. Thus, age, years since degree, and field of degree are associated with almost all doctorate-level salary differentials for underrepresented ethnic groups.

Compared with natives at any level of degree, foreign-born individuals with S&E degrees show no statistically significant salary differences when controlling for age, years since degree, and field of degree.

Effects of Occupation and Employer on Salary Differentials

Obviously, occupation and employer characteristics affect compensation.† Academic and nonprofit employers typically pay less for the same skills that employers pay for in the private sector, and government compensation falls somewhere between the two groups. Other factors affecting salary are relation of work performed to degree earned, whether the person is working in S&E, whether the person is working in research and development, size of employer, and U.S. region. However, occupation and employer characteristics may not be determined solely by individual choice, for they may also reflect in part an individual's career success.

When comparing women with men and underrepresented ethnic groups with non-Hispanic whites and Asians, controlling for occupation and employer reduces salary differentials only slightly beyond what is found when controlling for age, years since degree, and field of degree. For foreign-born individuals compared with natives, controls for occupation and employer characteristics also produce only small changes in estimated salary differentials, but in this case, the controls result in small negative salary differentials at the master's (–2.8 percent) and doctorate (–2.8 percent) levels.

Effects of Family and Personal Characteristics on Salary Differentials

Marital status, children, parental education, and other personal characteristics are often associated with differences in compensation. Although these differences may indeed involve discrimination, they may also reflect many subtle individual differences that might affect work productivity.‡ As with occupation and employer characteristics, controlling for these characteristics changes salary differentials only slightly at any degree level. However, most of the remaining salary differentials for women disappear when the regression equations allow for the separate effects of marriage and children for each sex. Marriage is associated with higher salaries for both men and women, but marriage has a larger positive association for men. Children have a positive association with salary for men but a negative association with salary for women.

* In the regression equation, this is the form: age, age,^{2} age,^{3} age,^{4} years since highest degree (YSD), YSD,^{2} YSD,^{3} YSD.^{4}

** Included were 20 dummy variables for NSF/SRS SESTAT field-of-degree categories (out of 21 S&E fields; the excluded category in the regressions was "other social science").

† Variables added here include 34 SESTAT occupational groups (excluding "other non-S&E"), whether a person said his job was closely related to his degree, whether a person worked in R&D, whether his employer had less than 100 employees, and the census region of the employer.

‡ Variables added here include dummy variables for marriage, number of children in the household younger than 18, whether the father had a bachelor's degree, whether either parent had a graduate degree, and citizenship. Also, sex, nativity, and ethnic minority variables are included in all regression equations.

Text table 3-10.
Employed 1997 and 1998 S&E bachelor's and master's degree recipients, by sector of employment and field of degree: 1999

		Sector of employment[a] (percent distribution)						
		Educational		Noneducational				
Degree[b]	Total employed (thousands)	Four-year college and university	Other institution	Private, for-profit company	Self-employed	Nonprofit organization	Federal Government	State or local government
S&E bachelor's	539.2	8	10	63	1	7	4	7
All sciences	442.4	9	12	58	2	9	4	8
All engineering	96.7	4	1	86	<0.5	1	5	4
S&E master's	118.1	12	9	57	2	7	5	7
All sciences	80.6	15	12	48	3	10	4	9
All engineering	37.6	8	<0.5	78	1	1	8	4

[a]Sector of employment in which the respondent was working on his or her primary job held on April 15, 1999. In this categorization, those working in four-year colleges and universities or university-affiliated medical schools or research organizations were classified as employed in the "four-year college and university" sector. Those working in elementary, middle, secondary, or two-year colleges or other educational institutions were categorized in the group "other institution." Those reporting that they were self-employed but in an incorporated business were classified in the "private, for-profit sector."

[b]For graduates with more than one eligible degree at the same level (bachelor's/master's), the degree for which the graduate was sampled was used.

NOTE: Details may not add to totals because of rounding. Percentages were calculated on unrounded data.

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), National Survey of Recent College Graduates, 1999.

Science & Engineering Indicators – 2002

neering earned the highest salaries ($46,000). The same pattern was true for master's degree graduates: master's degree-recipients in computer and information sciences earned the highest median salaries ($58,000), as did those who earned master's degrees in electrical/electronics, computer, and communications engineering ($60,000).

Recipients of Doctoral Degrees

Analyses of labor market conditions for Ph.D.-holding scientists and engineers often focus on the ease or difficulty of beginning careers for new Ph.D. recipients. Several recent developments have contributed to these concerns, including demographic changes (which have slowed the growth of undergraduate enrollment), reductions in defense and research funding, growth in the importance of Ph.D. programs at foreign schools, and rates of Ph.D. production that approach or exceed the high levels realized at the end of the Vietnam draft.

Since the 1950s, the Federal Government has actively encouraged graduate training in S&E through numerous mechanisms. However, widespread unemployment or involuntary departure from S&E by many new Ph.D.-holding scientists and engineers could adversely affect the quality of scientific research in the United States. If labor market difficulties are real but temporary, promising students may be discouraged from pursuing degrees in S&E fields. To the extent that doctoral-level training provides higher level skills, this circumstance could eventually reduce the ability of industry, academia, and government to perform R&D. If labor market difficulties are long term, graduate education may need to be restructured to both maintain quality research and better prepare students for their real career options. In either case, when much high-level human capital goes unused, society loses potential opportunities for new knowledge and economic advancement, and individuals become frustrated with their careers. Of course, that some highly skilled individuals become either unemployed or employed IOF because they are unable to secure desired employment may reflect their unrealistic labor market expectations.

Most individuals who complete an S&E doctorate are looking for more than steady employment at a good salary. Their technical and problem-solving skills make them highly employable, but opportunity to do the type of work they want and for which they have been trained is important to them. For that reason, no single measure can satisfactorily describe the S&E labor market. Some of the available labor market indicators, such as unemployment rates, out-of-field and in-field employment, satisfaction with field of study, employment in academia, postdoctorate appointments, and salaries, are discussed below.

Aggregate measures of labor market conditions changed only slightly for recent doctoral degree-recipients in S&E (defined here as 1–3 years after receipt of degree). Unemployment fell from 1.5 percent in 1997 to 1.2 percent in 1999. (See text table 3-11.) Likewise, the portion of recent Ph.D. recipients reporting that they were either working outside their fields because jobs in their fields were not available or involuntarily working part time decreased slightly from 4.5 to 4.2 percent. These aggregate numbers mask numerous changes, both positive and negative, in many individual disciplines. In addition, IOF and unemployment rates in many fields moved in opposite directions.

Unemployment Rates

Even for relatively good labor market conditions in the general economy, the 1.2 percent unemployment rate for recent S&E Ph.D. recipients is very low; the April 1999 unem-

ployment rate for all civilian workers was 4.4 percent.[14] In 1997, recent graduates in several Ph.D. disciplines had unemployment rates above 3 percent, which was still low but unusually high for a highly skilled group. Between 1997 and 1999, unemployment rates fell for recent Ph.D. recipients in most disciplines; the largest decrease was in chemistry, in which the unemployment rate fell from 3.5 to 0.5 percent. Unemployment rates of less than 1 percent were found in civil engineering (0.0 percent), mechanical engineering (0.3 percent), electrical engineering (0.76 percent), mathematics (0.7 percent), computer sciences (0.9 percent), physics and astronomy (0.0 percent), and economics (0.5 percent).[15]

[14]People are said to be unemployed if they were not employed during the week of April 15, 1999, and had either looked for work during the preceding four weeks or were laid off from a job.

[15]An unemployment rate of 0.0 does not mean that "zero" people in that field were unemployed; it means that the estimated rate from NSF's sample survey was less than 0.05 percent.

Text table 3-11.
Labor market rates for recent doctorate recipients one to three years after Ph.D.: 1997 and 1999
(Percentages)

Ph.D. field	Unemployment rate 1997	Unemployment rate 1999	Involuntary out-of-field rate 1997	Involuntary out-of-field rate 1999
All S&E	1.5	1.2	4.5	4.2
Engineering	1.0	0.9	3.6	2.7
Chemical	1.7	1.7	5.8	1.8
Civil	0.0	1.5	5.5	0.0
Electrical	0.6	0.7	3.2	2.5
Mechanical	0.5	0.3	2.7	3.2
Other	1.6	0.9	3.0	3.6
Life sciences	1.7	1.1	2.6	2.5
Agriculture	2.2	0.0	7.3	3.1
Biological sciences	1.5	1.3	2.2	2.5
Computer sciences and mathematics	0.6	0.8	6.5	4.1
Computer sciences	0.7	0.9	2.1	1.8
Mathematics	0.6	0.7	11.0	6.2
Physical sciences	2.1	0.4	6.9	6.6
Chemistry	3.5	0.5	3.3	2.4
Geosciences	1.0	1.2	6.3	9.4
Physics and astronomy	0.7	0.0	12.2	11.1
Social sciences	1.6	2.1	5.4	5.7
Economics	0.9	0.5	5.2	4.2
Political science	2.6	3.4	7.9	11.6
Psychology	1.2	1.0	3.8	3.5
Sociology and anthropology	2.5	1.6	7.7	11.9
Other	2.5	1.9	7.1	4.4

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Survey of Doctorate Recipients, 1997 and 1999.

Science & Engineering Indicators – 2002

Involuntarily Working Outside Field

Another 4.2 percent of recent S&E Ph.D. recipients in the labor force reported that they could not find (if they were seeking) full-time employment that was "closely related" or "somewhat related" to their degrees.[16] Although this measure is more subjective than the unemployment rate, the IOF rate often proves to be a more sensitive indicator of labor market difficulties for a highly educated and employable population. However, this tool is best used along with the unemployment rate as measures of two different forms of labor market distress.

The highest IOF rates were found for recent Ph.D. graduates in sociology and anthropology (11.8 percent) and political science (11.6 percent). These two fields also had unemployment rates that were among the highest. The lowest IOF rates were found in computer sciences (1.8 percent) and civil engineering (0.0 percent).

Tenure-Track Positions

Most S&E recipients do not ultimately work in academia, and in most S&E fields, this has been true for several decades. See chapter 10, "The Academic Doctoral S&E Workforce." In 1999, for S&E Ph.D.-holders four to six years since receipt of degree, 22.2 percent were in tenure-track or tenured positions at four-year institutions of higher education. (See text table 3-12.) Across fields, tenure-program academic employment for those four to six years since receipt of Ph.D. ranged from 6.5 percent in chemical engineering to 50.7 percent in political science. For Ph.D.-holders one to three years since receipt of degree, only 13.7 percent were in tenure programs, but this rate reflects the increasing use of postdoctoral appointments (or postdocs) by recent Ph.D.-holders in many fields.

Although academia must be considered just one possible sector of employment for S&E Ph.D.-holders, the availability of tenure-track positions is an important aspect of the job market for those who seek academic careers. The fall in rate of tenure-program employment for those four to six years since receipt of Ph.D. from 26.6 percent in 1993 to 22.2 percent in 1999 reflects both job opportunities in academia and alternative opportunities for employment. For example, one of the largest declines in tenure-program employment occurred in computer sciences (from 51.5 percent in 1993 to 31.6 percent in 1999), in which other measures of labor market distress are low, and computer science departments report difficulties recruiting faculty.[17] The attractiveness of other employment may also explain drops in tenure-program rates for several engineering disciplines. However, it is less likely to explain the smaller but steady drops in tenure-program employment rates in fields showing other measures of distress, such as physics and mathematics (both of which have large IOF rates) and biological sciences (which have low unem-

[16]Individuals were considered IOF if they said their jobs were not related to their degree because no jobs in their field were available or if they were part-time because a full-time job was not available. The IOF rate is a percentage calculated by dividing the number of such individuals by the total number in that segment of the labor force.

[17] See Computing Research Association (1997).

Text table 3-12.
Doctorate recipients holding tenure and tenure-track appointments at four-year institutions: 1993 and 1999
(Percentages)

Ph.D. field	Years since receipt of doctorate 1993 1–3	1993 4–6	1999 1–3	1999 4–6
All S&E	18.4	26.6	13.7	22.2
Engineering	16.0	24.6	7.3	15.2
Chemical	8.1	14.0	2.4	6.5
Civil	24.7	27.1	20.3	33.6
Electrical	17.6	26.9	3.7	11.9
Mechanical	13.5	29.5	6.4	15.1
Other	13.9	21.3	9.5	16.0
Life sciences	12.6	24.8	11.3	21.8
Agriculture	15.6	27.0	13.6	23.3
Biological sciences	12.1	24.8	10.9	22.0
Computer sciences and mathematics	39.7	54.1	20.8	36.7
Computer sciences	37.1	51.5	20.3	31.6
Mathematics	41.8	56.0	21.3	41.0
Physical sciences	9.7	18.2	8.1	15.2
Chemistry	7.7	16.3	9.4	14.2
Geosciences	12.7	26.2	14.3	24.0
Physics and astronomy	12.0	17.7	3.5	12.0
Social sciences	26.4	29.2	24.0	28.7
Economics	46.6	48.6	30.4	34.3
Political science	53.9	47.1	37.3	50.7
Psychology	12.7	15.5	14.9	16.0
Sociology and anthropology	37.9	46.9	33.4	43.4
Other	37.4	48.8	30.4	48.6

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Survey of Doctorate Recipients, 1993 and 1999.

Science & Engineering Indicators – 2002

ployment and IOF rates but show other indications of labor market distress). Between 1993 and 1999, small increases in tenure-program rates for Ph.D. recipients four to six years since receipt of degree were found in chemistry, geosciences, psychology, and sociology and anthropology.

Relation of Occupation to Field of Degree

By strict definition of occupational titles, 17 percent of employed recent Ph.D. recipients were in occupations outside S&E, often performing administrative or management functions. When asked how related their jobs were to their highest degrees achieved, only a small portion of recent Ph.D. recipients employed in non-S&E occupations said that their jobs were unrelated to their degrees. (See text table 3-13.) By field, the percentages ranged from 1.5 percent for recent Ph.D. graduates in psychology to 14.2 percent for recent Ph.D. graduates in physics and astronomy.

Satisfaction With Field of Study

One indicator of the quality of employment available to recent graduates is simply their answers to this question: "If you had the chance to do it over again, how likely is it that you would choose the same field of study for your highest degree?" When asked of those who received S&E degrees one to five years after their previous degrees, 16.6 percent of Ph.D. recipients said they were "not at all likely" compared with 20.2 percent of bachelor's recipients. (See text table 3-14.) This regret of field choice is lowest for recent Ph.D. recipients in computer sciences (6.8 percent), electrical engineering (9.8 percent), and social sciences (12.5 percent). The regret is greatest in physics (24.4 percent), chemistry (23.9 percent), and mathematics (22.4 percent).

Postdoctorate Appointments

A postdoctorate appointment (or postdoc) is defined here as a temporary position awarded in academia, industry, or government for the primary purpose of receiving additional research training. This definition has been used in the *Survey of Doctorate Recipients* when asking respondents about current and past postdoctorate positions they have held.[18] Data on postdoctorates are often analyzed in relation to recent Ph.D. labor market issues. Besides wanting to receive more training in research, recent Ph.D. recipients may accept temporary and usually lower paying postdoctorate positions because permanent jobs in their fields are not available.

Science and Engineering Indicators 1998 included an analysis of a one-time postdoctorate module from the *1995 Survey of Doctorate Recipients* that showed a slow increase

[18]It is clear, however, that the exact use of the term "postdoctorate" differs among academic disciplines, universities, and sectors that employ postdoctorates. These differences in usage have probably affected the self-reporting of postdoctorate status in the Survey of Doctorate Recipients.

Text table 3-13.
Recent Ph.D. scientists and engineers, by field of degree and relationship between Ph.D. field of study and occupation: 1999
(Percentages)

Ph.D. field	Relation of occupation to degree field: Same field	Other S&E	Related non-S&E	Nonrelated non-S&E
All S&E	71.1	11.9	14.4	2.6
Computer sciences	89.0	1.8	9.1	0.0
Engineering	75.0	17.8	5.5	1.7
Life sciences	65.2	7.5	24.1	3.2
Mathematics	84.2	3.1	6.3	6.4
Social sciences	74.6	5.8	16.9	2.7
Physical sciences	65.0	24.5	8.0	2.5

NOTE: Percentages may not add to 100 because of rounding.

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Survey of Doctorate Recipients, 1999.

Science & Engineering Indicators – 2002

Text table 3-14.
Recent S&E graduates "not at all likely" to choose same field of study if they could do it over again by field and level of degree (one to five years after degree): 1997
(Percentages)

Field of degree	Bachelor's	Master's	Doctorate
All S&E fields	20.2	12.6	16.6
Engineering	11.3	12.6	14.8
Chemical	9.5	13.1	13.0
Civil	14.2	16.6	20.9
Electrical	8.3	6.5	9.8
Mechanical	10.2	16.6	16.0
Life sciences	16.8	13.9	18.3
Agriculture	20.7	18.4	20.7
Biological sciences	16.0	14.0	18.0
Computer sciences and mathematics	8.9	6.6	14.5
Computer sciences	6.8	5.3	6.8
Mathematics	12.0	10.3	22.0
Physical sciences	16.1	18.6	23.3
Chemistry	15.7	27.2	23.9
Geoscience	25.2	12.5	20.3
Physics	9.7	17.0	24.4
Social sciences	27.3	14.3	12.5
Economics	23.7	11.8	12.6
Political science	25.5	19.6	13.3
Psychology	28.4	13.7	10.8
Sociology and anthropology	31.2	15.7	15.5

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), SESTAT Data File, 1997.

Science & Engineering Indicators – 2002

in the use of postdocs in many disciplines over time.[19] Additionally, in physics and biological sciences (fields with the most use of postdocs), median time spent in postdocs extended well beyond the one to two years found in most other fields.

[19] This was measured cross-sectionally by looking at the percentage of those in each graduation cohort who reported ever being in a postdoc position.

Data from 1999 show a small decline from 1995 in the percentage of recent S&E Ph.D. recipients entering postdoctorate positions—from 32.7 percent of 1994 graduates in 1995 to 31.5 percent of 1998 graduates in 1999. However, in the biological sciences, which account for about two-thirds of all postdocs, the postdoc rate one year after receipt of degree increased slightly from 59.6 to 61.2 percent. At the same time, physics, the other traditionally large postdoc field, experienced a decline in the incidence of postdocs one year after receipt of degree from 57.1 percent in 1995 to 47.0 percent in 1999. In fields other than physics or biological sciences, the postdoctorate rate one year after receipt of degree continued a slow decline from 21.2 percent in 1995 and 19.9 percent in 1997 to 18.9 percent in 1999.

Reasons for Taking a Postdoc

Postdocs in 1999 were asked to state their reasons for taking their current postdoctorate appointments; for all fields of degree, 32.1 percent gave "other employment not available" as their primary reason. (See text table 3-15.) Most respondents gave reasons consistent with the defined training and apprenticeship functions of postdoctorate appointments—e.g., 20.2 percent said that postdocs were generally expected for careers in their fields, 17.6 percent said they were seeking additional training in their fields, and 11.1 percent said they were seeking additional training outside their fields.

What Were 1997 Postdocs Doing in 1999?

Of those in postdoctorate positions in April 1997, 33.8 percent remained in a postdoctorate position in April 1999 (see text table 3-16)—a small reduction from the 38.0 percent of 1995 postdocs who were still postdocs in 1997 (*Science and Engineering Indicators 2000*). Only 15.1 percent transitioned from a postdoctorate to a tenure-track position at a four-year educational institution (down from 16.5 percent in 1997); 16.1 percent found other employment at an educational institution; 25.0 percent were at a for-profit firm; 6.0 percent were employed at a nonprofit institution or by government; and 1.4 percent were unemployed.

Text table 3-15.
Primary reason for taking current postdoc by field: 1999
(Percentages)

Ph.D. field	Additional training in Ph.D. field	Training outside Ph.D. field	Postdoc generally expected in field	Work with particular person or place	Other employment not available	Other
All S&E fields	17.6	11.1	20.2	15.9	32.1	3.2
Biological sciences	16.7	9.6	19.4	14.1	38.0	2.2
Chemistry	17.3	16.7	11.8	28.4	24.8	1.0
Engineering	20.5	13.8	22.4	20.5	16.2	6.6
Geoscience	12.0	6.1	31.5	38.2	12.2	0.0
Physics	10.6	13.2	25.8	8.4	38.3	3.6
Psychology	23.0	11.0	19.1	11.6	31.8	3.7

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Survey of Doctorate Recipients, 1999.

Science & Engineering Indicators – 2002

No information is available on the career intentions of those in postdoctorate positions, but it is often assumed that a postdoc is valued most by academic departments at research universities. However, more postdocs in each field accept employment with for-profit firms than obtain tenure-track positions, and many tenure-track positions are at schools where a research record is not of central importance.

Salaries for Recent S&E Ph.D. Recipients

For all fields of degree, the median salary for recent S&E Ph.D. recipients in 1999 was $49,000, a change of 13.5 percent from 1997. By field, salaries ranged from a low of $34,000 in biological sciences to a high of $75,000 in electrical engineering. (See text table 3-17.) For all Ph.D. recipients, those in the top 10 percent of salary distribution (90th percentile) earned $80,000. The 90th percentile salaries varied by fields, from a low of $60,000 for those in sociology and anthropology to a high of $101,000 for those in computer sciences. At the 10th percentile, representing the lowest pay for each field, salaries ranged from $24,000 for those in biology to $51,000 for those in electrical engineering.

Salaries for recent S&E Ph.D. recipients by sector of employment are provided in text table 3-18. In 1999, the median salary for a postdoc one to three years since receipt of degree was $30,000, less than one-half the median salary for a recent Ph.D. recipient working for a private company ($68,000). Many of the salary differentials between S&E fields are narrower when examined within employment sector. For those in tenure-track positions, median salaries ranged from $38,000 for chemistry to $61,000 for chemical engineering. At private, for-profit companies, median salaries ranged from $54,000 for sociology and anthropology to $82,000 for computer sciences.

Changes in median salaries for recent bachelor's, master's, and Ph.D. graduates (defined here as one to five years since receipt of degree) are shown in text table 3-19. For all S&E fields, median salaries for recent Ph.D. recipients rose 4.7 percent from 1997 to 1999; for bachelor's and master's degree graduates, median salaries rose 0.0 percent and 2.5 percent, respectively. Several individual disciplines reflected larger increases for Ph.D. recipients, including double-digit increases in physics (10.4 percent), mathematics (12.5 percent), computer sciences (12.0 percent), and economics (10.3 percent). A decline in median salaries occurred in biology (–3.7 percent).

Text table 3-17.
Salary distribution for recent doctorate recipients (1–3 years after degree): 1999
(Dollars)

Ph.D. field	Percentile 10th	25th	Median	75th	90th
Total	26,100	35,000	48,800	65,000	80,000
Computer sciences	48,000	60,000	75,000	89,000	101,000
Mathematical sciences	35,000	38,000	45,000	60,000	75,000
Life sciences	24,000	28,000	35,000	50,000	67,000
Physical sciences	27,000	35,000	52,000	65,000	76,000
Social sciences	30,000	37,200	45,000	56,000	75,000
Engineering	42,700	56,000	66,700	76,000	88,000

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Survey of Doctorate Recipients, 1999.

Science & Engineering Indicators – 2002

Age and Retirement

The size of the S&E workforce, its productivity, and opportunities for new S&E workers are all greatly affected by the age distribution and retirement patterns of the S&E workforce. For many decades, rapid increases in new entries led to a relatively young S&E workforce with only a small percentage near traditional retirement ages. This general pic-

Text table 3-16.
What 1997 postdocs were doing in 1999, by field
(Percentages)

Ph.D. field	Postdoc	Tenure-track at four-year institution	Other education job	For-profit job	Government job	Unemployed
All S&E fields	33.8	15.1	16.1	25.0	6.0	1.4
Biological sciences	45.0	13.9	13.9	18.0	5.5	1.8
Chemistry	21.9	6.8	6.9	52.0	5.8	3.5
Engineering	21.1	17.3	11.9	41.2	6.9	1.7
Physics	31.8	7.6	26.4	23.4	7.9	0.0
Psychology	21.2	18.5	23.1	32.8	9.6	0.0

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), merged 1997 and 1999 file from NSF's Survey of Doctorate Recipients.

Science & Engineering Indicators – 2002

Text table 3-18.
Median salaries for recent U.S. doctorate recipients (1–3 years after degree), by sector of employment: 1999
(Dollars)

Ph.D field	Total	Private, noneducational	Government	Tenure-track at four-year institution	Postdoc	Other educational
Total	48,800	68,000	55,000	43,400	30,000	33,000
Computer sciences	75,000	82,000	66,000	53,000	—	60,000
Engineering	66,700	70,000	65,000	56,300	38,000	55,000
Life sciences	35,000	61,000	48,000	42,500	28,000	36,000
Mathematical sciences	45,000	60,500	55,200	39,500	40,000	38,000
Social sciences	45,000	53,000	52,400	40,000	30,500	35,000
Physical sciences	52,000	64,000	58,000	39,400	32,700	39,000

— = Fewer than 50 cases.

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Survey of Doctorate Recipients, 1999.

Science & Engineering Indicators – 2002

Text table 3-19.
Change in median salaries for S&E graduates one to five years after degree: between 1997 and 1999
(Percentages)

Field of degree	Bachelor's	Master's	Doctorate
All S&E fields	0.0	2.5	4.7
Engineering	7.5	10.0	7.5
Chemical	11.9	5.2	3.1
Civil	5.7	4.2	9.1
Electrical	9.3	9.1	7.1
Mechanical	8.8	2.0	3.3
Life sciences	0.0	6.3	–2.8
Agriculture	0.0	11.3	10.1
Biological sciences	0.0	6.3	–3.7
Computer and mathematical sciences	13.5	7.7	9.7
Computer sciences	9.8	9.1	12.0
Mathematical sciences	3.5	12.5	12.5
Physical sciences	0.0	9.9	8.3
Chemistry	3.7	14.3	2.9
Geoscience	–3.6	–7.7	5.0
Physics	0.0	11.1	10.4
Social sciences	3.8	6.1	7.1
Economics	15.2	0.0	10.3
Political science	7.1	8.1	12.5
Psychology	4.2	1.3	1.2
Sociology and anthropology	4.2	3.3	12.6

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Scientists and Engineers Statistical Data System (SESTAT), 1997 and 1999.

Science & Engineering Indicators – 2002

ture is rapidly changing as the individuals who earned S&E degrees in the late 1960s and early 1970s move into what is likely to be the latter part of their careers.

The possible effects of age distribution on scientific productivity are controversial. Increasing average age may mean increased experience and greater productivity among scientific workers. Others argue that it can reduce the opportunities for younger scientists to work independently. Indeed, in many fields, scientific folklore as well as actual evidence indicate that the most creative research comes from younger people. Ongoing research on the cognitive aspects of aging and the sociology of science is relevant to this debate but will not be reviewed here.

Age and Implications for the S&E Workforce

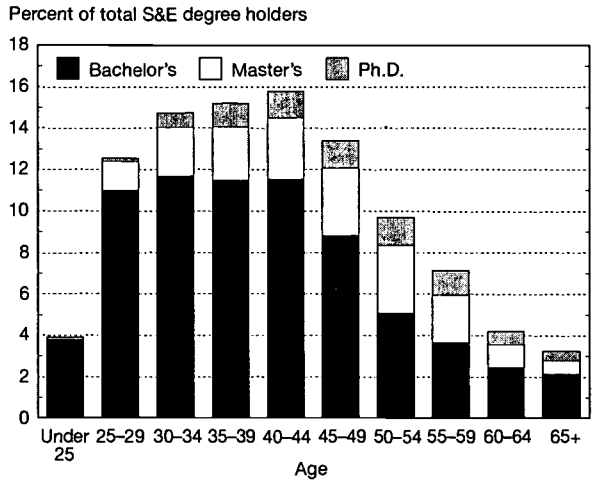
Age distribution among scientists and engineers in the workforce is affected by net immigration, morbidity, mortality, and, most of all, historical S&E degree production patterns. Age distributions for S&E degree recipients in 1999 are given by degree level and broad field of degree in appendix table 3-36. With the exception of new fields such as computer sciences (in which 56 percent of degree-holders are younger than age 40), the greatest population density of individuals with S&E degrees occurs between ages 40 and 49. This is seen in figure 3-17, which shows the age distribution of the S&E-degreed labor force broken down by level of degree. In general, most people in the S&E-degreed labor force are in their most productive years—the late 30s through early 50s, the largest group being ages 40–44. More than one-half of S&E-degreed workers are age 40 or older, and the 40–44 age group is nearly 4 times as large as the 60–64 age group.

This general pattern also holds true for those with Ph.D.s in S&E. Ph.D.-holders are somewhat older than those who have less advanced S&E degrees; this circumstance occurs because there are fewer Ph.D.-holders in younger age categories, reflecting that time is needed to obtain this degree. The greatest population density of S&E Ph.D.-holders occurs for those ages 45 to 54 years.

For all degree levels and fields, only a small portion of the S&E-degreed labor force was near traditional retirement ages: 11.8 percent overall were 55 or older. This circumstance suggests several likely effects on the future S&E labor force that are important and often overlooked:

- Barring large reductions in degree production or similarly large increases in retirement rates, the number of trained

Figure 3-17.
Age distribution of labor force with S&E highest degrees: 1999



See appendix table 3-36. *Science & Engineering Indicators – 2002*

scientists and engineers in the labor force will continue to increase for some time. The number of individuals currently receiving S&E degrees greatly exceeds the number of S&E-degreed workers near traditional retirement ages.

- Barring large increases in degree production, the average age of S&E-degreed workers will rise.
- Barring large reductions in retirement rates, the total number of retirements among S&E-degreed workers will dramatically increase over the next 20 years. This may be particularly true for Ph.D.-holders because of the steepness of their age profile.

Retirement Patterns for the S&E Workforce

The retirement behavior of individuals can differ in complex ways. Some individuals "retire" from a job while continuing to work full or part time, sometimes for the same employer, whereas others leave the workforce without a "retired" designation from a formal pension plan. Three ways of thinking about changes in workforce involvement for S&E degree-holders are summarized in text table 3-20: leaving full-time employment, leaving the workforce, and retiring from a particular job.

By age 62, 50 percent of S&E bachelor's and master's degree-recipients were not employed full time. For S&E Ph.D.-holders, this 50 percent mark was not reached until age 66, three years later. Longevity also differs by degree level when measuring those leaving the workforce entirely: one-half of S&E bachelor's and master's degree-recipients left the workforce entirely by age 65, but Ph.D.-holders did not do so until age 68. Formal retirement also occurs at somewhat higher ages for Ph.D.-holders: more than 50 percent of S&E bachelor's and master's degree-recipients "retired" from employment by age 63 compared with age 66 for S&E Ph.D.-holders.

Data on S&E degree-holders leaving full-time employment by ages 55 to 69 are shown in figure 3-18. For all degree levels, the portion of S&E degree-holders who work full time declines fairly steadily by age. After age 55, full-time employment for S&E doctorate-holders becomes significantly greater than for bachelor's and master's degree-recipients. At age 69, more than 27 percent of S&E Ph.D.-holders work full time compared with 13 percent of bachelor's or master's degree-recipients.

Academic employment may be one reason for a slower retirement rate among Ph.D.-holders. Text table 3-21 shows rates at which S&E Ph.D.-holders left full-time employment by sector of employment between 1997 and 1999.[20] Within each age group (except ages 66–70), a smaller portion of S&E Ph.D.-holders employed in 1997 at four-year colleges or universities or by government left full-time employment com-

[20]As a practical matter, it would be difficult to calculate many of the measures of retirement used previously in this chapter by sector of employment. However, a two-year transition rate can be calculated using the NSF/SRS SESTAT data file matched longitudinally at the individual level.

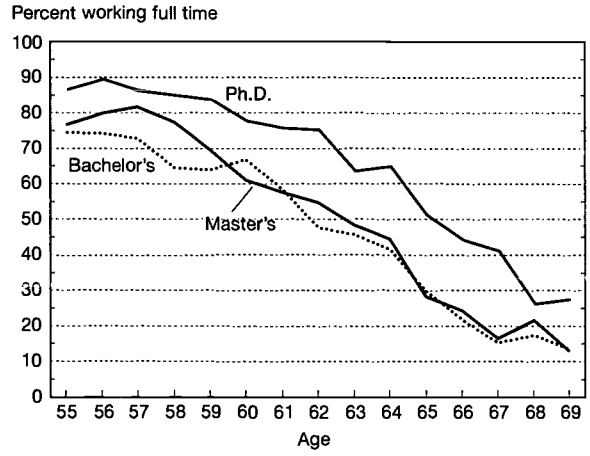
Text table 3-20.
Retirement ages for holders of S&E highest degrees: 1999

Highest degree	First age at which more than 50 percent are: Not working full time	Not in labor force	Retired from any job
Bachelor's	62	65	63
Master's	62	65	62
Doctorate	66	68	66

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Scientists and Engineers Statistical Data System (SESTAT), 1999.

Science & Engineering Indicators – 2002

Figure 3-18.
Older S&E degree holders working full time: 1999



See appendix table 3-50. *Science & Engineering Indicators – 2002*

pared with S&E Ph.D.-holders employed by for-profit companies and in all sectors combined.

Although slower retirement for S&E Ph.D.-holders (particularly in academia) is significant and of some policy interest, it is important to recognize that this does not mean that academic or other Ph.D.-holders seldom retire. Indeed, figure 3-18 indicates that their retirement patterns are similar to those for bachelor's and master's degree-recipients; retirement for Ph.D.-holders is just delayed two or three years. Even the two-year transition rates for academia in text table 3-21 show more than 40 percent of those ages 66–70 leaving full-time employment.

Although many S&E degree-holders who formally "retire" from one job continue to work full or part time, this occurs most often among those younger than age 63. (See text table 3-22.) The drop in workforce participation among the "retired" is more pronounced for part-time work; i.e., older retired S&E workers are more likely to be working full time than part time. Retired Ph.D. scientists and engineers follow this pattern, albeit with somewhat greater rates of postretirement employment than shown by bachelor's and master's degree-recipients. See sidebar, "Are Information Technology Careers Difficult for Older Workers?"

Projected Demand for S&E Workers

During the 2000–2010 period, employment in S&E occupations is expected to increase about three times faster than the rate for all occupations. (See text table 3-23.) Although the economy as a whole is expected to provide approximately 15 percent more jobs over this decade, employment opportunities for S&E jobs are expected to increase by about 47 percent (about 2.2 million jobs).

Approximately 86 percent of the increase in S&E jobs will likely occur in computer-related occupations. Overall employment in these occupations across all industries is expected to increase by about 82 percent over the 2000–2010 decade, adding almost 1.9 million new jobs. The number of jobs for computer software engineers is expected to increase from 697,000 to 1.4 million, and employment for computer systems analysts is expected to grow from 431,000 to 689,000 jobs.

Within engineering, environmental engineering is projected to have the biggest relative employment gains, increasing by 14,000 jobs, or about 27 percent. Computer hardware engineering is also expected to experience above-average employment gains, growing by 25 percent. Employment for all engineering occupations is expected to increase by less than 10 percent.

Job opportunities in life science occupations are projected to grow by almost 18 percent (33,000 new jobs) over the 2000–2010 period; at 27 percent (10,000 new jobs), medical science occupations are expected to experience the largest growth. Employment in physical science occupations is expected to increase by about 18 percent (from 239,000 to 283,000 jobs); slightly less than one-half of these projected job gains are for environmental scientists (21,000 new jobs).

Social science occupations are expected to experience above-average growth (20 percent) over the decade largely due to the employment increases anticipated for market and survey researchers (27 percent, or 30,000 new jobs). Demand for psychologists is also projected to be favorable (18 percent, or 33,000 new jobs).

Text table 3-21.
Employed, 1997 S&E doctorate holders leaving full-time employment by 1999: by sector of employment in 1997
(Percentages)

Age in 1997 (years)	All sectors	Four-year schools	For-profit company	Government
51–55	5.6	4.1	6.4	3.9
56–60	9.5	5.1	17.3	5.8
61–65	21.6	18.3	33.5	19.8
66–70	45.1	43.2	38.4	64.7
71–73	32.6	29.7	—	—

— = Insufficient sample size for estimate

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Scientists and Engineers Statistical Data System (SESTAT), 1997 and 1999.

Science & Engineering Indicators – 2002

Text table 3-22.
S&E-degreed individuals who have "retired" but continue to work: 1999
(Percentages of those retired)

	Highest degree					
	Bachelor's		Master's		Ph.D.	
Age (years)	Part time	Full time	Part time	Full time	Part time	Full time
50–55	12.1	52.9	12.5	66.8	16.9	57.0
56–62	14.4	27.8	21.3	36.9	17.0	38.7
63–70	14.5	8.3	17.1	11.9	19.3	11.6
71–75	8.1	8.4	11.9	3.3	15.2	6.1

NOTE: Retired means those who said they had ever retired from any job.

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Scientists and Engineers Statistical Data System (SESTAT), 1999.

Science & Engineering Indicators – 2002

The Global S&E Workforce and the United States

"There is no national science just as there is no national multiplication table." —Anton Chekov (1860–1904)

Science is a global enterprise. The common laws of nature cross political boundaries, and the international movement of people and knowledge made science global long before "globalization" became a label for the increasing interconnections among the world's economies. The United States (and other countries as well) gains from new knowledge discovered abroad

Are Information Technology Careers Difficult for Older Workers?

Compared with other science and technology careers, many assert that information technology (IT) is more hostile toward older workers. It has been claimed that cultural factors associated with a younger average age in IT occupations, on-the-job time pressures often associated with short project cycles, and rapid skill obsolescence associated with rapid changes in technology all adversely affect conditions for older IT workers. Recent information on this issue follows:

- The unemployment rate in 1999 for workers older than age 40 who had computer science degrees (any level) was 1.7 percent, greater that the 0.9 percent unemployment rate for those age 40 and younger with computer science degrees. However, this is a low rate of unemployment and is lower than the 1.9 percent unemployment rate found for non-IT science and engineering (S&E) graduates over age 40.
- Looking more broadly at all S&E graduates in IT occupations, IT workers over age 40 had an unemployment rate of 1.8 percent compared with 0.6 for younger IT workers and 1.8 percent for other S&E-trained workers over age 40.
- Looking at all college-educated IT workers (including non-S&E) between 1988 and 1993, those over age 40 left computer occupations at a much lower rate (14.1 percent) than did IT workers under age 25 (24.7 percent), and they left at about the same rate as IT workers ages 25–40 (14.3 percent).
- College-educated IT workers over age 40 faced greater risk of layoff during the 1988–1993 period: about 10.4 percent of 1988 computer occupation holders over age 40 were laid off during this five-year period compared with a 9.0 percent layoff rate for all college-educated computer workers and a 4.4 percent layoff rate for other college graduates.

Examining various data sources on IT workers and taking public testimony, a recent National Academy of Sciences Panel on the Information Technology Workforce concluded in part that:

> [T]he data are insufficient to establish either the presence or absence of age discrimination.... With all that said, the committee believes that the nation cannot afford to underutilize valuable human resources...and the differential experiences of older IT workers indicates some likelihood that this qualified segment of the workforce is not being fully utilized.

Text table 3-23.
Total S&E jobs: 2000 and projected 2010
(Numbers in thousands of jobs)

Occupation	2000	2010	Change
Total, all occupations	145,571	167,754	22,183
All S&E occupations	4,706	6,904	2,197
Scientists	3,241	5,301	2,059
Life scientists	184	218	33
Computer and mathematical occupations	2,408	4,308	1,900
Computer specialists	2,318	4,213	1,895
Mathematical science occupations	89	95	5
Physical scientists	239	283	44
Social scientists	410	492	82
Engineers	1,465	1,603	138

See appendix table 3-53. *Science & Engineering Indicators – 2002*

and from increases in foreign economic development. U.S. industry also increasingly relies on R&D performed abroad. The nation's international economic competitiveness, however, depends upon the U.S. labor force's innovation and productivity.

Other chapters in *Science and Engineering Indicators 2002* provide indirect indicators on the global labor force: production of new scientists and engineers through university degree programs is reported in chapter 2, and indicators of work performed by the global S&E labor force are provided in the chapter's discussion of international patenting activity and in chapter 5's data on R&D expenditures.

Few direct measures of the global S&E labor force exist. One source of data is the reports on the number of researchers in Organisation for Economic Co-operation and Development (OECD) member countries. From 1993 to 1997, the number of reported researchers in OECD countries increased by 23.0 percent (a 5.3 percent average annual rate) from approximately 2.46 million to 3.03 million. (See figure 3-19.) During this same period, comparable U.S. estimates increased 11.8 percent (a 3.7 percent average annual rate) from approximately 965,000 to 1.11 million. Although researchers in the United States, Japan, and the European Union made up 85.7

percent of the OECD total in 1997, the greatest growth in researchers came from other OECD countries, increasing 120 percent, or from 196,000 to 433,000.[21]

It is not, however, only OECD countries that have scientists and engineers. Figure 3-20 shows an estimate from disparate data sources during the 1990s of the global distribution of tertiary education graduates—roughly equivalent in U.S. terms to those who have earned at least technical school or associate degrees but also including all degrees up to Ph.D.[22] About one-fifth of the estimated 240 million tertiary graduates in the labor force were in the United States. However, of the 10 countries with the largest number of tertiary graduates, 3 are non-OECD: Russia, China, and India.

Migration of Scientists and Engineers to the United States

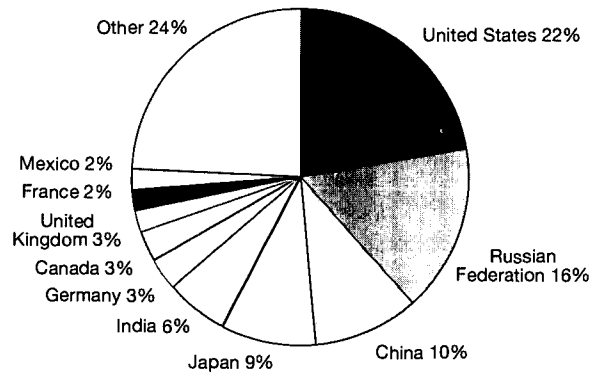
Migration of skilled S&E workers across borders is increasingly seen as a major determinant of the quality and flexibility of the labor force in most industrial countries. The knowledge of scientists and engineers can be transferred across national borders more easily than other skills. Additionally, any cutting-edge research or technology inevitably creates unique sets of skills and knowledge that can be transferred through the physical movement of people. The United States has benefited and continues to benefit greatly from this international flow of knowledge and personnel.

In April 1999, 27 percent of doctorate-holders in S&E in the United States were foreign born. (See text table 3-24.)[23] The lowest percentage of foreign-born doctorate-holders was in psychology (7.6 percent), and the highest percentage was in civil engineering (51.5 percent). Almost one-fifth (19.9 percent) of those with master's degrees in S&E were foreign born. Even at the bachelor's degree level, 9.9 percent of those with S&E degrees were foreign born; the largest percentages of degrees were in chemistry (14.9 percent), computer sciences (15.2 percent), and engineering (14.6 percent).

Origins of S&E Immigrants

Immigrant scientists and engineers come from various countries. Countries contributing more than 30,000 natives to the 1.5 million S&E degree-holders in the United States are shown in figure 3-21 by S&E doctorate and by high degree achieved in S&E. Although no one source country dominates, of those with S&E high degrees, 8 percent came from India, 7 percent came from China, 4 percent came from the Philippines, and 4 percent came from Germany (including

Figure 3-20.
Global distribution of workers with tertiary education: 1990–98

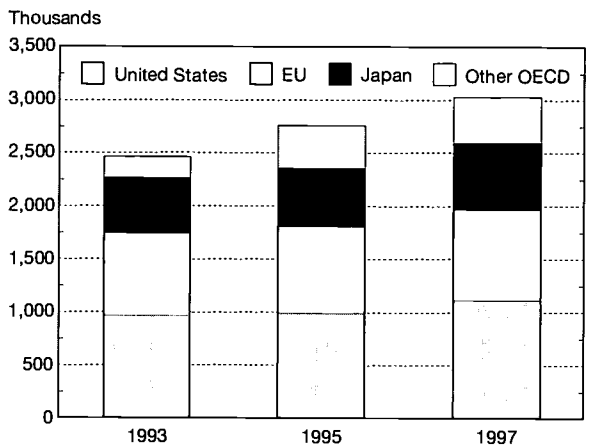


NOTES: Estimates are based on various original data sources and reporting years and are not appropriate for direct comparisons between countries but rather as a rough indicator of the global high-education workforce. No data available from countries representing around 10 percent of global population. "Tertiary education" roughly corresponds to an associate degree in the United States.

SOURCES: World Bank World Development Indicators, China National Bureau of Statistics: 1999 China Statistical Yearbook, Insituto Brasilerio de Geografia e Estatistica.

Science & Engineering Indicators – 2002

Figure 3-19.
Total researchers in OECD countries



EU = European Union

OECD = Organisation for Economic Co-operation and Development

SOURCE: Organisation for Economic Co-operation and Development Main S&E Indicators.

Science & Engineering Indicators – 2002

[21] Although these numbers represent OECD staff estimates of total researchers in all member countries, the rapid growth of "other OECD" may represent in part improvements in reporting.

[22] The primary data source used is World Bank data on labor size and percentage of the labor force with a tertiary education, supplemented with data from various national data agencies. However, these data come from different years for different countries and are the result of estimates from very different national data collection systems. Hence, these data are not suitable for making direct comparisons between countries. In addition, data were not available from countries representing about 10 percent of the global population.

[23] Because NSF's demographic data collection system is unable to refresh its sample of those with S&E degrees from foreign institutions (as opposed to foreign-born individuals with a new U.S. degree, who are sampled) more than once per decade, counts of foreign-born scientists and engineers are likely to be underestimates. Foreign-degreed scientists and engineers are included in the 1999 estimate only to the extent that they were in the United States in April 1990. In 1993, 34.1 percent of foreign-born doctorate recipients in S&E and 49.1 percent of foreign-born bachelor's recipients in S&E had acquired their degrees from foreign schools.

Text table 3-24.
Foreign-born S&E-trained U.S. scientists and engineers, by field of highest degree and highest degree level: 1999
(Percentages)

Field of highest degree	Total labor force	Bachelor's	Master's	Doctorate
All S&E	12.2	9.9	19.9	27.0
Engineering	19.8	14.6	31.1	44.6
Chemical	20.2	14.9	34.9	40.8
Civil	21.2	16.1	35.5	51.5
Electrical	23.3	18.3	33.5	47.2
Mechanical	16.5	11.6	33.4	49.2
Other	17.0	11.3	24.2	40.9
Life sciences	11.7	8.8	13.7	26.1
Agriculture	7.9	5.4	14.9	22.7
Biological sciences	13.3	10.4	14.0	27.0
Computer and mathematical sciences	17.1	12.8	26.4	35.4
Computer sciences	21.1	15.2	34.3	46.4
Mathematical sciences	12.5	10.2	15.4	31.1
Physical sciences	15.8	11.2	17.2	29.3
Chemistry	19.3	14.9	24.8	29.7
Geosciences	7.9	5.3	9.8	19.1
Physics and astronomy	18.2	9.8	18.9	32.5
Other	10.4	9.8	8.4	36.1
Social sciences	7.5	6.7	10.0	12.9
Economics	13.5	11.2	25.8	25.9
Political science	7.2	6.3	11.9	15.2
Psychology	6.2	6.1	6.4	7.6
Sociology and anthropology	6.1	5.3	12.4	12.7
Other	7.8	6.4	10.8	21.6

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Scientists and Engineers Statistical Data System (SESTAT), 1999

Science & Engineering Indicators – 2002

those born in the former East Germany). By region, 57 percent came from Asia (including the Western Asia sections of the Middle East), 24 percent came from Europe, 13 percent came from Central and South America, 6 percent came from Canada and Oceania, and 4 percent came from Africa.

The 1999 data (which are the most recent) on Immigration and Naturalization Service (INS) counts of permanent visas issued to immigrants in S&E show a small decrease in permanent visas for each S&E occupation. (See figure 3-22.) However, the total number of immigrants employed in S&E is somewhat higher than that before 1992—a year in which various legislative and administrative changes took effect. See sidebars, "High-Skill Migration to Japan" and "Foreign Scientists and Engineers on Temporary Work Visas."

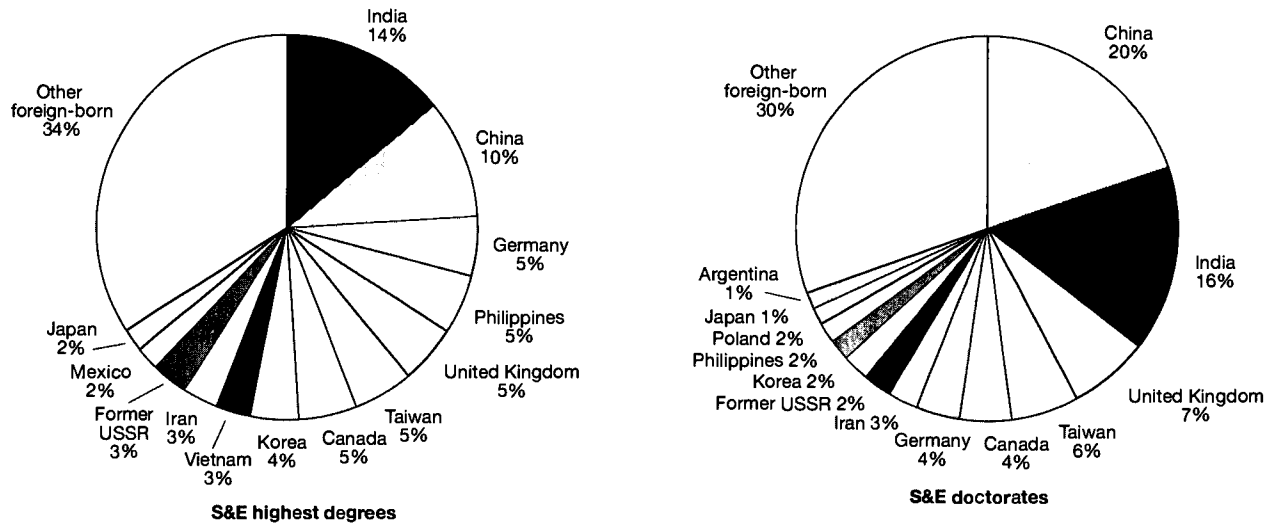
The quantity of permanent visas issued in recent years has been greatly affected by both immigration legislation and administrative changes at INS. The 1990 Immigration Act led to increases in the number of employment-based visas available, beginning in 1992. The 1992 Chinese Student Protection Act enabled Chinese nationals in the United States on student or other temporary visas to acquire permanent resident visas. These changes have allowed more scientists and engineers to obtain permanent visas.[24]

Stay Rates for U. S. Ph.D. Recipients With Temporary Visas

How many foreign students who receive S&E Ph.D.s from U.S. schools remain in the United States? According to a report by Michael Finn (2001) of the Oak Ridge Institute for Science and Education, 51 percent of 1994–95 U.S. S&E doctorate recipients with temporary visas were still in the United States in 1999. The actual numbers of foreign students staying after obtaining their Ph.D.s imply that approximately 3,500 foreign students remained from each annual cohort of new S&E doctorates in all fields. By field, the percentages ranged from 26 percent in economics to 63 percent in computer sciences. (See text table 3-27.) Within each discipline, the stay rate was mostly stable for the 1994–95 graduation cohort between 1996 and 1999. Quite possibly, however, some of this stability came from individuals in this cohort who reentered the United States and thus replaced others who left. Finn also finds an increase

[24]In addition, the easier availability of occupation-based permanent visas affects our measurements: many scientists enter on family-based visas, for which reporting of occupation is optional. If more of these individuals were using occupational visas, the number of foreign-born individuals identified as having S&E occupations would be greater.

Figure 3-21.
Foreign-born with S&E highest degrees by place of birth: 1999

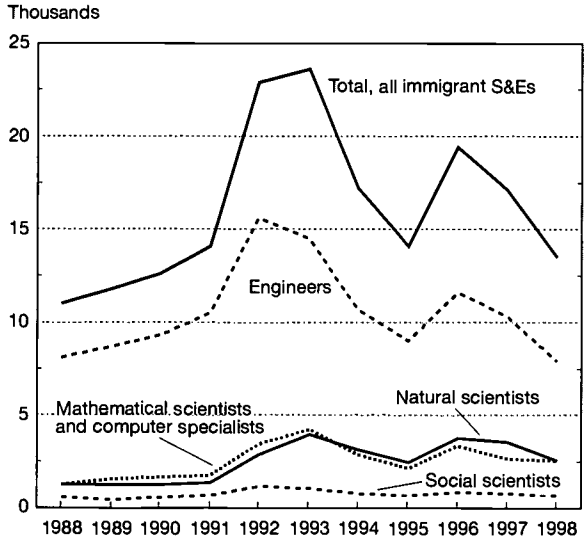


SOURCE: NSF/SRS 1999 Scientists and Engineers Statistical Data System file.

See appendix table 3-51 and 3-52.

Science & Engineering Indicators – 2002

Figure 3-22.
Immigration and naturalization service counts of permanent visas to S&E occupations: 1988–98



SOURCE: Immigration and Naturalization Service Administration Records.

Science & Engineering Indicators – 2002

over time in the shorter one-to-two-year stay rate of temporary visa S&E doctorate recipients from 40 percent in 1989 to 63 percent in 1999. This increase in the short-term stay rate may reflect increased opportunities for postdocs in the U.S. as well as an increased ability of industry to hire high-skilled workers on temporary visas.

Conclusion and Summary

The U.S. S&E labor market continues to grow both in absolute numbers and in its percentage of the total labor market. Even without the dramatic growth of IT jobs, other areas of S&E employment have had strong growth over the past two decades.

In general, labor market conditions for those with S&E degrees, although always better than for college graduates as a whole, have improved during the 1990s. Labor market conditions for new Ph.D. recipients have also been good by most conventional measures—S&E doctorate-holders are employed and doing work relevant to their training—but the gains have come in the nonacademic sectors (i.e., in most fields, a smaller percentage of recent Ph.D. recipients are obtaining tenure-track positions).

The age structure of the U.S. S&E labor force is likely to produce several major changes in the S&E labor market over the next decade. The number of individuals with S&E degrees reaching traditional retirement ages is expected to triple. Despite this, if S&E degree production remains at current rates, the number of S&E-trained individuals in the labor market will likely continue to grow for some time, albeit at a lower rate, as the number of new graduates continues to exceed the number of retirees.

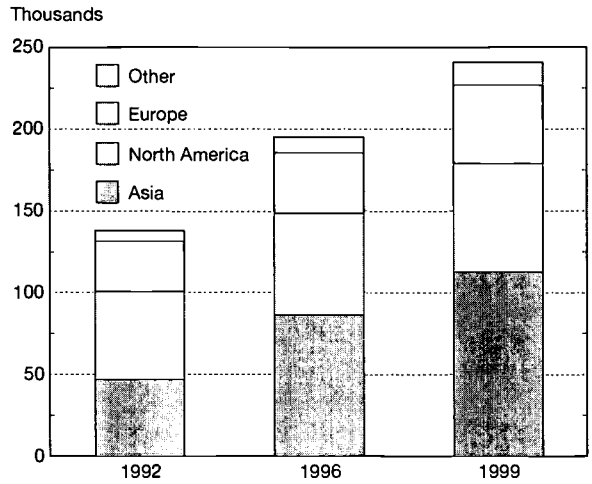
The globalization of the S&E labor force is expanding in two ways: location of S&E employment is becoming more internationally diverse, and S&E workers are becoming more internationally mobile. Although both trends are highlighted by the high-profile international competition for IT workers, every field of science and technology has been affected.

High-Skill Migration to Japan

Visa programs for temporary high-skilled workers have been a focus of recent political debate and legislative change in the United States, Germany, Canada, and many other developed countries. A 1989 revision of Japanese immigration laws made it easier for high-skilled workers to enter Japan with "temporary" visas, which allowed employment and residence for an indefinite period (although the same visa classes are used for work visits that may last for only a few months).

Scott Fuess (Fuess 2001) of the University of Nebraska (Lincoln) and the Institute for the Study of Labor (Bonn) has examined 12 Japanese temporary visa occupation categories associated with high-skilled workers and has written about the growing importance and acceptance of this labor source in Japan. In 1999, 240,936 workers entered Japan in high-skill visa categories—a 75 percent increase since 1992. (See figure 3-23.) For comparison, this is 40 percent of the number of Japanese university graduates entering the labor force each year and nearly double the number of entries to the United States in roughly similar categories (H-1b, L-1, TN, O-1, O-2).

Figure 3-23.
High-skilled worker visas in Japan, entries



SOURCE: Adapted from S. Fuess Jr., *Highly Skilled Workers and Japan: Is There International Mobility?*, University of Nebraska (Lincoln) and Institute for the Study of Labor (Bonn), 2001.

Science & Engineering Indicators – 2002

Foreign Scientists and Engineers on Temporary Work Visas

The use of various forms of temporary work visas by foreign-born scientists has been a subject of policy discussion in recent years. Many newspaper and magazine stories have been written on legislation that temporarily increased the 65,000 annual quota for the H-1b visa program, which provides visas for up to six years for individuals to work in occupations requiring at least a bachelor's degree (or to work as fashion models). Although often thought to be for information technology workers, H-1b visas are used to hire a wide variety of skilled workers.

An H-1b visa is sometimes used to fill a position not considered temporary, for a company may view an H-1b visa as the only way to employ workers waiting long periods for a permanent visa. Because applications for H-1b visas are filed by companies for positions rather than for particular individuals, these applications greatly outnumber the visas actually issued and even the applications by individuals for those visas.

Occupational information on H-1b admissions has not been released, but data are available on the occupations for which companies have been given permission to hire H-1b visa holders. (See text table 3-25.) More than one-half (53.5 percent) of H-1b certifications were for computer-related or electrical engineering positions. Another 4.1 percent were for medical occupations, primarily various types of therapists and technicians but also including medical researchers. Other science and engineering fields garnered 19.7 percent of the certifications; education (including professors) received 5.3 percent, and all other occupations totaled 18.9 percent of 1999 H-1b certifications.

Text table 3-25.
October 1999 to February 2000 S&E-related occupations on approved H-1b petitions

Occupation	Occupations: Number	Occupations: Percentage of total petitions
Total	81,262	100.0
Computer related	42,563	53.5
Engineering and architecture	10,385	13.1
Education	4,419	5.3
Medical	3,246	4.1
Social sciences	1,963	2.5
Life sciences	1,843	2.3
Mathematical and physical sciences	1,453	1.8
Non–S&E-related occupations	15,390	18.9

SOURCE: Immigration and Naturalization Service administrative data.

Science & Engineering Indicators – 2002

Scientists and engineers may also receive temporary work visas through intracompany transfer visas (L-1 visas), high-skilled worker visas under the North American Free Trade Agreement (TN-1 visas, a program primarily for Canadians now but granting full access for Mexican professionals by 2004), work visas for individuals with outstanding abilities (O-1 visas), and several smaller programs. In addition, there are temporary visas used by researchers, who may also be students (F-1 and J-1 visas), or postdocs and visiting scientists (mostly J-1 visas but often H-1b visas or other categories). Counts of visas issued for each of these categories are shown in text table 3-26. The annual quota of H-1b visas is controlled through issuance of visas to workers rather than through applications from companies. Anecdotally, some firms that expect to hire multiple workers on H-1b visas seek permission for many positions, and this affects the distribution of occupations outlined in text table 3-25.

Text table 3-26.
FY 1996 temporary visas issued in major categories likely to include scientists and engineers

Category	Issued
Work visa	
H-1b (specialty occupations requiring bachelor's equivalent)	58,327
L-1 (intracompany transfers)	32,098
TN (NAFTA visa for professionals)	29,252
O-1 (people of extraordinary ability)	2,765
O-2 (workers assisting O-1)	1,594
Student/exchange visa	
F-1 (students)	241,003
J-1 (exchange visitors)	171,164

SOURCE: Immigration and Naturalization Service administrative data.

Science & Engineering Indicators – 2002

Text table 3-27.
Recipients of 1992–93 doctorates with temporary visas at time of degree who remained in United States: 1994–97

S&E field	Temporary residents	Percent in U.S. in: 1994	1995	1996	1997
Total	16,391	48	51	52	53
Physical sciences and mathematics	4,821	55	59	60	61
Life sciences	3,765	48	51	53	54
Social sciences	2,278	29	31	32	32
Engineering	5,527	49	53	53	54

SOURCE: M. Finn, *Stay Rates of Foreign Doctorate Recipients from U.S. Universities* (Oak Ridge, TN: Oak Ridge Institute for Science and Engineering, 2000).

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Chapter 4
U.S. and International Research and Development: Funds and Alliances

Highlights

National R&D Support

♦ **Since 1994, research and development (R&D) in the United States has risen sharply, from $169.2 billion to an estimated $265 billion in 2000.** In real terms (adjusting for inflation), this rise reflects an increase of $71 billion in 1996 dollars, which was the greatest real increase in R&D for any six-year period in the nation's history.

♦ **Private industry, which provided 68 percent of total R&D funding in 2000, pays for most of the nation's R&D.** Private industry itself used nearly all (98 percent) of these funds in performing its own R&D; most (71 percent) of the funds were used to develop products and services rather than to conduct research.

♦ **Federal R&D support, in absolute terms, expanded between 1980 and 2000, from $30 billion to $70 billion, which, after inflation, amounted to a small real growth rate of 1 percent per year.** In 1980, Federal R&D support accounted for 47 percent of the nation's total R&D effort. By 2000, Federal sources accounted for considerably less (26 percent) of the U.S. R&D total.

♦ **In fiscal year (FY) 2001, the Department of Defense (DOD) will obligate the most funds among Federal agencies for R&D support—$36 billion or 45 percent of all Federal R&D obligations.** The agency obligating the second largest amount in R&D support is the Department of Health and Human Services with $19 billion, followed by the National Aeronautics and Space Administration with $10 billion, the Department of Energy with $7 billion, and the National Science Foundation with $3 billion.

♦ **The budget allocation for health-related R&D increased dramatically between FY 1982 and FY 2001 with an average real annual growth rate of 5.8 percent.** As a result, health-related R&D rose from approximately one-quarter of the Federal, nondefense, R&D budget allocation in FY 1982 to nearly one-half by FY 2001.

National R&D Performance

♦ **Industry performed the largest share of the nation's R&D—75 percent.** Universities and colleges performed 11 percent, and the Federal Government performed 7 percent. Federally Funded Research and Development Centers (FFRDCs), which are administered by various industrial, academic, and nonprofit institutions, accounted for an additional 4 percent, and other nonprofit organizations accounted for 3 percent.

♦ **From 1994 to 2000, R&D performed by industry (including their FFRDCs) grew at a remarkable rate of 7 percent per year in real terms.** In contrast, Federal intramural research over the same period increased by less than 1 percent per year in real terms.

♦ **In the industrial sector in 1999, computer and electronic products alone accounted for 20 percent of all industrial R&D and 15 percent of the nation's total R&D.** Computers and electronics accounted for $36 billion in performance R&D, which exceeded the total amount of R&D performed by all universities and colleges and their administered FFRDCs combined ($34 billion). The next largest industrial sector, transportation equipment, also performed $34 billion in R&D in 1999. The chemicals sector performed $20 billion in R&D, as did trade, a nonmanufacturing sector. Another nonmanufacturing sector, information, performed $15 billion in R&D.

♦ **A recent NSF survey has led to upward revisions in R&D performance estimates for the nonprofit sector.** R&D performance by nonprofit organizations is expected to reach $9 billion in 2000, reflecting an average annual growth of 6 percent in real terms since 1990.

♦ **In 1999, California had the highest level of R&D expenditures within its borders, $48 billion.** The six states with the highest levels of R&D expenditures, California, Michigan, New York, Texas, Massachusetts, and Pennsylvania (in descending order), accounted for approximately one-half of the entire national effort.

♦ **The nation spent $48 billion on basic research in 2000, $55 billion on applied research, and $162 billion on development.** These totals are the result of continuous increases over several years. Since 1980 they reflect, in real terms, a 5 percent annual increase for basic research, a 4 percent increase for applied research, and a 4 percent increase for development.

Federal R&D Tax Credit

♦ **In 1998, 9,800 corporate tax returns claimed $5.2 billion in research and experimentation (R&E) credits, up 18.4 percent from 1997 claims.** The unusual doubling of the credit over 1996–97 followed a 12-month gap in the credit.

♦ **The tax credit claims were equivalent to $3.3 billion (4.6 percent) of Federal R&D outlays in FY 1998.** Although R&E claims data for tax year 2000 are not available, the credit generated an estimated outlay equivalent of $2.5 billion, or 3.4 percent of Federal R&D outlays in FY 2000.

Domestic R&D Collaborations

♦ **More than 800 research joint ventures (RJVs) were formed in the United States from 1985 to 2000 (including 39 in 2000) according to filings required by the National Cooperative Research and Production Act (NCRPA).** New filings peaked in 1995 at 115 after increasing successively since 1986. These research collaborations involved more than 4,200 unique businesses and

organizations, of which more than 3,000 (about three-fourths) were U.S.-based.

- **Half of the RJVs over the entire 1985–2000 period involved companies in three industries: electronic and electrical equipment, communications, and transportation equipment.** Universities participated in 15 percent of all RJVs, and 11 percent had at least one Federal laboratory member.
- **In 2000, Federal agencies involved in R&D and technology transfer activities reported 4,209 invention disclosures, 2,159 patent applications, and 1,486 patents issued.** Since fiscal year 1997, a total of 5,655 patents have been issued to federal agencies.
- **A total of 2,924 Cooperative Research and Development Agreements (CRADAs) involving 10 Federal agencies and laboratories were active in 2000.** The largest participants by far are DOD laboratories (1,364 active CRADAS or 47 percent of the total) and DOE (687 or 23 percent). The number of active CRADAs increased rapidly in the early- and mid-1990s, reached a peak of 3,688 in fiscal year 1996, and stabilized around 3,000 since then.
- **The Small Business Innovation Research (SBIR) program, designed to increase small firms' participation in Federal R&D activity, awarded a total of $1.1 billion in R&D money to approximately 4,600 projects in 1999.** Ten agencies participated in the program in FY 1999. DOD and HHS accounted for $514 million (47 percent) and $314 million (29 percent), respectively, of SBIR funding.

International Comparisons of National R&D Trends

- **The United States accounts for approximately 44 percent of total R&D expenditures in all Organisation for Economic Co-operation and Development (OECD) countries combined. R&D investments in the United States continue to outdistance, by more than 150 percent, R&D investments made by Japan, the second largest performer.** The United States spent more on R&D activities in 1999 than did all other "group of seven" (G-7) countries (Canada, France, Germany, Italy, Japan, and the United Kingdom) combined. In 1998, total nondefense R&D spending in those six countries was slightly more (6 percent) than nondefense R&D spending in the United States.
- **The ratio of R&D spending to gross domestic product (GDP) is one of most widely used indicators of a country's commitment to growth in scientific knowledge and technology development.** As a result of a worldwide slowing in R&D spending during the early 1990s, the latest R&D/GDP ratio for most G-7 countries is no higher now than it was a decade ago. The United States ranked fifth among OECD countries in terms of reported R&D/GDP ratios for the 1996–98 period (2.7 percent). Sweden leads all countries for GDP devoted to R&D (3.7 percent), followed by Japan (3.0 percent), Finland (2.9 percent), and Switzerland (2.7 percent).
- **Although reported data by character of the work are somewhat sparse, development spending (typically performed by industry) accounts for the largest R&D share in most countries (usually approximately 60 percent of the total).** Relative to shares reported in other countries, basic research spending in the United States (16 percent of its R&D total) is less than the shares reported for France and Italy (25 and 22 percent, respectively) but higher than reported for Japan and South Korea (12 and 14 percent, respectively). Basic research accounts for 16 percent of Russia's R&D total.
- **Structural R&D shifts are under way in many G-7 and other OECD countries.** As an indication of an overall pattern of increased university-firm interactions, the proportion of academic R&D funding from industry sources (for G-7 countries combined) climbed from 2.5 percent of the academic R&D total in 1981 to 5.4 percent in 1990 and to 6.4 percent in 1998.
- **Even though most OECD countries perform R&D in support of multiple industry sectors, the distribution of the industrial R&D effort in the United States is among the most widespread and diverse.** This circumstance may indicate a national inclination and ability to become globally competitive in numerous industries rather than specialize in a few industries or niche technologies. Within countries, the electrical equipment sector often is among the largest performers of the industrial R&D effort, accounting for 20 percent or more of the industry R&D total. In addition to the United States, numerous countries report substantial increases in their service sector R&D expenditures during the past 25 years.
- **The most noteworthy trend among G-7 and other OECD countries has been the relative decline in government R&D funding.** In 1998, 31 percent of all OECD R&D funds was derived from government sources—down considerably from the 41 percent share reported for 1988. In aggregate terms, this change reflects a decline in industrial reliance on government funds for R&D performance. In 1988, the government provided 20 percent of the funds used by industry conducting R&D within OECD countries. By 1998, the government's share of the industry R&D total had fallen by one-half, to 10 percent of the total.
- **Government R&D priorities also have shifted somewhat among OECD countries during the past decade.** As a result of relative decreases not only in the United States but also in the United Kingdom and France, the national defense share of the government R&D total in all OECD countries combined declined from 43 percent in 1988 to 30 percent in 1998.
- **Among nondefense objectives, government R&D spending shares also changed somewhat during the 1988–98 period: government R&D shares have increased most for health and the environment and for various nondirected R&D (including many basic research) activities.**

Conversely, the relative share of government R&D support provided for economic development programs (which include the promotion of agriculture, fisheries and forestry, industry, infrastructure, and energy) has declined considerably, from 31 percent of the combined OECD governments' nondefense total in 1981 to 23 percent in 1998.

International R&D Alliances

- **In 2000, 574 new technology or research alliances worldwide were reported in six major sectors: information technology (IT), biotechnology, advanced materials, aerospace and defense, automotive, and nonbiotechnology chemicals.** The vast majority involved companies from the United States, Japan, and countries of Western Europe. The number of new alliances reported in this international database between 1990 and 2000 (6,477) was nearly twice the number formed during the previous 10-year period, 1980–89 (3,826). The 1990–2000 total includes 2,658 (41 percent) alliances involving exclusively U.S.-owned companies.
- **The share of biotechnology partnerships reached an all-time high of 35 percent in 2000 (199 of 574), continuing an increasing trend that began in 1991.** This is the first year that biotechnology alliances have outnumbered IT partnerships.
- **The United States and Europe were prime locales for biotechnology alliances during the 1990s.** Of the 1,500 biotechnology alliances in the past decade, 41 percent involved only companies in the United States and another 34 percent involved pairings of U.S. companies and European companies.

International Industrial R&D Investments

- **As of 1998, the latest year for which data are available, 715 R&D facilities in the United States were operated by 375 foreign-owned companies, including 251 (35 percent) owned by Japanese parent companies.** Other countries with significant presence were Germany with 107 facilities (15 percent), and the United Kingdom with 103 facilities (14 percent). On the other hand, by 1997 U.S. companies had established at least 186 R&D facilities overseas.
- **R&D spending by U.S. affiliates of foreign companies in the United States increased 28 percent in 1997–98, from $17 billion to $22 billion, the largest single-year increase since 1990.** When combined with the $15 billion spent abroad on R&D by U.S.-based companies, this yields a "net inflow" of R&D expenditures of more than $7 billion, compared with $3 billion a year earlier.
- **Chemical and computer and electronic product manufacturing had the largest single-industry shares of foreign R&D spending in the United States in 1998 (33 and 20 percent, respectively).** They include the largest subsectors attracting foreign R&D funding: pharmaceuticals and communications equipment. More than one-half of the R&D performed on chemicals and pharmaceuticals by foreign-owned subsidiaries in the United States is performed by Swiss and German units.
- **Of the $15 billion spent abroad in R&D by the nation's majority-owned foreign affiliates in 1998, more than two-thirds took place in five countries: Canada, France, Germany, Japan, and the United Kingdom.** Approximately three-fourths of all R&D performed overseas is in four manufacturing sectors: transportation equipment (30 percent), chemicals (27 percent), electronic equipment (8 percent), and industrial machinery (7 percent). R&D performed in chemicals and pharmaceuticals overseas reached $4 billion in 1998; nearly $1 billion was located in the United Kingdom. Of the $4.5 billion in automotive and other transportation equipment research performed overseas, 42 percent was located in Germany, and 21 percent in Canada.
- **Within the IT sector, foreign R&D in the U.S. emphasizes the manufacturing component, whereas R&D by foreign affiliates of U.S. companies emphasizes the services component.** The share of information services in R&D spending abroad (8.3 percent) was five times larger than that industry's share in foreign R&D (1.5 percent) in 1998. On the other hand, computer and electronic product manufacturing accounted for 20 percent of total foreign R&D in the United States, or double its 10 percent share in R&D funds spent abroad.
- **The Industrial Globalization R&D (IGRD) index, defined as the average of foreign and overseas R&D spending shares for a given industry, is an indicator of the degree of internationalization of R&D spending.** By this measure, chemical R&D flows exhibit the highest degree of internationalization (IGRD index of 25), followed by transportation equipment (IGRD index of 19) and computer manufacturing (IGRD index of 15).

Introduction

Chapter Overview

Research and development (R&D) is widely recognized as being key to economic growth, along with factors such as "education, training, production engineering, design, and quality control" (Freeman and Soete 1999). Although R&D expenditures never have exceeded 3 percent of the U.S. economy and the precise effects of R&D have been difficult to measure (or sometimes even identify), scientific and government communities continue to study R&D expenditures to understand and improve the patterns of technological change that occur in the economy and society. As Rosenberg (1994) expressed:

> Science will often provide the capability to acquire information about technological alternatives that we do not presently possess, but *science does not make the acquisition of this information cost less*....One valuable perspective on the cost of acquiring information is offered by the available data on R&D expenditures. These data are additionally valuable in showing the extent to which the generation and diffusion of knowledge has become an economic activity.

R&D decisionmaking—how much money different organizations spend and the areas of science or engineering on which they spend it—is critical to the future of the U.S. economy and national well-being. For this reason, the United States and many other nations collect extensive R&D expenditure data that are disseminated worldwide for study by analysts in a wide variety of fields.

In addition to indicating the direction of technological change, R&D expenditure data also measure the level of economic purchasing power that has been devoted to R&D projects compared with other economic activities. Industrial (private sector) funding of R&D, for example, may be considered an economic metric of how important R&D is to companies, since companies could easily devote those same funds to other business activities. Likewise, government support for R&D reflects governmental and societal commitment to scientific and engineering advancement, an objective that must compete for dollars against other functions served by discretionary government spending. The same basic notion is true for the other sectors that fund R&D: universities, colleges, and other nonprofit organizations.

Total R&D expenditures, therefore, reveal the perceived economic importance of R&D relative to all other economic activities. Because institutions invest in R&D without knowing the final outcome (if they did, then it would not be R&D), the amount they devote is based on their perception, rather than on their absolute knowledge, of R&D's value. Such information about R&D's perceived relative value is also extremely useful for economic decisionmaking. Of course, R&D data alone are not enough to accurately analyze the future growth of a field of study or an industrial sector, but they represent important input into such analyses. In addition to the total amount of R&D expenditures, a policy variable of equal importance is the composition of this R&D (Tassey 1999). Both econometric work and case studies have demonstrated the different but equally important roles of each phase of the R&D life cycle. Over this cycle, different classes of R&D funders and performers rise in importance, then give way to others. The availability and timeliness of these different participants determine the success or failure of technology-intensive industries relative to foreign competitors. This chapter is designed to provide a broad understanding of the nature of R&D expenditures and the implications of R&D expenditures for science and technology (S&T) policy.

Chapter Organization

This chapter is organized into five major parts that examine trends in R&D expenditures. The first and second parts look into R&D funded and performed solely in the United States. The first part contains information on economic measures of R&D spending in the United States and trends in financial support for R&D, giving particular attention to direct Federal R&D support as well as indirect fiscal measures to stimulate R&D growth. The second part describes trends in total R&D performance in the United States; areas addressed include industrial R&D performance and R&D performance by geographic location, character of work, and field of science.

The third part summarizes available information on R&D collaborations, alliances, and partnerships. It contains sections on intersector and intrasector R&D partnerships and alliances, including private-private, public-private, and public-public collaborations that have formed both domestically and internationally.

The fourth part compares R&D trends across nations. It contains sections on total and nondefense R&D spending, ratios of R&D to gross domestic product (GDP) among different nations, international R&D funding by performer and source (including information on industry subsectors and academic science and engineering fields), the character of R&D efforts (or R&D efforts separated into basic research, applied research, and development components), and international comparisons of government R&D priorities and tax policies.

The fifth part provides statistics on international R&D investment flows. It contains a review of the U.S. international R&D investment balance, discusses patterns in overseas and foreign R&D performed in the United States in terms of expenditures and facility placement, and offers a new Industry Globalization R&D (IGRD) index as a way of measuring which industries have adopted the most internationalized approach in their R&D activities.

R&D Support in the United States

Since 1994, R&D in the United States has risen sharply, from $169.2 billion to an estimated $264.6 billion in 2000.[1] In real terms (adjusting for inflation), this rise has been from $176.2 billion to $247.5 billion in constant 1996 dollars, reflecting an annual real growth rate of 5.8 percent. The increase of $71.3 billion 1996 dollars between 1994 and 2000 is the greatest single real increase for any six-year period in

[1]At the time this report was written, estimated data for 2000 were the latest figures available on R&D expenditures.

the history of the R&D data series, which began in 1953. (See figure 4-1.) The consistent pattern of R&D growth is noteworthy, implying a broad-based, increased interest in the promotion of R&D activities. See sidebar, "Definitions of Research and Development."

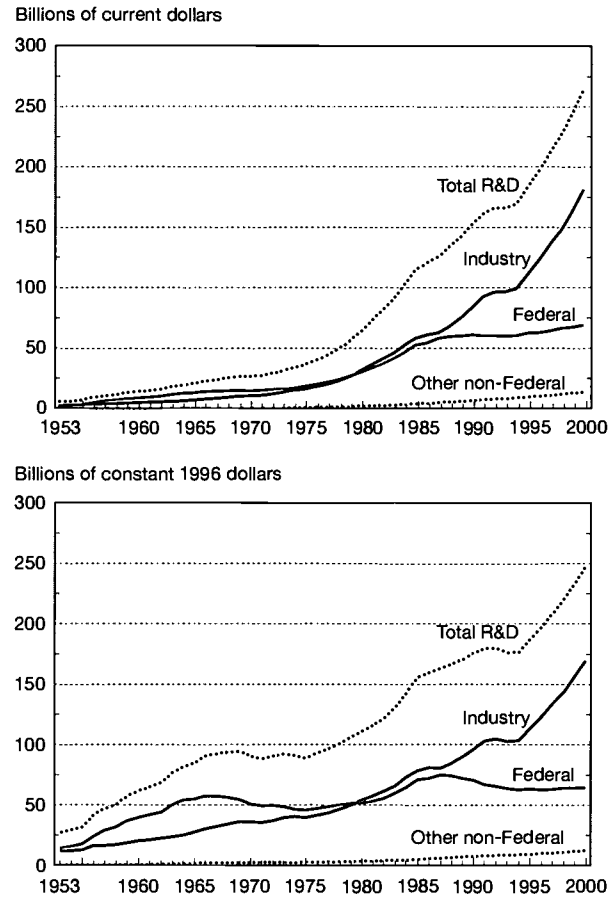
By comparison, gross domestic product (GDP), the main measure of the nation's total economic activity, grew in real terms by 4 percent per year between 1994 and 2000. Thus, R&D has generally been outpacing the growth of the overall economy since 1994. As a result, R&D as a proportion of GDP has risen from 2.40 percent in 1994 to 2.66 percent in 2000.

Organizations that conduct R&D often receive outside funding; conversely, organizations that fund R&D often do not perform all R&D themselves. Therefore, in any discussion of the nation's R&D, a distinction must be made between where the money came from originally (R&D expenditures characterized by source of funds) and where the R&D is actually being performed (R&D expenditures categorized by performer).

Private industry, which provided 68.4 percent ($181.0 billion) of total R&D funding in 2000, pays for most of the nation's R&D. Private industry itself used nearly all of these funds (98.1 percent) in performing its own R&D; most of the funds (70.9 percent) were used to develop products and services rather than to conduct research. In 2000, the Federal Government provided the second largest share of R&D funding, 26.3 percent ($69.6 billion), and the other sectors of the economy (i.e., state governments, universities and colleges, and nonprofit institutions) contributed the remaining 5.3 percent ($14.0 billion). (See figures 4-1, 4-2, and 4-3; and text table 4-1.)

Briefly, in terms of R&D performance—and discussed in greater detail below—industry in 2000 accounted for an even larger share of the total (74.6 percent), followed by universities and colleges (11.4 percent) and the Federal Government (7.2 percent). Federally Funded Research and Development Centers (FFRDCs), which are administered by various industrial, academic, and nonprofit institutions, accounted for an additional 3.5 percent, and other nonprofit organizations accounted for 3.3 percent. (See text table 4-1.)[2]

Figure 4-1.
National R&D funding, by source: 1953–2000



See appendix tables 4-5 and 4-6.

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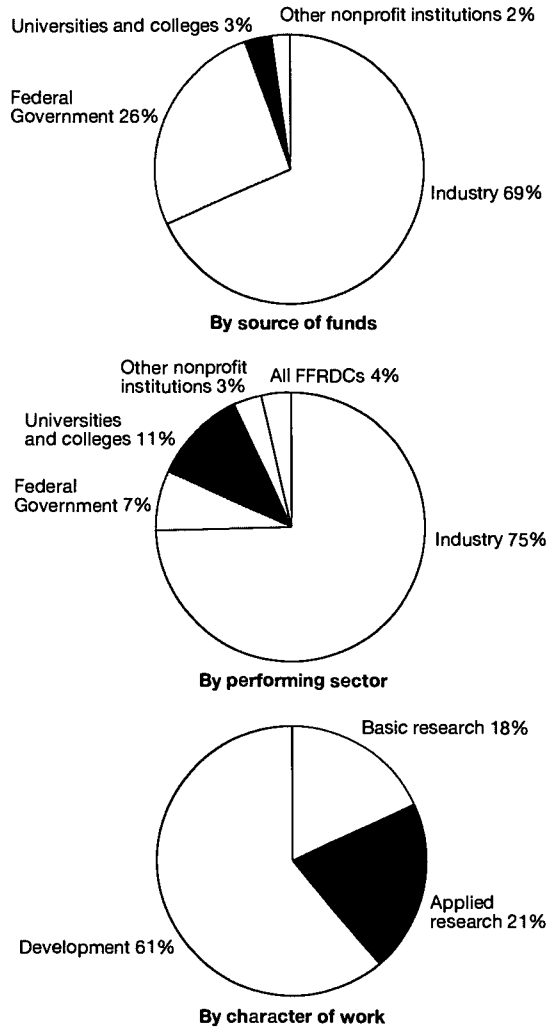
National R&D Growth Trends

Between 1953 and 1969, R&D expenditures grew substantially at a real annual rate of 8.2 percent. However, starting in 1969 and for nearly a decade thereafter, R&D growth failed to keep up with either inflation or general increases in economic output. In fact, between 1969 and 1975, real R&D expenditures declined by 0.9 percent per year, as both business and government tended to deemphasize research programs (See figure 4-1.) Federal funding, in particular, fell considerably during this period—down 2.9 percent in real terms, which was felt in both defense- and nondefense-related programs.

The situation turned around in the mid-1970s. Following an economic recovery from the 1974 oil embargo and the 1975 recession, R&D expenditures increased in real terms by approximately 74.8 percent from 1975 to 1985 (5.7 percent per year) compared with a 40.0 percent rise in real GDP over the same period. During the first half of this period (1975–80), there was considerable growth in Federal R&D funding for nondefense activities. Although defense-related R&D expenditures rose as well, much of the Federal R&D gain was attributable to energy-related R&D (particularly nuclear energy development) and to greater support for health-related R&D. Non-Federal R&D increases were concentrated in industry and resulted largely from greater emphasis on energy conservation and improved use of fossil fuels. Consequently, energy concerns fostered increases in R&D funding by both

[2]In some of the statistics provided in this chapter, FFRDCs are included as part of the sector that administers them. In particular, statistics on the industrial sector often include industry-administered FFRDCs as part of that sector because some of the statistics from the NSF Industry R&D Survey cannot be separated with regard to the FFRDC component. However, whenever a sector is mentioned in this chapter, the wording used will specify whether or not FFRDCs are included. FFRDCs are organizations exclusively or substantially financed by the Federal Government to meet particular requirements or to provide major facilities for research and associated training purposes. Each center is administered by an industrial firm, an individual university, a university consortia, or a nonprofit organization.

Figure 4-2.
Shares of national R&D expenditures: 2000



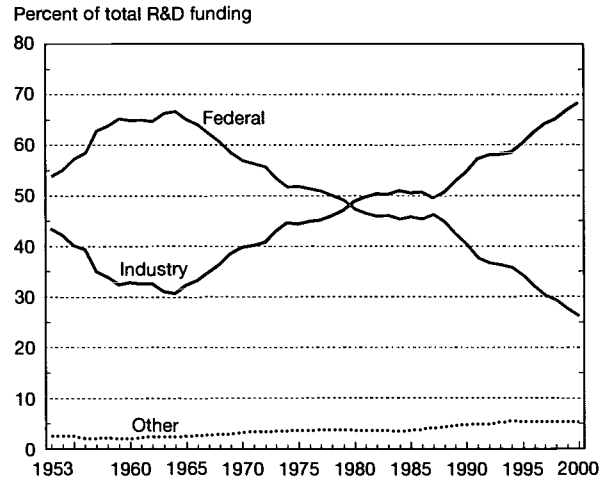
FFRDCs = Federally Funded Research and Development Centers

NOTE: Data labels rounded to nearest whole number. National R&D expenditures are an estimated $265 billion in 2000.

See appendix tables 4-3, 4-5, 4-7, 4-11, and 4-15.

Science & Engineering Indicators – 2002

Figure 4-3.
Shares of national R&D expenditures, by source of funds: 1953–2000



See appendix table 4-5. *Science & Engineering Indicators – 2002*

Federal and non-Federal sources. Support for energy R&D rose more than 150 percent in real terms between 1974 and 1979 and accounted for approximately one-half of the national increase in real R&D spending.

Overall, the 1975–80 R&D recovery witnessed an average growth rate of 4.5 percent per year. That annual rate remained between 4 and 5 percent through 1982, although the early 1980s saw a heavy shift toward defense-related activities. As a result of these increases in defense R&D, growth in real R&D expenditures accelerated to an average annual rate of 8.5 percent over 1982–85. Such rapid growth had not been seen since the Sputnik era of the early 1960s.

On average, R&D spending increased 7.0 percent per year in real terms in the first half of the 1980s, then again changed abruptly. In the nine years from 1985 to 1994, average annual R&D growth after inflation slowed to 1.4 percent, vis-à-vis a 2.8 percent annual real growth in GDP. Reductions in both Federal and non-Federal funding of R&D, as a proportion of GDP, had contributed to this slowing. However, it is primarily the decline in real Federal R&D funding that contributed to the slow growth of R&D in the early 1990s.[3]

This downward trend was reversed again in 1994, caused by substantial increases in industrial R&D, most notably in the computer and other information technology sectors.[4] As already indicated, R&D in the United States grew in real terms by 5.8 percent per year between 1994 and 2000, despite little real growth (0.5 percent per year) in Federal R&D support. During the same period, industrial support for R&D grew at a real annual rate of 8.6 percent. Much of this increase might be explained by the favorable economic conditions that generally existed during this period.

[3]These findings are based on performer-reported R&D levels. In recent years, increasing differences have been detected in data on federally financed R&D as reported by Federal funding agencies, on the one hand, and by performers of the work (most notably, industrial firms and universities), on the other hand. This divergence in R&D totals is discussed later in this chapter; see sidebar, "Tracking R&D: Gap Between Performer- and Source-Reported Expenditures."

[4]For a detailed discussion of this upturn, see Jankowski (1998).

Text table 4-1.
U.S. R&D expenditures, by performing sector, source of funds, and character of work: 2000
(Millions of dollars)

Performers	Source of funds: Total	Industry	Federal Government	U&Cs	Other nonprofit institutions	Percent distribution, by performer
Total R&D	264,622	181,040	69,627	8,166	5,789	100.0
Industry	197,280	177,645	19,635	NA	NA	74.6
Industry-administered FFRDCs	2,575	NA	2,575	NA	NA	1.0
Federal Government	19,143	NA	19,143	NA	NA	7.2
U&Cs	30,154	2,310	17,475	8,166	2,203	11.4
U&C-administered FFRDCs	5,801	NA	5,801	NA	NA	2.2
Other nonprofit institutions	8,750	1,085	4,079	NA	3,586	3.3
Nonprofit-administered FFRDCs	918	NA	918	NA	NA	0.3
Distribution by sources (%)	100.0	68.4	26.3	3.1	2.2	NA
Basic research, total	47,903	16,223	23,310	5,023	3,346	100.0
Industry	15,378	14,199	1,179	NA	NA	32.1
Industry-administered FFRDCs	704	NA	704	NA	NA	1.5
Federal Government	3,525	NA	3,525	NA	NA	7.4
U&Cs	20,656	1,421	12,857	5,023	1,355	43.1
U&C-administered FFRDCs	2,809	NA	2,809	NA	NA	5.9
Other nonprofit institutions	4,492	602	1,898	NA	1,991	9.4
Nonprofit-administered FFRDCs	339	NA	339	NA	NA	0.7
Distribution by sources (%)	100.0	33.9	48.7	10.5	7.0	NA
Applied research, total	55,041	36,400	14,460	2,577	1,604	100.0
Industry	37,648	35,396	2,252	NA	NA	68.4
Industry-administered FFRDCs	285	NA	285	NA	NA	0.5
Federal Government	5,826	NA	5,826	NA	NA	10.6
U&Cs	7,260	729	3,259	2,577	695	13.2
U&C-administered FFRDCs	1,401	NA	1,401	NA	NA	2.5
Other nonprofit institutions	2,504	275	1,320	NA	909	4.5
Nonprofit-administered FFRDCs	117	NA	117	NA	NA	0.2
Distribution by sources (%)	100.0	66.1	26.3	4.7	2.9	NA
Development, total	161,679	128,417	31,857	566	839	100.0
Industry	144,254	128,050	16,205	NA	NA	89.2
Industry-administered FFRDCs	1,586	NA	1,586	NA	NA	1.0
Federal Government	9,792	NA	9,792	NA	NA	6.1
U&Cs	2,238	160	1,360	566	153	1.4
U&C-administered FFRDCs	1,592	NA	1,592	NA	NA	1.0
Other nonprofit institutions	1,754	208	860	NA	686	1.1
Nonprofit-administered FFRDCs	463	NA	463	NA	NA	0.3
Percent distribution by sources (%)	100.0	79.4	19.7	0.3	0.5	NA

FFRDCs = Federally Funded Research and Development Centers; U&Cs = universities and colleges; NA = not applicable

NOTES: State and local government support to industry is included in industry support for industry performance. State and local government support to U&Cs ($2,197 million in total R&D) is included in U&C support for U&C performance.

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *National Patterns of R&D Resources: 2000 Data Update*, NSF 01-309 (Arlington, VA, March 2001). Available at <http://www.nsf.gov/sbe/srs/nsf01309/start.htm>.

Science & Engineering Indicators – 2002

Trends in Federal R&D Support by National Objective, Federal Agency, and Performer Sector

Federal Support as a Share of the Nation's R&D Efforts

In recent years, the Federal Government has contributed smaller shares of the nation's R&D funding. The Federal Government had once been the main provider of the nation's R&D funds, accounting for 53.9 percent in 1953 and as much as 66.8 percent in 1964. Its share of R&D funding first fell below 50 percent in 1979 and remained between 44 and 47 percent from 1980 to 1988. Since then, its share has fallen steadily to 26.3 percent in 2000, the lowest ever recorded in the history of the NSF's R&D data series. This decline in the Federal Government share, however, should not be misinterpreted as a decline in the actual amount funded. Federal support in 2000 ($69.6 billion), for example, actually reflects a 0.8 percent increase in real terms over its 1999 level. Because industrial funding increased much faster (see

Definitions of Research and Development

The National Science Foundation (NSF) uses the following definitions in its research and development (R&D) surveys. They have been in place for several decades and generally are consistent with international definitions.

R&D. According to international guidelines for conducting R&D surveys, research and development, also called research and experimental development, comprises creative work that is undertaken on a systematic basis. R&D is performed for the purpose of "increasing the stock of knowledge, including knowledge about humanity, culture, and society," and using "this stock of knowledge to devise new applications" (Organisation for Economic Co-operation and Development (OECD) 1994).

Basic research. The objective of basic research is to gain more comprehensive knowledge or understanding of the subject under study without specific applications in mind. In industry, basic research is defined as research that advances scientific knowledge but does not have specific immediate commercial objectives, although it may be in fields of present or potential commercial interest.

Applied research. Applied research is aimed at gaining the knowledge or understanding to meet a specific, recognized need. In industry, applied research includes investigations oriented to discovering new scientific knowledge that has specific commercial objectives with respect to products, processes, or services.

Development. Development is the systematic use of the knowledge or understanding gained from research directed toward the production of useful materials, devices, systems, or methods, including the design and development of prototypes and processes.

R&D plant. R&D plant includes the acquisition of, construction of, major repairs to, or alterations in structures, works, equipment, facilities, or land for use in R&D activities.

Budget authority. Budget authority is the authority provided by Federal law to incur financial obligations that will result in outlays.

Obligations. Federal obligations represent the amounts for orders placed, contracts awarded, services received, and similar transactions during a given period, regardless of when funds were appropriated or payment required.

Outlays. Federal outlays represent the amounts for checks issued and cash payments made during a given period, regardless of when funds were appropriated or obligated.

above), Federal support as a proportion of the total has continued to decline.

Federal R&D funding, in absolute terms, expanded between 1980 and 2000, from $30.0 to $69.6 billion, which, after inflation, amounted to a small, real growth rate of 1.1 percent per year. This rate, however, was not uniform across the period. From 1980 to 1985, Federal R&D funding grew on average by 6.3 percent in real terms annually. Nearly all of the rise in Federal R&D funding during the early 1980s was due to large increases in defense spending.

Federal support slowed considerably beginning in 1986, reflecting the budgetary constraints imposed on all government programs, including those mandated by the Balanced Budget and Emergency Deficit Control Act of 1985 (also known as the Gramm-Rudman-Hollings Act) and subsequent legislation (notably the Budget Enforcement Act of 1990, which legislated that new spending increases be offset with specific spending cuts). Between 1988 and 1994, Federal R&D support per year declined in real terms from $75.0 billion to $63.3 billion in constant 1996 dollars, but by 2000 had increased slightly to $65.1 billion. From 1996 to 2000, however, the direction of Federal R&D had shifted; for example, Federal support to academia, as a percentage of total Federal support, had risen from 22.2 to 25.1 percent.

Federal Support by National Objective

Defense- and Space-Related R&D. Defense-related R&D, as a proportion of the nation's total R&D, has shifted substantially. From 1953 to 1959, it rose from 48.0 to 54.3 percent; it then declined to a relative low of 24.3 percent in 1980. From 1980 to 1987, it climbed to 31.8 percent. It has fallen substantially since then, reaching a low of 13.6 percent in 2000. (See figure 4-4.)[5]

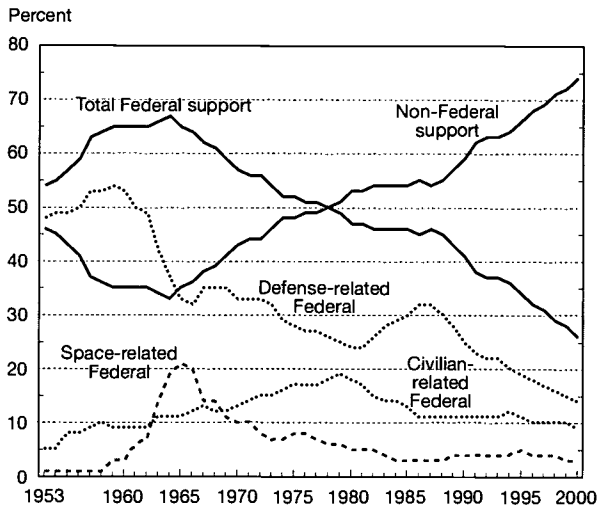
Space-related R&D funding, as a percentage of total R&D funding, reached a peak of 20.9 percent in 1965, during the height of the nation's efforts to exceed the Soviet Union in space travel. It then declined to a low of 3.0 percent in 1986. By 1995, it climbed back up to 4.5 percent, before, once again, slipping to 3.3 percent in 2000. Federal support for civilian-related (that is, nondefense-nonspace) R&D programs, as a percentage of total U.S. R&D, has been declining steadily since 1994, when it was 11.6 percent. It was 9.4 percent in 2000, the lowest since 1962 (when it had been 9.1 percent).

In 1980, the Federal budget authority for defense-related R&D was roughly equal to that for nondefense R&D.[6] (See insert in figure 4-5.) As a result of modifications to U.S. security measures in an evolving international arena, a defense-related R&D expansion occurred in the early and mid-1980s. For example, defense activities of the Department of Defense (DOD) and the Department of Energy (DOE) accounted for approximately one-half of the total Federal R&D budget au-

[5]These shares by national objective represent a distribution of performer-reported R&D data. They are distinct from the budget authority shares reported below that are based on the various functional categories constituting the Federal budget.

[6]R&D budget authority data represent a distribution of Federal source-reported data. See footnote 5.

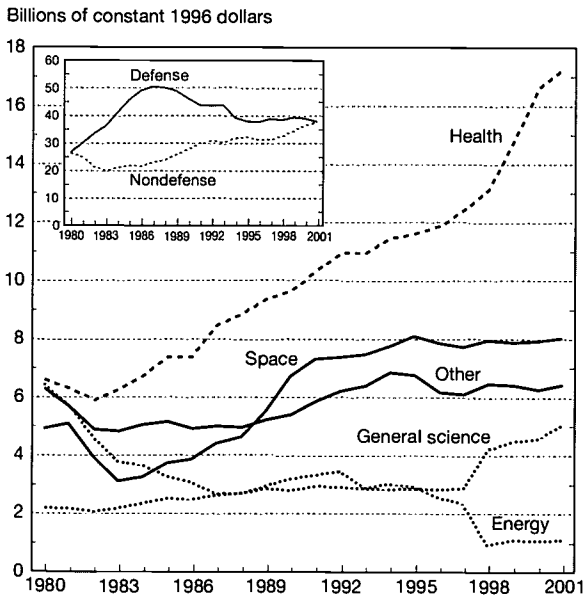
Figure 4-4.
Trends in Federal and non-Federal R&D expenditures as percentage of total R&D: 1953–2000



See appendix table 4-19. *Science & Engineering Indicators – 2002*

thority in 1980. By 1986, such defense-related activities peaked at 69 percent of the Federal R&D budget authority. (See figure 4-5.) This defense-related R&D expansion was followed by a period of defense-related R&D reductions in the late 1980s and the 1990s. Nondefense R&D, on the other hand, has been increasing steadily since 1983. For fiscal year (FY) 2001, the preliminary budget authority for defense R&D and for nondefense R&D are about equal ($41.4 and $41.3 billion, respectively) and are 42.2 and 43.3 percent higher in real terms than their respective 1980 levels.

Figure 4-5.
Federal R&D funding, by budget function: FYs 1980–2001



NOTES: "Other" includes all nondefense functions not separately graphed, such as agriculture and transportation. The 1998 increase in general science and decrease in energy resulted from a reclassification.

See appendix table 4-26. *Science & Engineering Indicators – 2002*

Of all the money authorized to be spent by the Federal Government on defense activities in 2001, according to the Federal budget authority, R&D (most of which is development) accounts for 14 percent. In contrast, R&D accounts for about 3 percent of the Federal nondefense budget authority, although many nondefense functions have much higher proportions. (See text table 4-2.) The budget allocation for defense programs declined by an average real annual rate of 1.7 percent from FY 1986 to FY 2001.

Civilian-Related R&D. Since 1986, the Federal budget authority for civilian-related R&D grew faster than that for defense-related R&D. In particular, the budget allocation for health- and space-related R&D increased substantially between FY 1986 and FY 2001, with average real annual growth rates of 5.8 and 5.0 percent, respectively. (As indicated in figure 4-5, most of this growth in the budget authority for space-related R&D occurred between FY 1986 and FY 1991.)

With regard to nondefense objectives (or "budget functions"), R&D accounts for 71.6 percent of funds for general science of which 80.7 percent is devoted to basic research. (See text table 4-2.) R&D accounts for only 7.4 percent of funds for natural resources and the environment, nearly all of which (91.7 percent) is devoted to applied R&D. Among funds for health, R&D represents 11.1 percent, most of which (55.1 percent) is devoted to basic research and nearly all of which is directed toward National Institutes of Health (NIH) programs.

At first glance, the R&D budget authority for energy appears to have declined rapidly in recent years, notably, from $2.3 billion in FY 1997 to only $0.9 billion in FY 1998 in constant 1996 dollars (as shown in figure 4-5). However, this effect was not an actual decline in economic resources devoted to energy R&D but merely the result of reclassification. Beginning in FY 1998, several DOE programs were reclassified from "energy" to "general science," so that the drop in energy R&D was equally offset by a rise in general science from $2.9 to $4.2 billion in constant 1996 dollars. (See also sidebar, "The Federal Science and Technology Budget and Related Concepts.")

Understanding the Growth in Federal Health-Related R&D. As illustrated in figure 4-5, the budget allocation for health-related R&D increased dramatically between FY 1982 and FY 2001, with an average real annual growth rate of 5.8 percent. As a result, health-related R&D rose from representing roughly one-quarter (27.5 percent) of the Federal, nondefense R&D budget allocation in FY 1982 to nearly one-half (45.6 percent) by FY 2001. Many individuals in the science community have expressed the concern that health-related R&D has received the lion's share of increases in Federal support for R&D, whereas the other broad areas (e.g., space, general science, energy, and the environment) have experienced much lower growth, or even declines, in Federal support.

Text table 4-2.
Budget authority for R&D by function and character of work: proposed levels for FY 2001
(Millions of dollars)

Budget function	Basic research	Applied research and development	R&D total	R&D as percentage of total budget
Total	20,259	62,472	82,730	7.7
National defense	1,262	40,152	41,414	13.6
Health	10,399	8,459	18,858	11.1
Space research and technology	1,761	6,971	8,732	66.7
General science	5,272	257	5,529	71.6
Natural resources and environment	162	1,771	1,932	7.4
Transportation	202	1,462	1,665	2.8
Agriculture	702	748	1,450	6.4
Energy	46	1,138	1,184	NA
All other	453	1,515	1,967	NA

NA = not applicable

NOTE: Total budget authority used in the percentage calculation (last column) includes only those functions in which R&D is conducted.

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Federal R&D Funding by Budget Function: Fiscal Years 1999–2001*, NSF 01-316 (Arlington, VA, 2001).

Science & Engineering Indicators – 2002

Although there is no consensus as to why health-related research has continued to receive increased Federal support, the current framework under which the Federal Government provides support for health and medical research can be traced back to important position statements made in the aftermath of World War II. These positions were expressed in two important reports: a 1947 report by J. Steelman entitled "Science and Public Policy" and a 1945 report by V. Bush entitled "Science—The Endless Frontier: A Report to the President on a Program for Postwar Scientific Research." These reports promoted support for other fields of science, but their specific focus on the topic of health research has supported the argument for growth in its Federal support since. In the early 1970s, medical research was promoted by the nation's war on cancer, and in the 1980s it was promoted by the nation's (and the world's) concern over the acquired immune deficiency syndrome (AIDS) epidemic (Jankowski 2001a). Growth in health-related R&D in the 1990s has supported research on cancer and AIDS as well, but a great deal of the new funding has been directed toward other disease areas. Part of the reason for the observed growth of health-related R&D stems from opportunities afforded by biotechnology research advances, but perhaps part of the growth comes also from the influence of disease-specific lobbying groups.

R&D by Federal Agency

According to preliminary data provided by Federal agencies, DOD will obligate the most funds among Federal agencies for R&D support in FY 2001, $36.4 billion (44.6 percent) of all Federal R&D obligations. (See text table 4-3.) The bulk of these funds ($32 billion) will be for development as compared with basic or applied research. The agency obligating the second largest amount in R&D support is the Department of Health and Human Services (HHS) with $19.2 billion, most of which ($10.4 billion) will be for basic research, followed by the National Aeronautics and Space Administration (NASA) with $9.6 billion (most of which will be for development), DOE with $6.8 billion (nearly equally divided among basic research, applied research, and development), and NSF with $3.2 billion (almost all of which will be for basic research). Together, these five agencies account for 92.2 percent of all estimated Federal support for R&D in 2001: 93.1 percent of Federal support for basic research, 78.7 percent of Federal support for applied research, and 97.7 percent of Federal support for development.

The majority of HHS's R&D support (57 percent) is directed toward academia. By preliminary estimates, HHS accounted for 61.9 percent of all Federal R&D obligations to universities and colleges, excluding university-administered FFRDCs in FY 2001. (See text table 4-4.) A total of 23.6 percent is spent internally, mostly in NIH laboratories. HHS also accounts for 71.6 percent of all Federal R&D obligations for nonprofit organizations in FY 2001. Approximately 6 percent of HHS R&D obligations are slated for industrial firms.

NSF and DOD are the other leading supporters of R&D conducted in academic facilities. (See text table 4-4.) Universities and colleges account for 82.8 percent of NSF's R&D budget. The bulk of the remaining NSF budget is divided between university-administered FFRDCs (6.1 percent), other nonprofit organizations (5.8 percent), and industry (3.6 percent). In FY 2001, DOD provides only 4.2 percent of its R&D support to universities and colleges, in contrast to 69.5 percent to industry and 23.6 percent to Federal intramural activities. By comparison, DOE provides 10.4 percent of its support to universities, 16.8 percent to industry, 12.8 percent to Fed-

The Federal Science and Technology Budget and Related Concepts

In recent years, alternative concepts have been used to isolate and describe fractions of Federal support that could be associated with scientific achievement and technological progress. In a 1995 report (National Academy of Sciences 1995), members of a National Academy of Sciences (NAS) committee proposed an alternative method of measuring the Federal Government's science and technology (S&T) investment. According to the committee members, this approach, titled the Federal Science and Technology (FS&T) budget, might provide a better way to track and evaluate trends in public investment in R&D. The FS&T concept differed from Federal funds for research in that it did not include major systems development supported by the Department of Defense and the Department of Energy, and it contained not only research but also some development and some R&D plant.

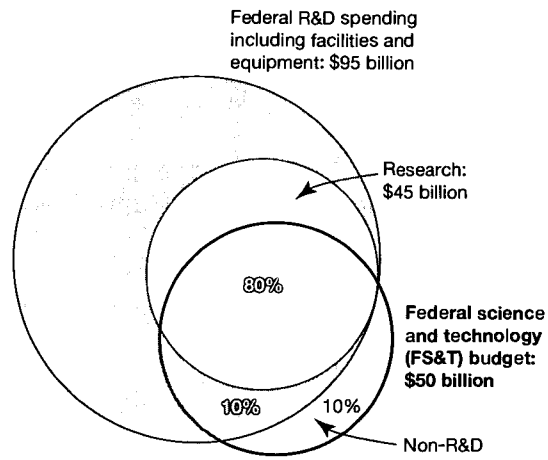
In the fiscal year (FY) 1999 budget, an alternative concept, the "Research Fund for America" (RFA), was introduced, which reflected an interest in addressing the FS&T concept previously proposed by NAS. Unlike the FS&T budget, however, which was constructed from components of the R&D budget, the RFA was constructed of easily tracked programs and included some non-R&D programs, such as National Science Foundation (NSF) education programs and staff salaries at the National Institutes of Health and NSF. The RFA consisted of only civilian (nondefense) R&D; it captured 94 percent of civilian basic research, 72 percent of civilian applied research, and 51 percent of civilian development. The FY 2000 budget referred to the concept "21st Century Research Fund," which was a slight modification of the RFA.

In the 2002 Budget of the United States, the 21st Century Research Fund is no longer mentioned, and the concept of the FS&T budget is readdressed. The new FS&T budget is approximately one-half of total Federal spending on R&D because it excludes funding for defense development, testing, and evaluation. It includes nearly all of the budgeted Federal support for basic research in FY 2002, more than 80 percent of federally supported applied research, and approximately 50 percent of federally supported nondefense development (U.S. Office of Management and Budget (OMB) 2001c).

As shown in figure 4-6, Federal R&D in the 2002 budget proposal, which includes expenditures on facilities and equipment, would reach a level of $95 billion. Of this amount, $45 billion would be devoted to basic and applied research alone. The FS&T budget would reach $50 billion and would include most of the research budget. However, differences in the definition of research and FS&T imply that not all research would be included in FS&T and vice versa. Moreover, a small proportion (10 percent) of FS&T funds would fall outside the category of Federal R&D spending.

Hence, the current FS&T budget developed by OMB largely includes the same programs that constitute the ongoing NAS FS&T categorization effort, a development that should ease analyses of these budgetary issues.

Figure 4-6.
Comparison of funding concepts in the FY 2002 budget proposal



NOTE: Percentages represent shares of the FS&T budget.

SOURCE: U.S. Office of Management and Budget, *Budget of United States Government: FY 2002* (Washington, DC, 2001).

Science & Engineering Indicators – 2002

eral intramural activities, and 35.3 percent to FFRDCs administered by universities and colleges.

Of all Federal obligations of R&D funds to FFRDCs in FY 2001, DOE accounted for 61.3 percent, NASA for another 19.8 percent, and DOD for 11.5 percent. More than one-half (59.1 percent) of DOE's R&D support is directed toward FFRDCs.

Unlike the other Federal agencies just mentioned, the U.S. Department of Agriculture (USDA), Department of Commerce (DOC), and Department of the Interior (DOI) spend most of their R&D obligations internally. Most of the R&D supported by these agencies is mission-oriented and conducted in their own laboratories, which are run, respectively, by the Agricultural Research Service, the National Institute for Standards and Technology (NIST), and the U.S. Geological Survey.

In contrast to total R&D obligations, which are devoted primarily to extramural R&D activities, only three agencies had intramural R&D expenditures that exceeded $1 billion in 2001 (which includes the costs associated with planning and administering extramural R&D programs): DOD, HHS (which includes NIH), and NASA. Together, these three agencies account for 76.2 percent of Federal intramural R&D.

Text table 4-3.
Federal R&D obligations, total and intramural by U.S. agency: FY 2001

Agency	Total R&D obligations (millions of dollars)	Total R&D obligations as share of Federal total (percent)	Intramural R&D[a] (millions of dollars)	Percentage of intramural R&D obligations	Percent change in real intramural R&D from previous year[b]
Federal Government total	81,526.2	100.0	19,352.4	23.7	–0.6
Department of Defense	36,396.6	44.6	8,578.8	23.6	–7.5
Department of Health and Human Services	19,234.6	23.6	3,678.1	19.1	3.7
National Aeronautics and Space Administration	9,602.4	11.8	2,496.9	26.0	5.5
Department of Energy	6,793.5	8.3	871.0	12.8	10.4
National Science Foundation	3,179.9	3.9	27.1	0.9	17.4
Department of Agriculture	1,779.3	2.2	1,250.5	70.3	8.0
Department of Commerce	1,127.0	1.4	775.8	68.8	0.9
Department of Transportation	866.1	1.1	289.3	33.4	36.4
Department of the Interior	619.4	0.8	545.9	88.1	8.0
Environmental Protection Agency	530.1	0.7	125.1	23.6	–3.3
Department of Veterans Affairs	367.0	0.5	367.0	100.0	–2.0
Department of Education	307.3	0.4	38.9	12.7	79.7
Agency for International Development	216.9	0.3	26.0	12.0	2.7
Smithsonian Institution	103.0	0.1	103.0	100.0	4.0
Department of Justice	102.8	0.1	44.7	43.5	10.6
Department of the Treasury	67.8	0.1	52.7	77.7	16.8
Department of Labor	66.0	0.1	22.3	33.8	9.8
Department of Housing and Urban Development	62.7	0.1	35.9	57.3	6.2
Nuclear Regulatory Commission	53.0	0.1	14.9	28.1	–35.7
Social Security Administration	41.6	0.1	1.2	2.9	–53.0
Federal Communications Commission	3.5	0.0	3.5	100.0	–12.1
Library of Congress	2.1	0.0	1.6	76.2	11.9
Department of State	1.5	0.0	0.5	33.3	–2.1
Federal Trade Commission	1.4	0.0	1.4	100.0	14.3
Appalachian Regional Commission	0.8	0.0	0.0	0.0	0.0
National Archives and Records Administration	0.1	0.0	0.1	0.0	0.0

[a]Intramural activities include actual intramural R&D performance and the costs associated with the planning and administration of both intramural and extramural programs by Federal personnel.

[b]Based on fiscal year GDP implicit price deflators. (See appendix table 4-1.)

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Federal Funds for Research and Development: Fiscal Years 1999, 2000, and 2001*, NSF 01-328 (Arlington, VA, June 2001).

Science & Engineering Indicators – 2002

Federal Support to Academia

The Federal Government has long provided the largest share of R&D funds used by universities and colleges. In the early 1980s, Federal funds accounted for roughly two-thirds of the academic total. By 1991, however, that share had dropped to 58.6 percent, and it has since remained between 58 and 60 percent. Although this share of funding has not changed much in recent years, the actual amount of funding, in real terms, has grown on average by 5.1 percent per year between 1985 and 1994 and by 3.2 percent between 1994 and 2000. For more information on academic R&D, see chapter 5.[7]

Federal Funding to Industry

The greatest fluctuation in Federal support has been in Federal funds to industry (excluding industry-administered FFRDCs), which rose from a low of $7.4 billion in constant 1996 dollars in 1953 (when the NSF time series began) to a relative maximum of $32.6 billion in 1966.[8] (See figure 4-7.) It then declined to a relative minimum of $19.7 billion (constant 1996 dollars) in 1975; rose sharply to $37.1 billion by 1987; and fell sharply again to $21.1 billion by 1994. From 1994 to 2000, Federal support to industry has been relatively unchanged, ranging from $18.4 to $21.1 billion in constant 1996 dollars. Most recently, between 1999 and 2000, there was a 4.6 percent decline, in real terms, in Federal funds for industrial R&D activities. Overall, the Federal share of industry's performance has been steadily declining since its peak of 56.7 percent reached in 1959. Much of that decline can be attributed to declines in Federal funding to industry for defense-related R&D activities.

[7]Related topics in this chapter include "Industry-University Collaboration" in the section "Research Alliances: Trends in Industry, Government, and University Collaboration" and "Higher Education Sector" under "International Comparisons of National R&D Trends".

[8]The 1953 value is actually an overestimate because the 1953 and 1954 figures for Federal support to industry include support to industry-administered FFRDCs; the figures for subsequent years do not.

Text table 4-4.
Estimated Federal R&D obligations, by performing sector and agency funding source: FY 2001

Character of work and performer	Total obligations ($ millions)	Primary funding source		Secondary funding source	
		Agency	Percent	Agency	Percent
Total R&D	81,526	DOD	45	HHS	24
Federal intramural laboratories	19,352	DOD	44	HHS	19
Industrial firms	33,026	DOD	77	NASA	14
Industry-administered FFRDCs	1,386	DOE	77	HHS	13
Universities and colleges	17,724	HHS	62	NSF	15
Universities and college FFRDCs	4,189	DOE	57	NASA	31
Other nonprofit organizations	4,176	HHS	72	NASA	9
Nonprofit-administered FFRDCs	978	DOE	56	DOD	40
Basic research, total	20,274	HHS	51	NSF	15
Federal intramural laboratories	3,650	HHS	46	USDA	17
Industrial firms	1,193	HHS	37	NASA	33
Industry-administered FFRDCs	325	DOE	67	HHS	33
Universities and colleges	10,906	HHS	59	NSF	23
Universities and college FFRDCs	1,747	DOE	65	NASA	22
Other nonprofit organizations	1,980	HHS	83	NSF	9
Nonprofit-administered FFRDCs	340	DOE	91	DOD	5
Applied research, total	18,414	HHS	33	DOD	17
Federal intramural laboratories	6,142	HHS	25	DOD	18
Industrial firms	3,925	DOD	37	NASA	36
Industry-administered FFRDCs	586	DOE	83	HHS	10
Universities and colleges	4,790	HHS	66	DOD	10
Universities and college FFRDCs	1,201	DOE	68	NASA	24
Other nonprofit organizations	1,360	HHS	68	NASA	8
Nonprofit-administered FFRDCs	130	DOE	72	DOD	10
Development, total	42,838	DOD	75	NASA	11
Federal intramural laboratories	9,560	DOD	74	NASA	13
Industrial firms	27,908	DOD	85	NASA	10
Industry-administered FFRDCs	474	DOE	77	DOD	18
Universities and colleges	2,027	HHS	68	DOD	21
Universities and college FFRDCs	1,241	NASA	49	DOE	36
Other nonprofit organizations	835	HHS	49	NASA	23
Nonprofit-administered FFRDCs	508	DOD	70	DOE	28

FFRDCs = Federally Funded Research and Development Centers; DOD = Department of Defense; HHS = Department of Health and Human Services; NASA = National Aeronautics and Space Administration; DOE = Department of Energy; NSF = National Science Foundation, USDA = Department of Agriculture.

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Federal Funds for Research and Development: Fiscal Years 1999, 2000, and 2001*, NSF 01-328 (Arlington, VA, June 2001).

Science & Engineering Indicators – 2002

Federal R&D financing for specific industrial sectors (including the industry FFRDCs that belong to those sectors) has varied markedly across time and across different industries. The Federal Government provided $22.5 billion for industry R&D in 1999, the most recent year for which detailed data by industrial category are available. Aerospace companies (or the industrial sector "aircraft and missiles") received 40.5 percent of Federal R&D funds provided to all industries. Consequently, 63.2 percent of the aerospace industry's R&D dollars came from Federal sources; the remaining 36.8 percent came from those companies' own funds. In comparison, the drugs and medicines sector in 1999 financed 100 percent of its R&D from company funds; machinery, 93.4 percent; computer and electronic products, 83.3 percent; transportation equipment other than aircraft and missiles, 95.3 percent; information services, 96.8 percent; and professional, scientific, and technical services, 75.7 percent.[9] See sidebar, "National Science Board Study on Federal Research Resources: A Process for Setting Priorities."

The Federal R&D Tax Credit

In addition to direct R&D funding and government-performed research, the Federal Government provides a research and experimentation (R&E) tax credit aimed at stimulating research investment. In particular, the credit reduces the costs of using internal funds to fund private R&D activities. This tax credit on incremental research expenditures has been in place in the United States since 1981, having been renewed 10 times because of its temporary status. Most recently, the R&E tax credit was reinstated in the Tax Relief Extension Act of 1999 through June 2004.[10] As of this writing, the FY 2002 budget of the Bush administration proposes to make the R&E credit permanent (U.S. OMB 2001a).

[9] The 100 percent company funding for the drugs and medicines sector does include the benefits this sector receives from R&D financed by NIH.

[10] Public Law 106-170, Title V, December 1999.

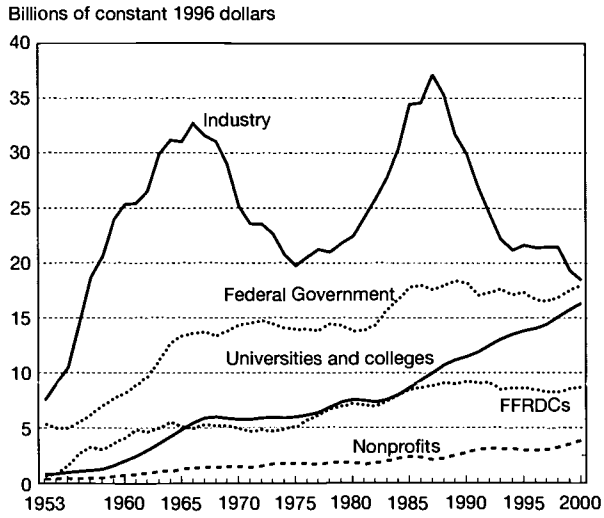
National Science Board Study on Federal Research Resources: A Process for Setting Priorities

The National Science Board (the Board) undertook an intensive two-year study on budget coordination and priority setting for government-funded research. The study included review of the literature on Federal budget coordination and priority setting for research, and invited presentations from and discussions with representatives of the Office of Management and Budget, the Office of Science and Technology Policy, the Federal R&D agencies, congressional staff, high-level science officials from foreign governments, experts on data and methodologies, and spokespersons from industry, the National Academies, research communities, science policy community, and academe. Discussions focused on research priority setting as it is practiced in government organizations, and possibilities for enhancing coordination and priority setting for the Federal research budget. After considering this information, the Board finds that:

- The appropriate focus for advice from the Board is the budget allocation processes for research within the White House and Congress that in the aggregate produce the Federal research portfolio.
- The allocation of funds to national research goals is ultimately a political process that should be informed by the best scientific advice and data available.
- A strengthened process for research allocation decisions is needed. Such allocations are based now primarily on faith in future payoffs justified by past success, but are difficult to defend against alternative claims on the budget that promise concrete, more easily measured results and are supported by large and vocal constituencies.
- The pluralistic framework for Federal research is a positive aspect of the system and increases possibilities for funding high-risk, high-payoff research. An improved process for budget coordination and priority setting should build on strengths of the current system and focus on those weaknesses that can be addressed by improved data and broad-based scientific input representing scientific communities and interests across all sectors.
- There is a need for regular evaluation of Federal investments as a portfolio for success in achieving Federal goals for research to identify areas of weakness in the national infrastructure for science and technology, and to identify a well-defined set of top priorities for major new research investments.
- Additional resources are needed to provide both Congress and the Executive branch with data, analyses, and expert advice to inform their decisions on budget allocations for research.

The full report, with NSB recommendations, can be accessed at: <http://www.nsf.gov/nsb/>.

Figure 4-7.
Federal R&D support, by performing sector: 1953–2000



FFRDCs = Federally Funded Research and Development Centers

See appendix table 4-6. *Science & Engineering Indicators – 2002*

The standard policy justification for a tax stimulus is that results from research, especially long-term research, often are hard to capture privately, as others might benefit directly or indirectly from it. Therefore, businesses might engage in levels of research below those that would benefit a broader constituency, such as a whole industry or the nation. In fact, many developed economies have in place some form of tax credit for research activity.[11]

Structure of the Credit and Tax Data

A regular credit is provided for 20 percent of qualified research above a base amount based on the ratio of research expenses to gross receipts for 1984–88. Younger companies follow different formulas. An alternative R&E credit is available for corporate fiscal years that began after June 30, 1996.[12] Both the regular and the alternative R&E credits include provi-

[11]For R&D tax policies abroad, see "Government Sector" under "International R&D by Performer, Source, and Character of Work" later in this chapter.

[12]The alternative credit is a lower rate that applies to all research expenses exceeding 1 percent of revenues or sales. The rates were raised by the 1999 Tax Relief Act to 2.65–3.75 percent. Companies may select only one of these two credit modes on a permanent basis, unless the Internal Revenue Service authorizes a change. The 1999 Act also extended the research credit to include R&D conducted in Puerto Rico and the U.S. possessions (U.S. OMB 2000).

sions for basic research payments paid to qualified universities or scientific research organizations above a certain base period amount. Qualified research covers "research undertaken to discover information, technological in nature, and useful in the development of a new or improved business component" (U.S. IRS 2000).[13] Because the focus is on domestic research performance, R&D conducted in the United States by foreign firms also is covered, whereas R&D conducted abroad by foreign affiliates of U.S. parent companies is not eligible.

The types of firms that claim the credit and their level of participation are affected by the provisions of the credit, including the definition of covered R&D and the spending base, offsetting credits or caps, and its temporary status. In addition, empirical studies of the effects of the tax credit also have to separate purely accounting effects, such as possible reclassification of activities or timing effects, from real changes in research spending. Thus, to assess precisely whether a particular tax incentive is inducing the kinds of research activities targeted by the credit is difficult at best. Nevertheless, Hall and Van Reenen (2000), based on a review of U.S. studies from the early 1980s to late 1990s, conclude that a dollar in tax credit likely stimulates a dollar of additional R&D. As an empirical generalization, however, this conclusion might not apply fully to certain segments of R&D performers, such as small companies or startup firms.

Total R&E credit claims and number of returns applying for the credit are available from Statistics of Income, Internal Revenue Service (IRS). In 1998 (the latest year for which these data are available), more than 9,800 returns claimed $5.208 billion in R&E credits, up 18.4 percent from 1997 dollar claims (U.S. IRS 2001).[14] The unusual doubling of the credit over 1996–97 followed a 12-month gap in the credit. (See text table 4-5). However, not all R&E claims are allowed because there is a limitation on the reduction of a company's total tax liability. Most claimants applied for the regular 20 percent credit. In 1998, total basic research credits were $398 million, or 7.6 percent of the total R&E credit, claimed by 551 returns.

Nearly three-fourths of R&E credit claims come from manufacturing corporations in any given year. An analysis by Whang (1998) using 1995 tax data identified pharmaceuticals, motor vehicles, aircraft, electronics, and computers as the industries with the largest claims. The author also reported that firms with at least $250 million in assets accounted for three-fourths of the dollar value of all credit claims for the same tax year. Another study, based on a 1998 survey sponsored by the Small Business Administration (SBA), found that only 71 of 194 (37 percent) small firms that responded to a question on the R&E tax credits reported claiming the credit (Cordes, Hertzfeld, and Vonortas 1999). Furthermore, only 28 of the survey firms claiming the tax credit reported that the credit stimulated additional R&D by an amount equal to or more than the amount of the credit. Of the small firms not claiming the credit, approximately one-half failed to exceed the statutory base for the credit, and about one-fourth considered the tax credit procedures too complicated to allow their participation.[15]

[13]The credit excludes research in the social sciences and humanities.

[14] Data for active corporations, other than forms 1120S, 1120-TEIT, and 1120-RIC.

Text table 4-5.
Research and experimentation tax credit claims

Year	Billions of current dollars	Number of tax returns
1990	1.547	8,699
1991	1.585	9,001
1992	1.515	7,750
1993	1.857	9,933
1994	2.423	9,150
1995	1.422	7,877
1996	2.134	9,709
1997	4.398	10,668
1998	5.208	9,849

SOURCE: U.S. Department of the Treasury, Internal Revenue Service, Statistics of Income, unpublished tabulations (Washington, DC, 2001).

Science & Engineering Indicators – 2002

Federal Budget Impact

In the language of the Federal budget, R&E credits fall in the category of tax expenditures—government revenue losses due to preferential provisions. According to the Treasury Department, the largest tax expenditures are those associated with the individual income tax. Tax expenditures from corporate income taxes relate mostly to cost recovery for certain investments, including research activities. The outlay-equivalent measure is one of three accounting methods used to estimate these tax expenditures.[16] This method translates R&E credits in terms comparable to Federal R&D outlays. This allows a comparison of the cost of the tax expenditure with that of a direct Federal outlay (U.S. OMB 2001a).

According to this measure, tax credit claims in 1998 were equivalent to outlays of $3.270 billion, or 4.6 percent of direct Federal R&D outlays in FY 1998 (See figure 4-8.) Although R&E claims data for tax year 2000 are not available, the credit generated an estimated outlay equivalent of $2.510 billion, or 3.4 percent of Federal R&D outlays in FY 2000. In constant 1996 dollars, the average outlay equivalent over 1981–2000 is $2.1 billion.

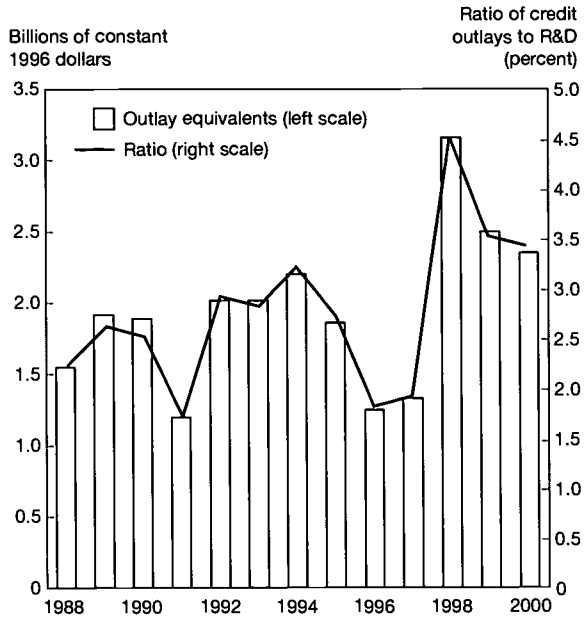
Historical Trends in Non-Federal Support

R&D financing from non-Federal sources grew by 5.9 percent per year after inflation between 1953 and 1980. Between 1980 and 1985, concurrent with gains in Federal R&D spending, it grew by an even faster rate of 7.6 percent per year in

[15] The study is based on a random sample of 1,053 small firms (fewer than 500 employees), of which 91 percent were privately owned; 198 small firms completed the survey. The average responding firm had a mean age of 23 years, 79 employees, and $5.7 million in annual sales.

[16] The other two measures are revenue loss and present value of tax expenditures. For a comparison of these methods, see U.S. OMB (2001a).

Figure 4-8.
Budgetary impact of Federal research and experimentation tax credit: FYs 1988–2000



NOTE: The ratio of credit outlays to R&D is the outlay equivalent cost of the tax credit divided by total Federal R&D outlays.

See appendix table 4-30. *Science & Engineering Indicators – 2002*

real terms. It then slowed to 4.4 percent between 1985 and 1990 and to 3.3 percent between 1990 and 1995 but rose to 8.2 percent over the 1995–2000 period.

As already discussed, most non-Federal R&D support is provided by industry. Of the 2000 non-Federal support total ($195 billion), 92.8 percent ($181 billion) was company funded. Industry's share of national R&D funding first surpassed that of the Federal Government in 1980, and it has remained higher ever since. From 1980 to 1985, industrial support for R&D, in real dollars, grew at an average annual rate of 7.7 percent. This growth was maintained through both the mild 1980 recession and the more severe 1982 recession. (See figure 4-1.) Key factors behind increases in industrial R&D included a growing concern with international competition, especially in high-technology industries; the increasing technological sophistication of products, processes, and services; and general growth in defense-related industries, such as electronics, aircraft, and missiles.

Between 1985 and 1994, growth in R&D funding from industry was slower, averaging only 3.1 percent per year in real terms. This slower growth in industrial R&D funding was only slightly greater than the real growth of the economy over the same period (in terms of real GDP), which was 2.8 percent. In contrast, from 1994 to 2000, non-Federal R&D support grew in real terms by 8.6 percent per year compared with 4.0 percent for the economy overall.

R&D funding from other non-Federal sectors, namely, academic and other nonprofit institutions and state and local governments, has been more consistent over time. It grew in real terms at average annual rates of 6.4 percent between 1980 and 1985, 8.5 percent between 1985 and 1990, 3.8 percent between 1990 and 1995, and 5.5 percent between 1995 and 2000. The level of $14.0 billion in funding in 2000 was 4.9 percent higher in real terms than its 1999 level of $13.0 billion. Most of these funds had been used for research performed within the academic sector.

R&D Performance in the United States

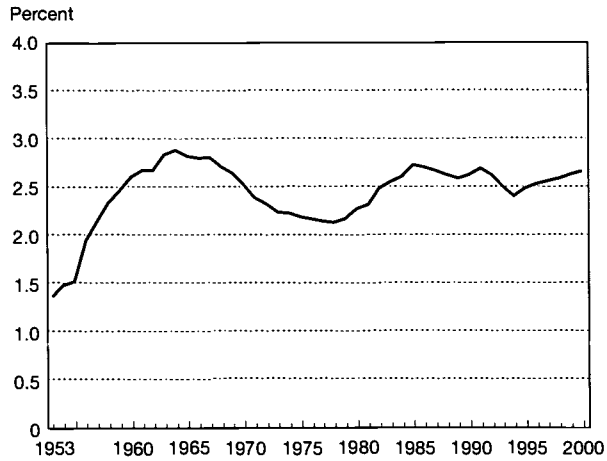
U.S. R&D/GDP Ratio

Growth in R&D expenditures should be examined in the context of the overall growth of the economy, because, as a part of the economy itself, R&D is influenced by many of the same factors. Furthermore, as mentioned earlier, the ratio of R&D expenditures to GDP may be interpreted as a measure of the nation's commitment to R&D relative to other endeavors.

A review of U.S. R&D expenditures as a percentage of GDP over time shows an initial low of 1.36 percent in 1953 (when the NSF data series began), rising to its highest peak of 2.88 percent in 1964, followed by a gradual decline to 2.12 percent in 1978. (See figure 4-9.) From that low in 1978, U.S. R&D expenditures again rose steadily to peak at 2.72 percent in 1985 and did not fall below 2.50 until 1993. In 1994, the rate dropped to 2.40, its lowest point since 1981. Starting in 1994, however, R&D/GDP has been on an upward trend as investments in R&D have outpaced growth of the general economy. As a result, the current ratio of 2.66 for 2000 is the highest the ratio has been since 1985.

The initial drop in the R&D/GDP ratio from its peak in 1964 largely reflects Federal cutbacks in defense and space R&D programs, although gains in energy R&D activities between 1975 and 1979 resulted in a relative stabilization of the ratio between

Figure 4-9.
Historical pattern of R&D as percentage of GDP: 1953–2000



See appendix tables 4-1 and 4-3.

Science & Engineering Indicators – 2002

2.1 and 2.2 percent. Over the entire 1965–78 period, the annual percentage increase in real R&D was less than the annual percentage increase in real GDP. When real R&D spending decreased during that period, real GDP also fell, but at a lower rate.

The rise in R&D/GDP from 1978 to 1985 was due as much to a slowdown in GDP growth as it was to increased spending on R&D activities. For example, the 1980 and 1982 recessions resulted in a slight decline in real GDP, but there was no corresponding reduction in R&D spending. During previous recessions, changes in funding for R&D tended to match or exceed the adverse movements of the broader economic measures.

The share of defense-related R&D dropped from 31 percent in 1985 to 23 percent in 1991. Commensurate with this change was the sharp fall in the share of federally funded R&D, from 46 percent in 1985 to 37.8 percent in 1991. (See figure 4-4.) This decline in Federal funding was counterbalanced by increased non-Federal funding, as described earlier in the discussion of industrial trends. Indeed, since the late 1980s, practically all of the rise in the R&D/GDP ratio has resulted from gains in industrial R&D spending.

From 1991 to 1994, the R&D/GDP ratio declined from 2.69 to 2.40. Since then, however, it has risen steadily. Between 1994 and 2000, the R&D supported by industry grew in real terms by 8.6 percent annually, whereas real GDP grew by 4.0 percent, largely explaining the rise in the R&D/GDP ratio to 2.66 in 2000. From 1992 to 2000, the ratio of research alone to GDP has remained at 1.0 percent, while the ratio of development to GDP has varied between 1.5 and 1.6 percent. Within the industrial sector, however, development plays a greater role. In 1999, for example, the ratio of research performance to net sales in industry was 0.8 percent, while the ratio of development to net sales was 2.0 percent.

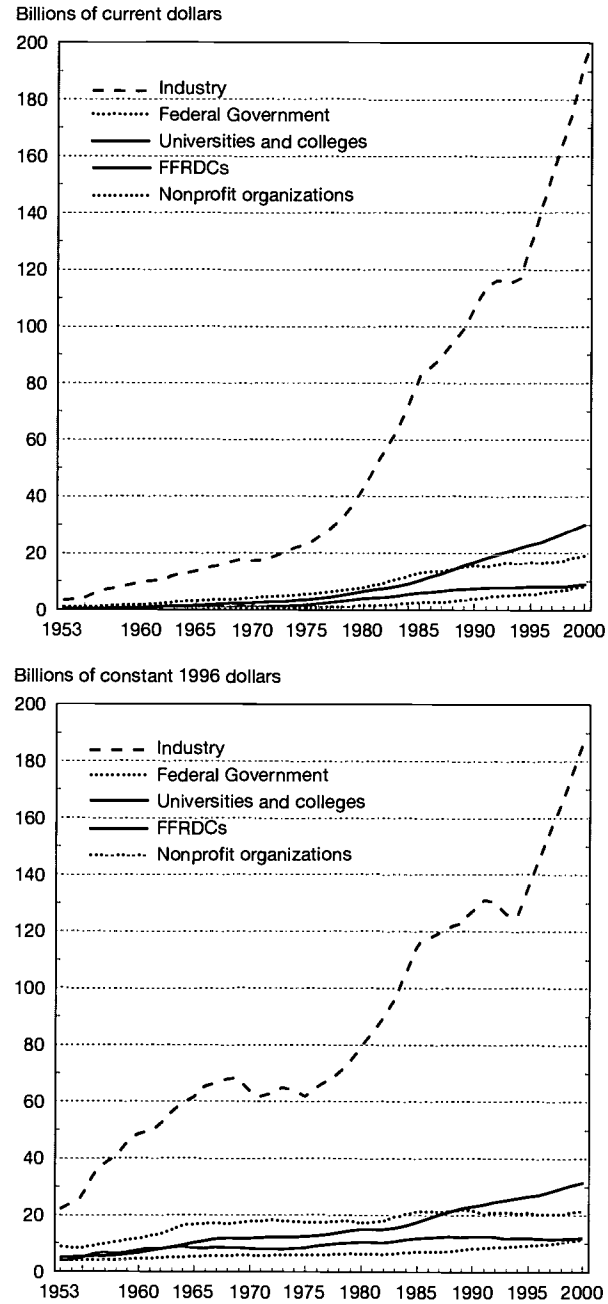
Rates of Growth Among Sectors

The sectoral shares of U.S. R&D performance have shifted significantly since the early 1980s. (See figure 4-10 for levels of expenditure.) In 1980, industry (including industry-administered FFRDCs) performed 70.3 percent of the nation's R&D; the academic sector (including academically administered FFRDCs) accounted for 13.9 percent; the Federal Government accounted for 12.4 percent; and the nonprofit sector (including nonprofit-administered FFRDCs) accounted for 3.3 percent. Industry's defense-related R&D efforts accelerated in the early 1980s, and its share of performance total rose to 73.4 percent in 1985.

From 1985 to 1994, R&D performance grew by only 1.4 percent per year in real terms for all sectors combined. This growth was not evenly balanced across performing sectors, however. R&D performance at universities and colleges (including their FFRDCs) grew by 4.4 percent per year in real terms compared with only 1.0 percent growth for industry (including their FFRDCs), a decline of 0.5 percent per year for Federal intramural performance and growth of 4.0 percent per year for nonprofit organizations (including their FFRDCs).

The 1994–2000 period witnessed dramatic changes in these growth rates. Total R&D performance, in real terms, averaged 5.8 percent growth per year, which was substantially higher than in the earlier sluggish period. Yet, R&D performance at universities and colleges (including their FFRDCs) grew by only 3.1 percent per year in real terms. Industry (including their FFRDCs) grew at a remarkable rate of 7.0 percent in real terms. Federal intramural performance increased by 0.8 percent per year in real terms. Finally, nonprofit organizations (including

Figure 4-10.
National R&D performance, by type of performer: 1953–2000



FFRDCs = Federally Funded Research and Development Centers

See appendix tables 4-3 and 4-4.

Science & Engineering Indicators – 2002

their FFRDCs), according to current estimates, increased their R&D by 5.3 percent per year in real terms over the same six-year period. According to preliminary estimates, these shifts in growth have led, in 2000, to academia (including FFRDCs) representing 13.6 percent of total U.S. R&D performance; Federal intramural activities, 7.2 percent; other nonprofit organizations (including FFRDCs), 3.6 percent; and private industry (including FFRDCs), 75.6 percent. (For level of expenditures in 2000, see text table 4-1.)

Federal R&D Performance

The Federal Government performed $19.1 billion of total U.S. R&D in calendar year 2000, a 2.3 percent rise in real terms from its 1999 level of $18.3 billion. Among the individual agencies, DOD has continued to perform the most intramural R&D; in fact, in FY 2001 it performed more than twice the R&D of the second largest R&D-performing agency, HHS (whose intramural R&D is performed primarily by NIH). (See text table 4-3.) However, DOD's intramural R&D performance has grown by less than 1 percent per year in real terms since FY 1980, reaching a level of $8.6 billion in FY 2001. Furthermore, an undetermined amount of DOD's intramural R&D ultimately appears to be contracted out to other extramural performers. NASA's intramural R&D has grown by 1.4 percent per year in real terms since 1980, to $2.5 billion in FY 2001, and HHS intramural performance rose by 4.0 percent to $3.7 billion. Together, these three agencies account for 76.2 percent of the total ($19.4 billion) Federal intramural R&D in FY 2001.

Total R&D performed by industrial, academic, and nonprofit FFRDCs reached $9.3 billion in calendar year 2000, which is essentially the same as its level of $9.0 billion in 1999 after adjusting for inflation. R&D at FFRDCs in 2000 represented 3.5 percent of the national R&D effort, most of which ($5.8 billion in 2000) was accounted for by university- and college-administered FFRDCs.

R&D in Nonprofit Organizations

A recent NSF survey has led to upward revisions in R&D performance estimates for the nonprofit sector (NSF 2001d). Based on a survey of FY 1996 and FY 1997 R&D at nonprofit organizations and on other available data for the past three years, R&D performance by nonprofit organizations is expected to reach $8.8 billion in 2000, reflecting an average annual growth of 5.5 percent, in real terms, since 1990. Such growth, however, varies considerably by source of funding. The average annual real growth in nonprofit intramural R&D over the same period was 8.0 percent for nonprofit R&D supported by nonprofit organizations themselves, 7.1 percent for nonprofit R&D supported by industry, and 3.5 percent for nonprofit R&D supported by the Federal Government.

Like the Federal Government, nonprofit organizations in recent decades have focused largely on medical and health

Text table 4-6.
Intramural R&D performance at nonprofit organizations, by type of organization and S&E field: FYs 1973 and 1997
(Millions of dollars)

Organization type	Total	Life sciences: Biological sciences	Life sciences: Agricultural sciences	Life sciences: Medical and health sciences	Psychology	Environmental and earth sciences	Physical sciences	Mathematics and computer sciences	Engineering	Social sciences	Other sciences
1973											
Total	786	162	167	26	30	19	72	37	136	130	5
Research institutes	487	104	44	11	18	9	50	34	98	113	5
Hospitals	163	40	98	6	5	0	5	2	2	6	—
Professional or technical societies	62	5	17	4	—	5	13	—	15	2	0
Private foundations	14	5	1	—	—	2	2	0	0	2	0
Science exhibitors	8	4	—	0	—	2	1	0	0	2	0
Trade associations	26	2	0	0	0	1	2	—	20	1	0
Other nonprofit organizations	26	3	7	5	6	0	0	—	—	4	0
1997											
Total	7,349	854	22	4,413	70	232	255	269	490	325	419
Research institutes	4,839	794	11	2,618	65	97	147	263	458	305	83
Hospitals	1,428	20	0	1,408	—	0	0	1	0	0	0
University-affiliated hospitals	464	0	0	463	0	0	0	1	0	0	0
Other voluntary nonprofit hospitals	965	20	0	945	—	0	0	0	0	0	0
Private foundations	458	28	11	386	4	2	11	3	—	10	2
Other nonprofit organizations[a]	624	13	1	2	0	133	97	2	32	10	334

— = Less than $0.5 million

[a]Other nonprofit organizations include professional and technical societies, academies of science or engineering, science exhibitors, academic consortia, industrial consortia, and trade associations.

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

SOURCES: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *R&D Activities of Independent Nonprofit Institutions* (Washington, DC, 1973); and NSF/SRS, *Research and Development Funding and Performance by Nonprofit Organizations: Fiscal Years 1996 and 1997*, Early Release Tables. Available at: <http://www.nsf.gov/sbe/srs/srs01411/start.htm>.

Science & Engineering Indicators – 2002

sciences. (See text table 4-6.) In 1973, only 3.3 percent of all R&D performed by nonprofit organizations was in medical and health sciences, but this share rose dramatically to 60 percent by 1997. In contrast, the agricultural sciences share of intramural nonprofit R&D fell from 21.3 percent in 1973 to 0.3 percent in 1997.

Recent Growth in Industrial R&D, by Sector, Firm Size, and R&D Intensity

R&D performance by private industry reached $199.9 billion in 2000, including $2.6 billion spent by FFRDCs administered by industrial firms. This total represents a 7.1 percent real increase over the 1999 level of $82.8 billion, which, in turn, reflects a smaller, although still noteworthy, real gain of 6.5 percent over 1998. In 2000, R&D performed by industry that was not federally financed rose 8.6 percent in real terms above the 1999 level. Overall, private companies (excluding industry-administered FFRDCs) funded 90.0 percent ($177.6 billion) of their 2000 R&D performance, with the Federal Government funding nearly all the rest ($19.6 billion, or 10 percent of the total).

In recent times, the greatest share of R&D in the United States has been performed by private industry through private industry's own funds.[17] This component of U.S. R&D has grown in importance, from 44 percent of total R&D in 1953, to 49 percent in 1980, to 55 percent in 1990, and 68 percent in 2000. The underlying causes for industry's growing share of R&D financing are complex. In part, the growth may be due to changes in Federal support in areas such as defense and space exploration. Other factors include S&E success stories in specific fields, such as information technology (IT) and biotechnology, in which industry plays a dominant role.

R&D in Manufacturing Versus Nonmanufacturing Industries

Until the 1980s, little attention was paid to R&D conducted by nonmanufacturing companies largely because service-sector R&D activity was negligible compared with the R&D operations of companies classified in manufacturing industries. Before 1983, nonmanufacturing industries accounted for less than 5 percent of the industry R&D total (including industrial FFRDCs), but by 1999 (the most current year for data on industrial sectors), it had reached 36.0 percent. In 1999, nonmanufacturing firms' R&D performance totaled $65.9 billion ($60.4 billion in funds provided by companies and other non-Federal sources and $5.5 billion in Federal support).

Beginning with the 1999 cycle, statistics from NSF's Survey of Industrial R&D have been published using the North American Industrial Classification System (NAICS). (See text table 4-7.) The development of NAICS has been a joint effort of statistical agencies in Canada, Mexico, and the United States. The system replaces the standard industrial classification (SIC) (1980) of Canada, the Mexican Classification of Activities and Products (1994), and SIC (1987) of the United States. NAICS was designed to provide a production-oriented system under which economic units with similar production processes are classified in the same industry. NAICS was developed with special attention to classifications for new and emerging industries, service industries, and industries that produce advanced technologies. NAICS eases comparability of information about the economies of the three North American countries and also increases comparability with the two-digit level of the United Nations International Standard Industrial Classification system (ISIC Revision 3).

Among manufacturers, the new computer and electronic products classification (NAICS 334) includes makers of computers and peripherals, semiconductors, and navigational and electromedical instruments. Among nonmanufacturing industries are information (NAICS 51) and professional, scientific, and technical services (NAICS 54). Information includes publishing (both paper and electronic), broadcasting, and telecommunications. Professional, scientific, and technical services include a variety of industries. Of specific importance for the survey are engineering and scientific R&D services (NSF 2001e).

Following these recent changes in classification, much of the historical data on R&D that had been subdivided according to the previous industrial categories cannot be reclassified into the current industrial categories. As a result, some of trends in the data by industrial category can no longer be observed after 1998 and must be started again, according to different groupings, in 1999. On the other hand, general patterns of change among major sectors are still identifiable. The most striking change in industrial R&D performance during the past two decades is the nonmanufacturing sector's increased prominence.

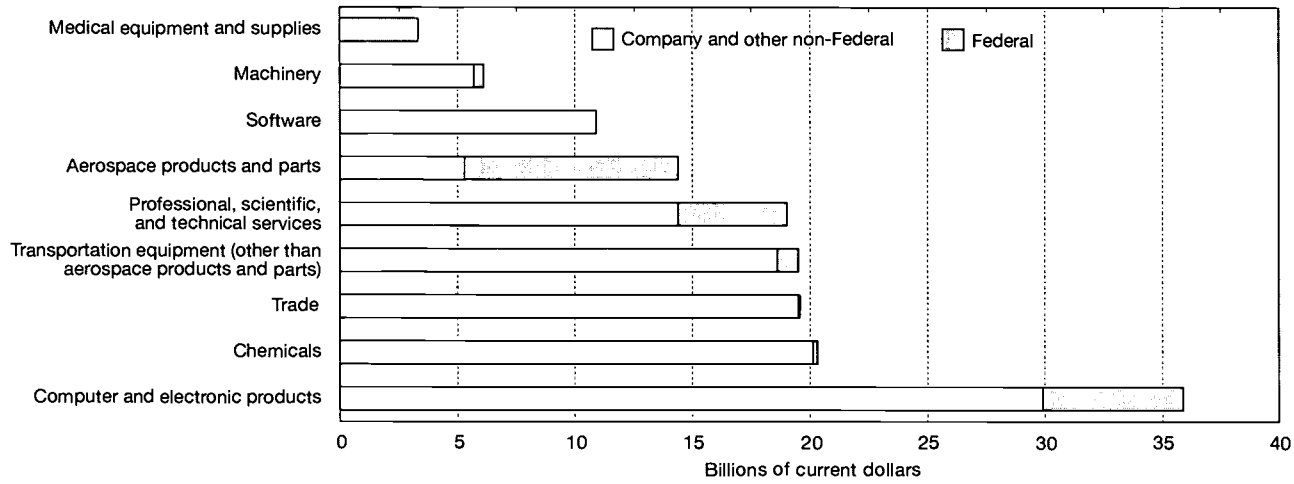
In 1999, the largest nonmanufacturing industry in the performance of R&D was trade (as it is classified in NAICS), which accounted for 10.7 percent of all industrial R&D performance. This was followed closely by professional, scientific, and technical services, accounting for another 10.4 percent of the total, then information, accounting for 8.4 percent.

Within the manufacturing industrial sector (including industry-administered FFRDCs associated with manufacturing), three subsectors dominate: computer and electronic products, transportation equipment, and chemicals. (See figure 4-11 and text table 4-7.) Under the new NAICS system of classification, the computer and electronic products sector accounted for the largest amount of R&D performed in 1999 among all industrial sectors—$35.9 billion. It accounted for 19.7 percent of all industrial R&D (including industry FFRDCs), as well as 14.7 percent of the entire nation's R&D, performed in 1999. Consequently, it exceeded the total amount of R&D performed in 1999 by all universities and colleges and their administered FFRDCs combined (which is only $34.1 billion). For this sector, industrial firms provided $29.9 billion in R&D support; the Federal Government funded the remainder.

Transportation equipment was a close second among the manufacturing sectors in R&D performed in 1999 with $34 billion in R&D, representing 18.6 percent of all industrial

[17]Some of this funding is supported through venture capital investments. For a discussion of the relationship between venture capital and R&D expenditures, see chapter 6.

Figure 4-11.
Industrial R&D performance for selected industries, by source of funds: 1999



See appendix tables 4-31, 4-32, and 4-33.

Science & Engineering Indicators – 2002

R&D (including R&D by industry-administered FFRDCs). Of these expenditures, 29.6 percent was federally funded, primarily for R&D on aerospace products (planes, missiles, and space vehicles). In addition to aerospace products, the sector includes a variety of other forms of transportation equipment, such as motor vehicles, ships, military armored vehicles, locomotives, and smaller vehicles like motorcycles, bicycles, and snowmobiles (U.S. OMB 1997).

Ranking third in R&D is chemicals, with $20.2 billion in 1999, for which less than 1 percent was federally funded. This sector includes the subsectors pharmaceuticals and medicines (61.0 percent of non-Federal R&D funding in the chemical sector); basic chemicals (13.2 percent); resin, synthetic rubber, fibers, and filament (11.1 percent); and other chemicals (14.7 percent).

Although a great deal of R&D in the United States is related in some way to health care services, companies specifically categorized in the health care services sector accounted for only 0.4 percent of all industrial R&D and for only 1.0 percent of all R&D by nonmanufacturing companies. These results illustrate that R&D data disaggregated according to industrial categories (including the distinction between manufacturing and nonmanufacturing industries) may not always reflect the relative proportions of R&D devoted to particular types of scientific or engineering objectives, or to particular fields of science or engineering.[18] The section "Cross-Sector Field-of-Science Classification Analysis" compensates to some extent for this limitation in the data by providing R&D expenditure levels associated with the broadly defined fields of life sciences and chemistry.

As a case in point, firms that perform R&D under contract to other firms are, by definition, in the service sector because the R&D they perform is, in fact, their "product," which is a service as opposed to manufactured goods. However, they often perform R&D under contract with a manufacturer, implying that those same R&D activities would have been classified as R&D in manufacturing if the same research firm were a subsidiary of the manufacturer. This is counterintuitive in that it implies that whether R&D is in manufacturing or in services is determined, in part, not by physical aspects of the R&D actions themselves but by the labels that have been placed on the firms that perform the R&D. Consequently, a growth in measured R&D in services may, in part, "reflect a more general pattern of industry's increasing reliance on outsourcing and contract R&D" (Jankowski 2001b).

R&D Spending by U.S. Corporations

In 1998, the top 20 U.S. corporations in R&D expenditures spent $54.0 billion on R&D. General Motors reported the most R&D in 1998 with $7.9 billion, followed by another company in the motor vehicle sector, Ford Motor Company, with $6.3 billion. (See text table 4-8.) The rest of the list is dominated by computers, electronic equipment, and software companies, and by pharmaceutical corporations.

Between 1996 and 1998, the total number of publicly held U.S. corporations reporting R&D spending fell from 3,256 to 3,028, although some of this decline is attributable to mergers among existing firms. The decline in the number of firms was not uniform across industrial sectors. For example, the aircraft, guided missiles, and space vehicles sector, which is characterized by relatively large corporations, included exactly 21 corporations in each of the three years. Similarly, the motor vehicles and surface transportation sector went down in number by only 1, from 71 to 70 corporations. This was due to the acquisition of Chrysler Corporation by the German firm Daimler-Benz, which removed Chrysler from the list of U.S. corporations performing R&D (although the R&D

[18]For a more detailed discussion of limitations in the interpretation of R&D levels by industrial categorization, see Payson (2000).

Text table 4-7.
Industrial R&D performance, by industry and source of funding: 1999
(Millions of dollars)

Industry	NAICS code	Total R&D	Company funded	Federally funded	Percent federally funded
All industries	21–23, 31–33, 42, 44–81	182,823	160,288	22,535	12.3
Manufacturing	31–33	116,921	99,865	17,055	14.6
Food	311	1,132	1,132	0	0.0
Beverage and tobacco products	312	D	D	0	NA
Textiles, apparel, and leather	313–16	334	334	0	0.0
Wood products	321	70	70	0	0.0
Paper, printing, and support activities	322, 323	D	2,474	D	NA
Petroleum and coal products	324	615	D	D	NA
Chemicals	325	20,246	20,051	194	1.0
Basic chemicals	3251	2,746	2,648	98	3.6
Resin, synthetic rubber, fibers, and filament	3252	D	2,216	D	NA
Pharmaceuticals and medicines	3254	D	12,236	D	NA
Other chemicals	325 minus (3251–52, 3254)	D	2,951	D	NA
Plastics and rubber products	326	1,785	1,785	0	0.0
Nonmetallic mineral products	327	D	595	D	NA
Primary metals	331	470	457	12	2.6
Fabricated metal products	332	1,655	1,608	46	2.8
Machinery	333	6,057	5,658	399	6.6
Computer and electronic products	334	35,932	29,939	5,993	16.7
Computers and peripheral equipment	3341	D	4,126	D	NA
Communications equipment	3342	6,003	5,797	206	3.4
Semiconductor and other electronic components	3344	10,701	10,624	77	0.7
Navigational, measuring, electromedical, and control instruments	3345	14,337	8,632	5,705	39.8
Other computer and electronic products	334 minus (3341–42, 3344–45)	D	760	D	NA
Electrical equipment, appliances, and components	335	D	3,820	D	NA
Transportation equipment	336	33,965	23,928	10,037	29.6
Motor vehicles, trailers, and parts	3361–63	D	17,987	D	NA
Aerospace products and parts	3364	14,425	5,309	9,117	63.2
Other transportation equipment	336 minus (3361–64)	D	632	D	NA
Furniture and related products	337	248	248	0	0.0
Miscellaneous manufacturing	339	3,851	3,825	26	0.7
Medical equipment and supplies	3391	D	3,251	D	NA
Other miscellaneous manufacturing	339 minus 3391	D	574	D	NA
Small manufacturing companies[a]	<50 employees	3,019	2,950	69	2.3
Nonmanufacturing	21–23, 42, 44–81	65,902	60,423	5,479	8.3
Mining, extraction, and support activities	21	D	2,352	D	NA
Utilities	22	142	126	17	12.0
Construction	23	691	690	2	0.3
Trade	42, 44, 45	19,616	19,521	95	0.5
Transportation and warehousing	48, 49	460	460	0	0.0
Information	51	15,389	14,892	497	3.2
Publishing	511	11,302	11,253	49	0.4
Newspaper, periodical, book, and database	5111	371	371	0	0.0
Software	5112	10,931	10,882	49	0.4
Broadcasting and telecommunications	513	D	1,393	D	NA
Other information	51 minus (511, 513)	D	2,246	D	NA
Finance, insurance, and real estate	52, 53	D	1,570	D	NA
Professional, scientific, and technical services	54	18,994	14,379	4,615	24.3
Architectural, engineering, and related services	5413	3,580	2,402	1,177	32.9
Computer systems design and related services	5415	D	3,989	D	NA
Scientific R&D services	5417	10,470	7,413	3,057	29.2
Other professional, scientific, and technical services	54 minus (5413, 5415, 5417)	D	575	D	NA
Management of companies and enterprises	55	D	72	D	NA
Health care services	621–23	642	631	10	1.6
Other nonmanufacturing	56, 61, 624, 71, 72, 81	D	752	D	NA
Small nonmanufacturing companies[a]	<15 employees	5,203	4,977	227	4.3

NAICS = North American Industry Classification System; D = data withheld to avoid disclosing operations of individual companies; NA = not available

[a]The frame from which the statistical sample was selected was divided into two partitions based on total company employment. In the manufacturing sector, companies with employment of 50 or more were included in the large company partition. In the nonmanufacturing sector, companies with employment of 15 or more were included in the large company partition. Companies in the respective sectors with employment below these values, but with at least 5 employees, were included in the small company partition. The purpose of partitioning the sample this way was to reduce the variability in industry estimates largely attributed to the random year-to-year selection of small companies by industry and the high sampling weights that sometimes were assigned to them. Because of this, detailed industry statistics were possible only from the large company partition. Statistics from the small company partition are shown separately and are included in manufacturing, nonmanufacturing, and all industries totals.

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Research and Development in Industry: 1999*, Early Release Tables (Arlington, VA, 2001)

Science & Engineering Indicators – 2002

Text table 4-8.
Top 20 R&D spending corporations: 1998

R&D rank				R&D (billions of dollars)			Percent change from	Sector	
1998	1997	1996	Corporation	1998	1997	1996	1996 to 1998	Major	Detailed
1	1	1	General Motors	7.900	8.200	8.900	–11.2	Motor vehicles and surface transportation	Motor vehicles and motor vehicle equipment
2	2	2	Ford Motor Co.	6.300	6.327	6.821	–7.6	Motor vehicles and surface transportation	Motor vehicles and motor vehicle equipment
3	3	3	Intl. Business Machines	4.466	4.307	3.934	13.5	Information and electronics	Multiple and miscellaneous computer and data processing services
4	4	7	Lucent Technologies	3.678	3.101	1.838	100.1	Information and electronics	Modems and other wired telephone equipment
5	5	4	Hewlett-Packard	3.355	3.078	2.718	23.4	Information and electronics	Electronic computers and computer terminals
6	6	5	Motorola	2.893	2.748	2.394	20.8	Information and electronics	Radio, TV, cell phone, and satellite communications equipment
7	7	8	Intel	2.509	2.347	1.808	38.8	Information and electronics	Electronic components (e.g., semiconductors, coils)
8	10	11	Microsoft	2.502	1.925	1.432	74.7	Information and electronics	Prepackaged software
9	9	9	Pfizer	2.279	1.928	1.684	35.3	Medical substances and devices	Drugs: pharmaceutical preparations
10	8	6	Johnson & Johnson	2.269	2.140	1.905	19.1	Medical substances and devices	Drugs: pharmaceutical preparations
11	11	18	Boeing	1.895	1.924	1.200	57.9	Aircraft, guided missiles, and space vehicles	Aircraft, guided missiles, and space vehicles
12	12	10	Merck & Company	1.821	1.684	1.487	22.4	Medical substances and devices	Drugs: pharmaceutical preparations
13	16	19	Eli Lilly & Company	1.739	1.382	1.190	46.2	Medical substances and devices	Drugs: pharmaceutical preparations
14	13	12	American Home Products	1.655	1.558	1.429	15.8	Medical substances and devices	Drugs: pharmaceutical preparations
15	15	14	Bristol Myers Squibb	1.577	1.385	1.276	23.6	Medical substances and devices	Drugs: pharmaceutical preparations
16	18	16	Procter & Gamble	1.546	1.282	1.221	26.6	Chemicals	Other chemical (e.g., soaps, ink, paints, fertilizers, explosives)
17	14	13	General Electric	1.537	1.480	1.421	8.2	Machinery and electrical equipment	Electrical equipment (industrial and household)
18	NA	NA	Delphi Automotive System	1.400	NA	NA	NA	Motor vehicles and surface transportation	Motor vehicles and motor vehicle equipment
19	31	50	Compaq	1.353	0.817	0.407	232.4	Information and electronics	Electronic computers and computer terminals
20	20	20	United Technologies	1.315	1.187	1.122	17.2	Aircraft, guided missiles, and space vehicles	Aircraft, guided missiles, and space vehicles

NA = not available

SOURCE: Standard & Poor's Compustat (Englewood, CO).

Science & Engineering Indicators – 2002

it performs within the United States is still collected by NSF's industrial R&D survey and included in this chapter's data on U.S. industrial R&D performance).[19] Chrysler was ranked number 12 in U.S. corporations' 1997 R&D spending. In contrast, between 1996 and 1998, the number of R&D-performing corporations fell from 1,477 to 1,382 in the information and electronics sector, from 629 to 566 in the medical substances and devices sector, and from 422 to 386 in the basic industries and materials sector (Shepherd and Payson 2001).

Industrial R&D and Firm Size

Industrial manufacturing R&D performers are typically quite different from industrial nonmanufacturing R&D performers; nonmanufacturing R&D performers tend to be smaller firms. (See text table 4-9.) Approximately 39,000 firms in the United States performed R&D in 1999; of these, 54 percent were in the nonmanufacturing sector. Yet, manufacturers account for 64 percent of total industry R&D performance (including federally funded industry performance). As a share of the nation's GDP, on the other hand, manufacturing accounts for less than 20 percent. The main reason for continued dominance in R&D performance is that among manufacturing firms, the largest in terms of number of employees tend to perform a relatively large amount of R&D. Among small R&D-performing firms (fewer than 500 employees) in both the manufacturing and nonmanufacturing sectors, those in the nonmanufacturing sector tend to conduct twice as much R&D per firm as those in the manufacturing sector. However, among large R&D-performing firms (more than 25,000 employees) in both sectors, those in the manufacturing firms tend to conduct more than 10 times as much R&D per firm as those in the nonmanufacturing sector.

Although R&D tends to be performed by large firms in the manufacturing sector and small firms in the nonmanufacturing sector, within each sector there is consider-

[19]The corporate R&D data were obtained from a source that differs from the NSF *Survey of Industrial Research and Development*; namely, from the *U.S. Corporate R&D* database (see Shepherd and Payson 2001). Consequently, the definition of R&D in this case is not equivalent to that of the NSF industry R&D survey, as indicated in this example about the Chrysler Corporation.

Text table 4-9.
Total funds for industry R&D performance and number of R&D-performing companies in manufacturing and nonmanufacturing industries, by size of company: 1999

Size of company (number of employees)	Total	Manufacturing	Nonmanufacturing
Funds for industrial R&D (millions of dollars)			
Total	182,823	116,921	65,902
5–25	7,004	738	6,265
25–49	4,750	791	3,959
50–99	7,225	2,183	5,042
100–249	7,213	2,623	4,591
250–499	7,892	2,190	5,701
500–999	7,032	3,763	3,269
1,000–4,999	24,840	15,561	9,278
5,000–9,999	16,376	10,893	5,483
10,000–24,999	24,922	18,014	6,908
25,000 or more	75,569	60,163	15,406
Number of R&D-performing companies			
Total	39,005	18,059	20,946
5–25	18,355	5,750	12,606
25–49	6,749	3,707	3,042
50–99	5,102	2,644	2,457
100–249	4,083	2,840	1,243
250–499	1,788	975	813
500–999	1,118	890	228
1,000–4,999	1,157	865	292
5,000–9,999	288	194	94
10,000–24,999	198	129	69
25,000 or more	167	65	102

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Research and Development in Industry: 1999*, Early Release Tables (Arlington, VA, 2001

Science & Engineering Indicators – 2002

able variation, depending on the type of industry. R&D tends to be conducted primarily by large firms in several industrial sectors: aircraft and missiles, electrical equipment, professional and scientific instruments, transportation equipment (not including aircraft and missiles), and transportation and utilities (which are in the nonmanufacturing sector). On the other hand, in these same sectors much of the economic activity is carried out by large firms to begin with, so the observation that most of the R&D in these sectors is also conducted by large firms is not surprising.

R&D Intensity

In addition to absolute levels of, and changes in, R&D expenditures, another key indicator of the health of industrial S&T is R&D intensity. R&D is similar to sales, marketing, and general management expenses in that it is discretionary, i.e., a nondirect revenue-producing item that can be trimmed when profits are falling. There seems to be considerable evidence, however, that R&D enjoys a high degree of immunity from belt-tightening endeavors, even when the economy is faltering, because of its crucial role in laying the foundation for future growth and prosperity. Nevertheless, whether industry devotes the right amount of economic resources to R&D has remained an open question. See sidebar, "Does Industry Underinvest in R&D?"

There are numerous ways to measure R&D intensity; the one used most frequently is the ratio of R&D funds to net sales.[20] This statistic provides a way to gauge the relative importance of R&D across industries and firms in the same industry. The industrial sectors with the highest R&D intensities in 1999 were scientific R&D services (32.1 percent), software (16.7 percent), communications equipment (11.6 percent), and computer systems design and related services (11.0 percent). Those with the lowest R&D intensities (less than 0.5 percent) were food, primary metals, broadcasting and telecommunications, and utilities. (See text table 4-10.) For all industries combined, the ratio of R&D to sales was 2.7 percent in 1999.

[20]Another measure of R&D intensity is the ratio of R&D to "value added" (which is sales *minus* the cost of materials). Value added is often used in studies of productivity analysis because it allows analysts to focus on the economic output attributable to the specific industrial sector in question by subtracting materials produced in other sectors. For a discussion of the connection between R&D intensity and technological progress, see, for example, Nelson (1988).

Does Industry Underinvest in R&D?

In a recent report by the National Institute for Standards and Technology (Tassey 1999), the author suggests that private industry may be underinvesting in R&D for the following reasons:

- **The riskiness of technology** must be factored in, not only in terms of achieving a technological advance but also in acquiring the ability to market it first. For example, if one firm initiates the research and makes the important discoveries but another firm is able to market the new technology first, then the firm that made the discovery would not recover its costs for R&D. Consequently, even though the economic returns to the second firm in this case would be very high, as would be the economic returns to society, the firm that initiated the effort may have good reason to be skeptical about its expected gains and therefore may be reluctant to initiate the work.
- **Spillovers from the technology** to other industries and to consumers, such as lower prices ("price spillovers") and increased general knowledge ("knowledge spillovers") may bring many benefits to the economy as a whole, independent of the returns to the firm that performs the R&D. As Tassey notes, "To the extent that rates of return fall below the private hurdle rate, investment by potential innovators will not occur."
- **Inefficiencies resulting from market structures,** in which firms may face high costs of achieving comparability when they are competing against each other in the development of technological infrastructure. For example, software developers are constrained, not only by the immediate development task at hand but also in having to ensure that the new software they develop is compatible with software and operating systems that other firms may be developing simultaneously. Here, greater efforts undertaken by industry or government to encourage standardization of emerging technologies would likely lead to higher returns to R&D.
- **Narrow corporate strategies.** According to Tassey, corporate strategies "often are narrower in scope than a new technology's market potential." In other words, companies in one line of business may not realize that the technological advances they make may have beneficial uses in other lines of business.* Thus, broader-based strategies that extend beyond a firm's immediate line of products would yield greater returns to R&D.
- **Large-scale technological infrastructure needs**. Like the Internet, technological infrastructure often yields high returns to individual companies and to the overall economy but often requires substantial levels of investment before any benefits can be realized. This argument is similar to the public-goods argument: for some large-scale R&D projects, funds from either government or an organized collaboration of industry participants may be necessary for the project to achieve the critical mass it needs to be successful. Once it is successful, however, high returns on the R&D invested might be realized.

Among NIST's general goals in addressing these issues is to encourage a "more analytically based and data-driven R&D policy."

*Levitt (1975) referred to this kind of problem as "marketing myopia."
SOURCE: Tassey (1999).

Performance by Geographic Location, Character of Work, and Field of Science

R&D by Geographic Location

The latest data available on the state distribution of R&D performance are for 1999. These data cover R&D performance by industry, academia, and Federal agencies, along with the federally funded R&D activities of nonprofit institutions.[21] In 1999, total R&D expenditures in the United States were $244.1 billion, of which $231.8 billion could be attributed to expenditures within individual states, with the remainder falling under an undistributed, "other/unknown" category. (See appendix tables 4-21 and 4-22.) The statistics and discussion below refer to state R&D levels in relation to the distributed total of $231.8 billion.

R&D is substantially concentrated in a small number of states. In 1999, California had the highest level of R&D performed within its borders—$48.0 billion—representing approximately one-fifth of the $231.8 billion U.S. total. The six states with the highest levels of R&D performance, California, Michigan, New York, Texas, Massachusetts, and Pennsylvania (in descending order), accounted for approximately one-half of the entire national effort. (See text table 4-11.) The top 10 states (the six above-mentioned states plus New Jersey, Illinois, Washington, and Maryland) accounted for approximately two-thirds of the national effort. (See appendix table 4-23.) California's R&D performance was 2.5 times as large as the R&D performance of the second highest state, Michigan, at $18.8 billion. After Michigan, ranking third was New York, with $14.1 billion, and the lowest of the top 10 states, Maryland, had $8.1 billion in R&D. The 20 highest ranking states in R&D expenditures accounted for 86.0 percent of the U.S. total; the lowest 20 states accounted for 4.5 percent.

[21]For historical data see appendix table 4-22. The state data on R&D contain 52 records: the 50 states; the District of Columbia and "other/unknown," which accounts for R&D in Puerto Rico and other nonstate U.S. regions; and R&D for which the particular state was not known. Approximately two-thirds of the R&D that could not be associated with a particular state is R&D performed by the nonprofit sector.

Text table 4-10.
Company and other (non-Federal) R&D funds as percentage of net sales in R&D-performing companies for selected industries: 1999

Industry	R&D as a percentage of sales
All industries	2.7
Manufacturing	3.2
Communications equipment	11.6
Pharmaceuticals and medicines	10.5
Navigational, measuring, electromedical, and control instruments	9.1
Semiconductor and other electronic components	8.3
Medical equipment and supplies	7.7
Computers and peripheral equipment	6.4
Resin, synthetic rubber, fibers, and filament	4.2
Machinery	3.3
Other chemicals	3.2
Aerospace products and parts	3.2
Motor vehicles, trailers, and parts	2.9
Electrical equipment, appliances, and components	2.3
Basic chemicals	2.0
Plastics and rubber products	1.9
Nonmetallic mineral products	1.5
Paper, printing and support activities	1.4
Fabricated metal products	1.4
Textiles, apparel, and leather	0.7
Furniture and related products	0.7
Wood products	0.5
Food	0.4
Primary metals	0.4
Nonmanufacturing	2.2
Scientific R&D services	32.1
Software	16.7
Computer systems design and related services	11.0
Architectural, engineering, and related services	6.8
Health care services	6.4
Management of companies and enterprises	5.7
Trade	5.5
Construction	3.1
Newspaper, periodical, book, and database information	2.0
Mining, extraction, and support activities	1.9
Finance, insurance, and real estate	0.5
Transportation and warehousing	0.5
Broadcasting and telecommunications	0.4
Utilities	0.1

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Research and Development in Industry: 1999*, Early Release Tables (Arlington, VA, 2001)

Science & Engineering Indicators – 2002

States vary widely in the size of their economies because of differences in population, land area, infrastructure, natural resources, and history. Consequently, variation in the R&D expenditure levels of states may simply reflect differences in their economic size or the nature of their R&D efforts. A basic way of controlling for this "size effect" is to measure each state's R&D level as a proportion of its gross state product (GSP). (See appendix table 4-23.) Like the term used in reference to the ratio of industrial R&D to sales, the proportion of a state's GSP devoted to R&D is referred to as R&D "intensity" or "concentration." Overall, the nation's total R&D to GDP ratio in 1999 was 2.63 percent. The top 10 rankings for R&D intensity were, in descending order, New Mexico (6.4 percent), Michigan (6.1 percent), Rhode Island (5.1 percent), Massachusetts (4.6 percent), Maryland (4.6 percent), the District of Columbia (4.5 percent), Washington (4.0 percent), California (3.9 percent), Delaware (3.9 percent), and Idaho (3.8 percent).

States have always varied in terms of the levels and types of industrial operations they contain. Thus, they also vary in the levels of R&D they contain by industrial sector. One measure of such variation among states is the extent to which their industrial R&D is in the manufacturing sector as opposed to the nonmanufacturing sector. Among the top 10 states in 1999 in industrial R&D performance, California, Massachusetts, Ohio, Texas, and Washington all had relatively low shares of R&D in the manufacturing sector (less than 64 percent, which was the national average). Higher levels of R&D in manufacturing, as a percentage of the total, were observed for Illinois, Michigan, New Jersey, New York, Ohio, and Pennsylvania. Among these 10 states, Michigan had the highest ratio of 92 percent, and Texas had the lowest ratio of 40 percent (industrial R&D in the manufacturing sector as a percentage of total industrial R&D). Part of this variation is attributable to differences among states in terms of their relative proportions of manufacturing and nonmanufacturing industries. Michigan, for example, is concentrated in motor vehicle manufacturing, and California devotes a great deal of R&D to software development and agricultural research. In Texas, 25 percent of industrial R&D performance took place in its computer and electronic products sector and another 20 percent in mining and extraction (including drilling for petroleum). Other factors, besides the locations of industrial production, may also play a role. For example, industries tend to perform research near universities that conduct the same type of research, enabling them to benefit from local academic resources.

Trends in National R&D by Character of Work

One traditional way to analyze trends in R&D performance is to examine the amount of funds devoted to basic research, applied research, and development. Admittedly, the traditional categories of basic research, applied research, and development do not always ideally describe the complexity of the relationship between science, technology, and innovation. However, alternative and perhaps more realistic models of the innovation process are probably too complicated to be used in collecting and analyzing comparable and reliable data for policymaking purposes and would not enable time-series analyses. See sidebar, "Choice of Right R&D Taxonomy Is a Historical Concern," later in the chapter. Nonetheless, in spite of these analytical limitations, these categories generally are useful to characterize the relative expected time horizons and types of investments.

The nation spent $47.9 billion on the performance of basic research in 2000, $55.0 billion on applied research and $161.7 billion on development. (See text table 4-1.) These totals are the result of continuous increases over several years. Namely,

Text table 4-11.
R&D performance by sector and R&D as percentage of GSP, for top 10 R&D performing states: 1999

Rank	Total R&D (millions of dollars)	Top 10 states in R&D performance, by performing sector: All R&D performers in state	Industry[a]	Universities and colleges[b]	Federal Government	Top 10 states in R&D intensity (states with highest R&D/GSP ratio): Top 10 states	R&D/GSP (percent)	GSP (billions of dollars)
1	47,965	California	California	California	Maryland	New Mexico	6.43	51.0
2	18,799	Michigan	Michigan	New York	District of Columbia	Michigan	6.10	308.3
3	14,110	New York	New York	Texas	Virginia	Rhode Island	5.07	32.5
4	12,429	Texas	Texas	Massachusetts	California	Massachusetts	4.64	262.6
5	12,190	Massachusetts	New Jersey	Pennsylvania	Alabama	Maryland	4.63	174.7
6	10,695	Pennsylvania	Massachusetts	Maryland	Florida	District of Columbia	4.50	55.8
7	10,536	New Jersey	Pennsylvania	Illinois	Ohio	Washington	3.98	209.3
8	9,719	Illinois	Illinois	North Carolina	Texas	California	3.90	1,229.1
9	8,336	Washington	Washington	Michigan	New Jersey	Delaware	3.87	34.7
10	8,087	Maryland	Ohio	Georgia	New Mexico	Idaho	3.85	34.0

GSP = gross state product

[a]Includes R&D expenditures of federally funded research and development centers (FFRDCs) administered by industry.

[b]Includes total R&D expenditures of FFRDCs administered by academic institutions.

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *National Patterns of R&D Resources: 2000 Data Update*, NSF 01-309 (Arlington, VA, March 2001). Available at <http://www.nsf.gov/sbe/srs/nsf01309/start.htm>.

Science & Engineering Indicators – 2002

since 1980 they reflect a 5.5 percent annual increase, in real terms, for basic research; a 3.9 percent increase for applied research; and a 3.8 percent increase for development. As a share of all 2000 R&D performance expenditures, basic research represented 18.1 percent, applied research represented 20.8 percent, and development represented 61.1 percent. These shares have not changed very much over time. For example, in 1980 basic research accounted for 13.9 percent, applied research accounted for 21.7 percent, and development accounted for 64.3 percent.

Basic Research. In terms of support, the Federal Government has always provided the majority of funds used for basic research. (See figure 4-12.) However, its share of funding for basic research as a percentage of all funding has fallen substantially, from 70.5 percent in 1980 to 48.7 percent in 2000. This decline in the Federal share of basic research support does not reflect a decline in the actual amount of Federal support, which, in fact, grew 3.5 percent per year in real terms between 1980 and 2000. Rather, it reflects a growing tendency for the funding of basic research to come from other sectors. From 1980 to 2000, industry's self-reported support for basic research grew at the rate of 10.0 percent per year in real terms.

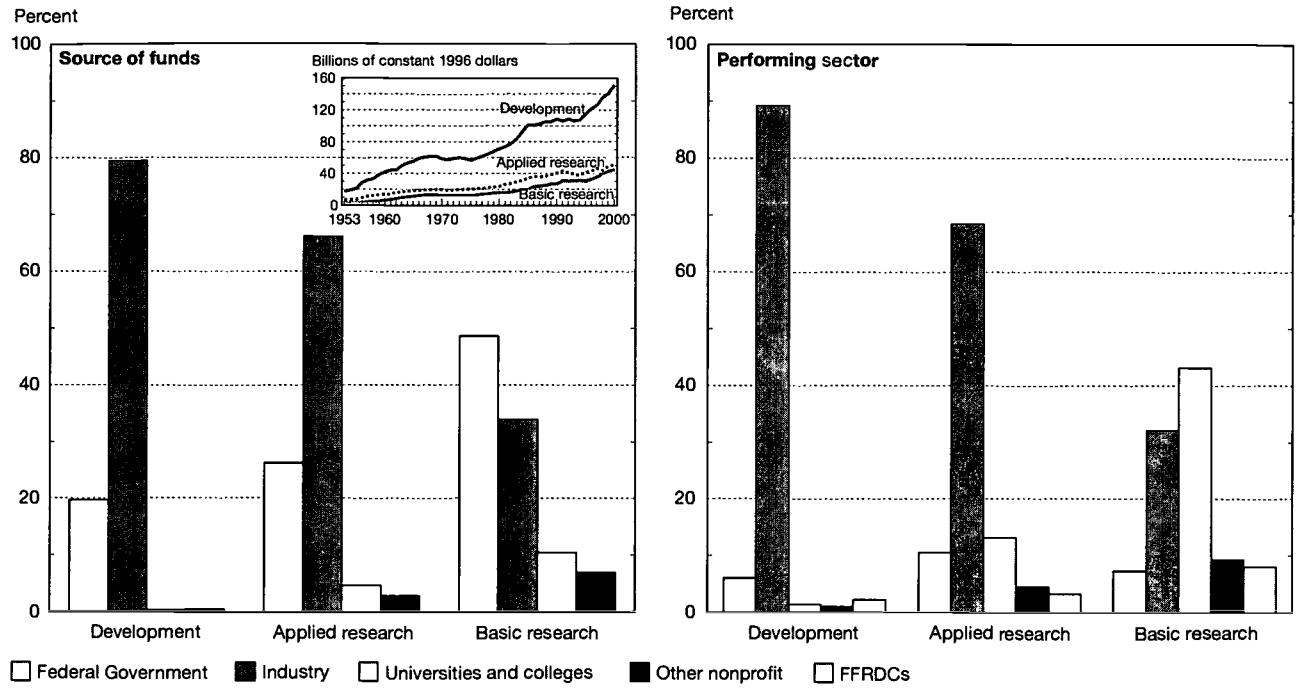
With regard to the performance of basic research in 2000, universities and colleges (excluding FFRDCs) accounted for the largest share with 43.1 percent ($20.7 billion), followed by industry with 32.1 percent ($15.4 billion). Their performance of basic research has undergone, on average, a 4.8 percent real annual increase since 1980. University-administered FFRDCs accounted for another 5.9 percent of total basic research performance in 2000. The dominant role played by universities and colleges in basic research is clearly related to the leading role that universities have in expanding general knowledge of S&E. Along the lines that general knowledge of science is a public good, the Federal Government provided 58.0 percent of the funding for basic research performed by universities and colleges. Non-Federal sources (industry, state and local governments, universities and colleges, and nonprofit organizations) provided the remaining 42.0 percent.

Applied Research. Applied research expenditures total $55.0 billion in 2000 and are performed much more by nonacademic institutions. They have been subject to greater shifts over time because of fluctuations in industrial growth and Federal policy. Applied research experienced a substantial average annual real growth of 7.4 percent between 1980 and 1985, followed by very low growth of 1.1 percent between 1985 and 1994, then rose again to 5.1 percent between 1994 and 2000. Increases in industrial support for applied research explain this recent upturn. Industrial support accounts for 66.1 percent ($36.4 billion) of the 2000 total for applied research and Federal support for 26.3 percent ($14.5 billion).

In the past two decades, Federal support for applied research has been intentionally deemphasized in favor of basic research. Consequently, in 2000 Federal funding for applied research is only 62.0 percent of that for basic research ($14.5 billion versus $23.3 billion, respectively), as reported by research performers.

Most applied research in calendar year 2000 (68.4 percent, or $37.6 billion) was performed by industry. In the same year, most of the nation's nonindustrial applied research was performed by universities and colleges and their administered FFRDCs ($8.7 billion) and the Federal Government ($5.8 billion). For Federal intramural applied research (for which data are organized by fiscal year), 24.7 percent in FY 2000 was

Figure 4-12.
National R&D expenditures, by source of funds, performing sector, and character of work: 2000



FFRDCs = Federally Funded Research and Development Centers

See appendix tables 4-7 through 4-18.

Science & Engineering Indicators – 2002

performed by HHS, 21.8 percent in FY 2000 was performed by DOD, and 11.6 percent was performed by DOC. Total Federal applied research performance has been remarkably level for 34 years, experiencing only a 0.8 percent average annual growth, in real terms, since 1966.

Development. Expenditures on development in calendar year 2000 totaled $161.7 billion, accounting for most of R&D expenditures. Therefore, historical patterns of development expenditures mirror historical patterns of total R&D expenditures. From 1980 to 1985, development grew on average by 7.2 percent per year in real terms as increasingly larger shares of the national R&D effort were directed toward R&D supported by DOD, which tends to be approximately 90 percent development. (See figure 4-13.) Between 1985 and 1994, on the other hand, development in real terms grew at an average annual rate of only 0.7 percent, from $74.5 billion in 1985 to $103.0 billion in 1994. Between 1994 and 2000, annual growth was back up to 5.9 percent in real terms to $161.7 billion in 2000, of which 79.4 percent was supported by industry and 19.7 percent by the Federal Government.

In terms of performance, industry accounted for 89.2 percent ($144.3 billion) of the nation's 2000 development activities, the Federal Government 6.1 percent ($9.8 billion), and all other performers 4.7 percent ($7.6 billion).

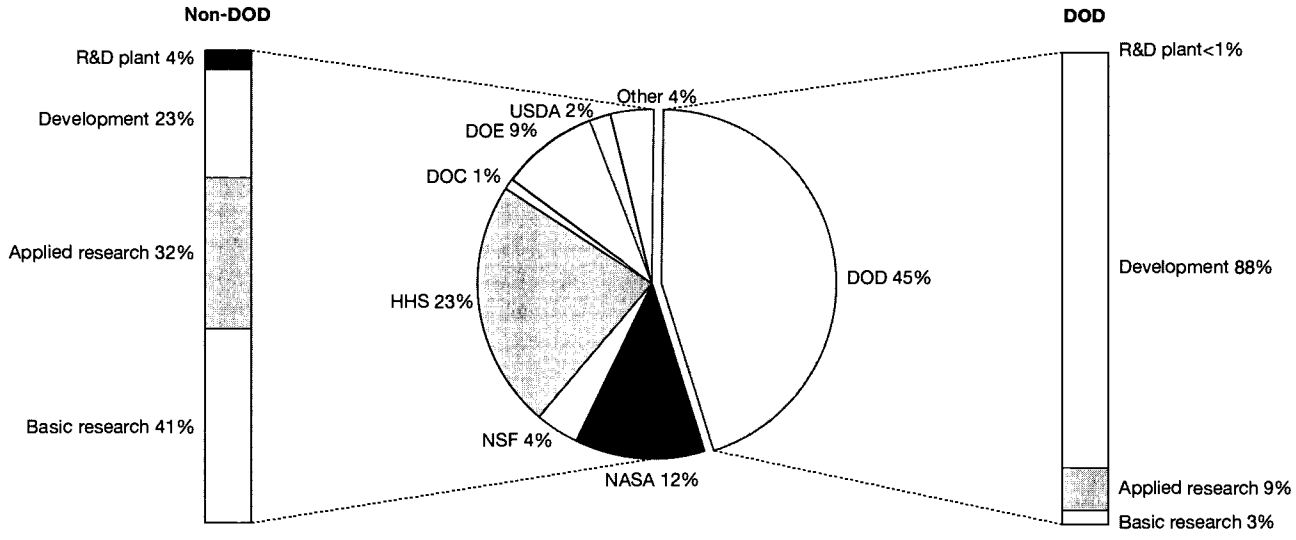
Federal Obligations for Research, by Field

Federal obligations for research alone (excluding development) will total $38.7 billion in FY 2001 by preliminary estimates. Life sciences will receive the largest portion of this funding (47.2 percent, or $18.2 billion), most of which will be provided by HHS. (See figure 4-14.) The next largest field in Federal obligations for research in FY 2001 will be engineering (18.3 percent), followed by physical sciences (11.5 percent), environmental sciences (8.4 percent), and mathematics and computer sciences (6.5 percent). Social sciences, psychology, and all other sciences will account for another 2.6 percent, 1.9 percent, and 3.6 percent, respectively.

In terms of agency contributions to these research efforts, HHS, primarily through NIH, will provide the most (42.8 percent) of all Federal research obligations in FY 2001. The next largest contributor will be NASA (12.2 percent) with substantial funding of research in engineering ($2.2 billion), physical sciences ($0.9 billion), and environmental sciences ($1.1 billion). (See figure 4-14.) DOE will provide 11.7 percent of research funding, primarily in the fields of engineering, physical sciences, and mathematics and computer sciences. DOD will fund a similar amount of research (11.4 percent of the total), primarily in the areas of engineering and mathematics and computer sciences. NSF will provide 8.2 percent of research funding, with between $0.5 and $0.7 billion contributed to each of the following fields: life sciences, engineering, physical sciences, environmental sciences, and mathematics and computer sciences.

Federal obligations for research have grown at different rates for different fields of S&E, reflecting changes in perceived public interest in those fields, changes in the national

Figure 4-13.
Projected Federal obligations for R&D and R&D plant, by agency and character of work: FY 2001

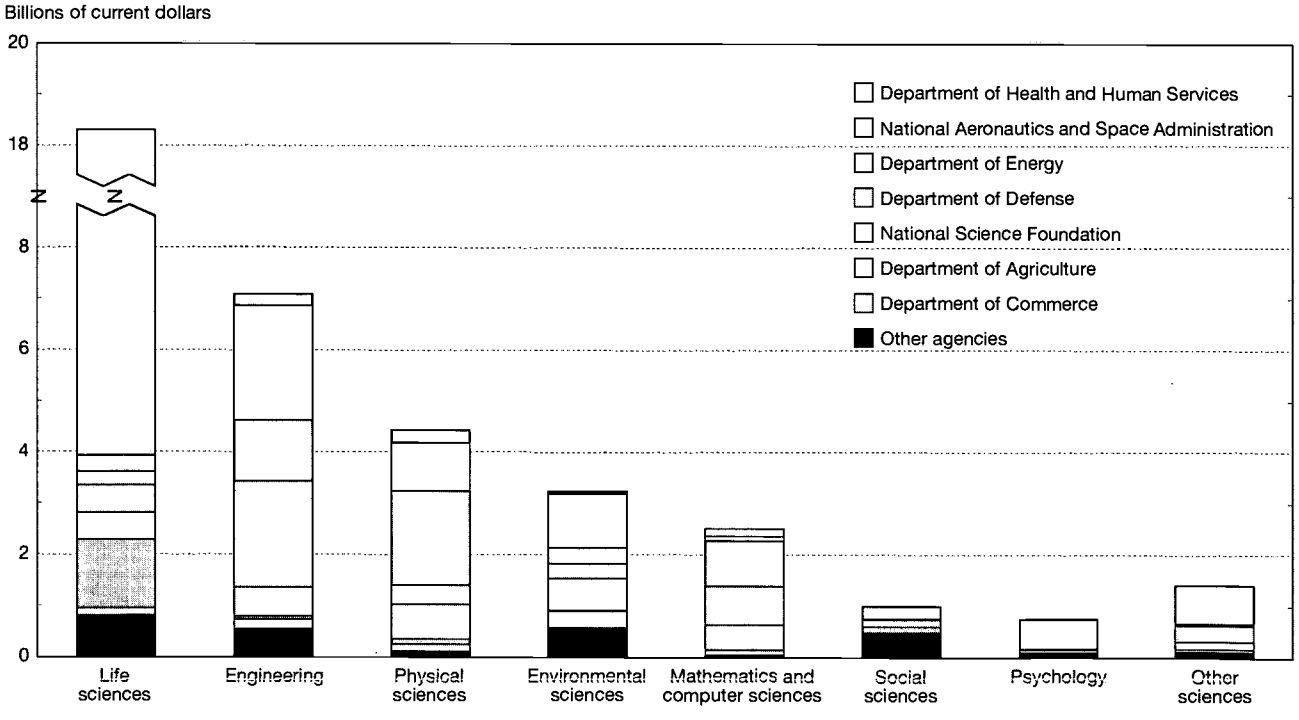


DOC = Department of Commerce; DOE = Department of Energy; DOD = Department of Defense; HHS = Department of Health and Human Services; NSF = National Science Foundation; NASA = National Aeronautics and Space Administration; USDA = U.S. Department of Agriculture

See appendix table 4-25.

Science & Engineering Indicators – 2002

Figure 4-14.
Federal obligations for research, by major science and engineering field, and agency: FY 2001



See appendix table 4-27.

Science & Engineering Indicators – 2002

resources (e.g., scientists, equipment, and facilities) that have been built up in those fields over time, as well as differences in scientific opportunities across fields. Based on preliminary estimates for FY 2001, the broad field of mathematics and computer sciences has experienced the highest rate of growth in Federal obligations for research, which was 8.3 percent per year in real terms between 1980 and 2001. Life sciences had the second highest rate with 3.9 percent, followed by psychology with 3.2 percent, environmental sciences with 1.3 percent, engineering with 1.2 percent, and physical sciences with 0.6 percent. Research in the social sciences (including anthropology, economics, political sciences, sociology, and other areas) experienced a slight decline of 0.12 percent.

These trends in Federal support for the above-mentioned broad fields of research, however, may not reflect trends for the smaller fields that they contain. For example, with regard to the broad field of mathematics and computer sciences, Federal support for research in mathematics grew by 3.8 percent per year in real terms between FY 1980 and FY 1999, whereas support for research in computer sciences grew by 10.2 percent.[22] During the same period, within life sciences, support for biological and agricultural research grew by 1.7 percent compared with research support for medical sciences, which grew by 4.6 percent. Within the physical sciences, support for astronomy grew by 1.8 percent, whereas support for chemistry declined by 0.23 percent.

Cross-Sector Field-of-Science Classification Analysis

Federal and academic research expenditures are often classified according to the S&E fields they support. However, it may also be useful to classify all R&D activity by specific S&E fields. Such classification, when applied to historical data, would indicate how R&D efforts in various fields of S&E have grown in economic importance over time. This information is potentially useful for science policy analysis and for planning and priority setting.

Classification of academic R&D by field of science is provided in detail in chapter 5. At present, the only additional sector for which there exist extensive data by field is the Federal Government. Industrial R&D, which represents three-fourths of all R&D performed in the United States, is not collected by field of study for three reasons:

- Unlike universities and Federal agencies, most private companies do not have the recordkeeping infrastructure in place to compile such statistics; thus, any efforts on their part to provide this additional information could be significantly burdensome to them.
- Much of the research by private firms is confidential, and the provision of such information to outsiders might compromise that confidentiality.
- Much of the R&D carried out by industry is interdisciplinary, especially at the development stage (e.g., the development of a new vehicle would involve mechanical engineering, electrical engineering, and other fields), which in many cases might make the splitting of R&D by field somewhat arbitrary.

Nonetheless, some analysis by field of study, wherever possible, shed light on overall levels of R&D support for general lines of inquiry. In particular, this problem can be circumvented by grouping fields within standard industrial categories, thereby creating categories of R&D that can be associated both with S&E fields and with related industrial categories. We focus in particular in two broad areas, chemistry (nonmedical) and chemical engineering, and life sciences. For ease in data interpretation, all academic and Federal FY data were converted to calendar year data so that they would be comparable to the data pertaining to industry categories (which are collected and provided on a calendar year basis).[23]

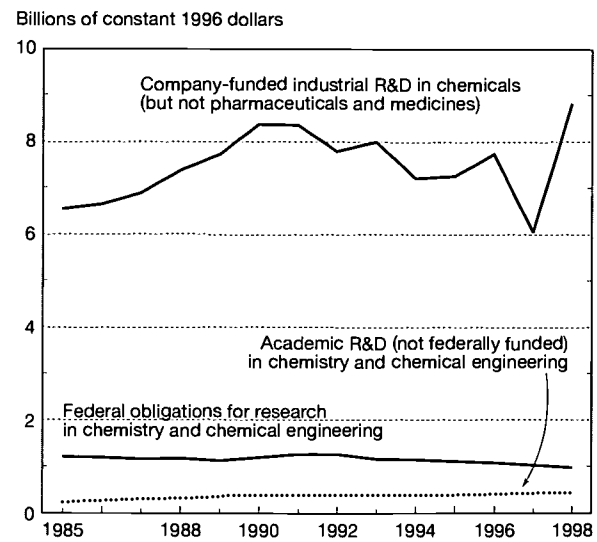
R&D in Chemistry (Nonmedical) and Chemical Engineering. In 1998, R&D in the broad area of chemistry and chemical engineering accounted for approximately $10.3 billion (in constant 1996 dollars). Three categories of R&D were identified in this area.[24] (See figure 4-15.) The largest of these categories, by far, is company-funded R&D in industrial chemicals and other chemicals (but not pharmaceuticals and medicines). In real terms (constant 1996 dollars), expendi-

[22]For these smaller field categories, the latest available data are for FY 1999.

[23]At this writing, the most recent data on academic R&D performance and Federal R&D obligations are for FY 1999. However, the conversion of these numbers from fiscal year to calendar year meant that only data estimates for calendar year 1998 were possible for these figures because estimation of calendar year 1999 data would have required fiscal year 2000 data, which were not available. All dollar amounts in this section are given in real terms (constant 1996 dollars).

[24]These categories exclude chemistry associated with medicine, which was included instead under life sciences.

Figure 4-15.
R&D associated primarily with chemistry (nonmedical) and chemical engineering



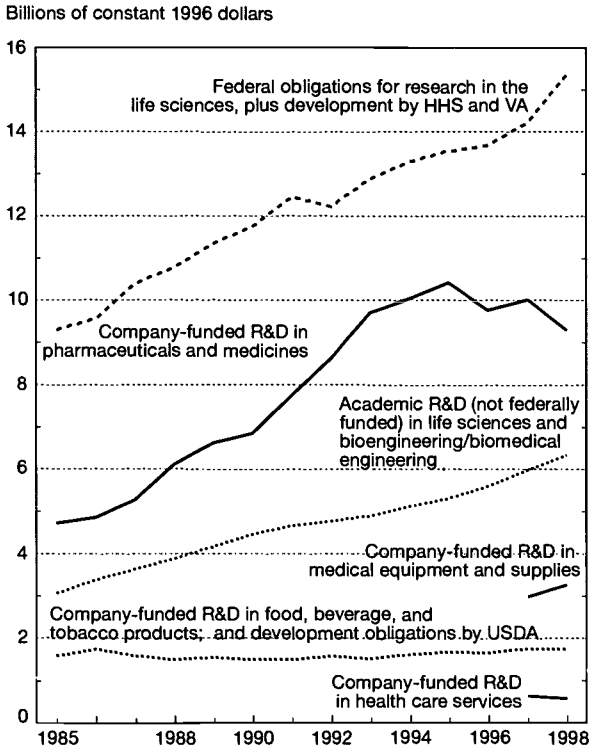
See appendix table 4-28.

Science & Engineering Indicators – 2002

tures in this category grew from $6.6 billion in 1985 to $8.8 billion in 1998, although the sector has displayed considerable year-to-year fluctuation between 1996 and 1998 (inclusive). The next two categories were much smaller. Federal obligations for research in chemistry and chemical engineering declined between 1985 and 1998, from $1.2 to $980 million (in constant 1996 dollars). Academic R&D (not federally funded) in chemistry and chemical engineering, the smallest category, grew steadily in real terms, from $237 million in 1985 to $444 million in 1998.

R&D in Life Sciences. The broad life sciences field accounted for $36.5 billion of R&D in 1998 (in constant 1996 dollars). R&D in this area is characterized by strong and fairly continuous real growth in its three largest categories. (See figure 4-16.) The largest of these three, Federal obligations for research in the life sciences, plus development expenditures by HHS and the Department of Veterans Affairs, rose from $9.3 billion in 1985 to $15.4 billion in 1998 in constant 1996 dollars. Company-funded R&D in pharmaceuticals and medicines grew dramatically in real terms, from $4.7 billion in 1985 to $10.4 billion in 1995 but then declined to $9.3 billion by 1998. In contrast, academic R&D (not federally funded) in life sciences and bioengineering/biomedical engineering grew continuously, from $3.0 billion in 1985 to $6.3 billion in 1998.

Figure 4-16.
R&D associated primarily with life sciences



HHS = Department of Health and Human Services; USDA = U.S. Department of Agriculture; VA = Department of Veterans Affairs

See appendix table 4-29.

Science & Engineering Indicators – 2002

With regard to food and other traditional products, however, company-funded R&D in food, beverage, and tobacco products, and development expenditures by USDA, show virtually no real R&D growth. That is, as shown in figure 4-16, R&D for this combined subcategory grew only from $1.6 to $1.7 billion between 1985 and 1998. Finally, two new categories of industrial R&D in the life sciences, arising from the new NAICS classification system, are company-funded R&D in health care services and company-funded R&D in medical equipment and supplies. In 1998, the former accounted for $566 million in R&D and the latter for $3.3 billion, in constant 1996 dollars.

Research Alliances: Trends in Industry, Government, and University Collaboration

All major players involved in the creation, diffusion, and commercialization of R&D have experienced changes in how innovation activities are financed, organized, and performed (Jankowski 2001a; Mowery 1998). Well-known risks of conducting scientific research and commercializing its results have been compounded by the increased speed and interdisciplinary nature of technological developments. In this environment, collaborations and alliances, at home or overseas, allow partners to share R&D costs, pool risks, and enjoy access to firm-specific know-how and commercialization resources (Hagerdoon, Link, and Vonortas 2000; Vonortas 1997). In the policy arena, changes in antitrust regulations, intellectual property policy, and technology transfer have fostered a new setting for collaborative research since the early 1980s. (See sidebar, "Major Federal Legislation Related to Cooperative R&D and Technology Transfer.") These changes have paralleled policy and market trends in other advanced economies, contributing to a national and global economy increasingly dependent on knowledge-based competition and networking.

Joint research activities complement other tools to acquire or develop technology, from licensing off-the-shelf technologies to mergers and acquisitions (M&A). Corporate R&D planning increasingly requires a combination of technology exchange (acquisition of external R&D outputs as well as spinoff of noncore technologies) and strategic R&D alliances to excel in innovation and market performance (Arora, Fosfuri, and Gambardella 2000).[25] Even local and Federal Government agencies have developed technology strategies to maximize regional competitive advantage and national benefits. Universities also have adjusted to this new environment by increasing funding links, technology transfer, and collaborative research activities with industry and Federal agencies over the last two decades.

At the same time, collaborative networks are not without risks. Unintended transfer of proprietary technology is always a concern for businesses. Cultural differences among differ-

[25]M&A activity and international R&D investments are covered in a separate section below.

Major Federal Legislation Related to Cooperative R&D and Technology Transfer

- **Stevenson-Wydler Technology Innovation Act (1980)**—required Federal laboratories to facilitate the transfer of federally owned and originated technology to state and local governments and to the private sector.
- **Bayh-Dole University and Small Business Patent Act (1980)**—permitted government grantees and contractors to retain title to federally funded inventions and encouraged universities to license inventions to industry. The act is designed to foster interactions between academia and the business community.
- **Small Business Innovation Development Act (1982)**—established the Small Business Innovation Research (SBIR) program within the major Federal R&D agencies to increase government funding of research with commercialization potential within small, high-technology companies.
- **National Cooperative Research Act (1984)**—encouraged U.S. firms to collaborate on generic, precompetitive research by establishing a rule of reason for evaluating the antitrust implications of research joint ventures. The act was amended in 1993 by the National Cooperative Research and Production Act, which let companies collaborate on production as well as research activities.
- **Federal Technology Transfer Act (1986)**—amended the Stevenson-Wydler Technology Innovation Act to authorize cooperative research and development agreements (CRADAs) between Federal laboratories and other entities, including state agencies.
- **Omnibus Trade and Competitiveness Act (1988)**—established the Competitiveness Policy Council to develop recommendations for national strategies and specific policies to enhance industrial competitiveness. The act created the Advanced Technology Program and the Manufacturing Technology Centers within NIST to help U.S. companies become more competitive.
- **National Competitiveness Technology Transfer Act (1989)**—amended the Stevenson-Wydler Act to allow government-owned, contractor-operated laboratories to enter into cooperative R&D agreements.
- **National Cooperative Research and Production Act (1993)**—relaxed restrictions on cooperative production activities, enabling research joint venture participants to work together in the application of technologies they jointly acquire.
- **Technology Transfer Commercialization Act (2000)**—amended the Stevenson-Wydler Act and the Bayh-Dole Act to improve the ability of government agencies to license federally owned inventions.

ent industries, academic or government partners, or international collaborators present additional difficulties for managing alliances. On the other hand, the degree of cohesion among members may bring unintended anticompetitive behavior or may conflict with other economic or science policy objectives. For example, industry-university and industry-government collaborations have highlighted concerns about adequate availability of research findings in certain scientific areas.[26]

Types of Research Partnerships

Collaborations can be classified and analyzed according to several criteria. By type of members, there are a variety of business, university, and government combinations, including government-to-government technical collaborations. In terms of activities, business alliances may focus on manufacturing, services, marketing, or technology-based objectives. For example, according to an OECD paper, R&D alliances represent as many as 23 percent of all types of alliances in North America compared with 14 percent in Western Europe and 12 percent in Asia (Kang and Sakai 2000). Also according to this study, North America is the only region in which the share of R&D alliances is higher than the share of manufacturing alliances.

Technology-based collaboration broadly defined includes joint research activities, technology codevelopment, contract research, and technology exchange (licensing and cross-licensing). In particular, strategic research partnerships (SRPs), a subset of these broad interactions, emphasize joint R&D activities as opposed to contract research or other exclusively financing or exchange transactions. SRPs can take the form of formal joint ventures (a specific term in many legal codes internationally) or more informal agreements. Types of SRPs found in available databases and published studies include research joint ventures (RJVs), cooperative R&D agreements, and strategic technology alliances.

According to Hagerdoon, Link, and Vonortas (2000), in the early 1970s the majority of research partnerships were equity-based research corporations, but "[b]y the mid-1990s, more than 85 percent of research partnerships did not involve equity investments." This is attributed in large part to the higher degree of organizational flexibility of nonequity agreements. Still, SRPs of any type constitute a highly flexible tool for pursuing new technology venues. A relatively small participation in any one alliance may bring the full benefits of the research outputs, which may be further developed or commercialized. Furthermore, these partnerships may evolve into other types of agreements or acquisitions, or they may serve as an entry into new geographic markets over time.

Dedicated databases tracking these developments and sponsored in part by NSF include the Cooperative Research (CORE) database, the National Cooperative Research Act (NCRA)-RJV database, and the Cooperative Agreements and Technology Indicators database compiled by the Maastricht

[26]For an overview of the issues, see Behrens and Gray (2001); Feldman et al. (2001); Brooks and Randazzese (1998); and Cohen et al. (1998).

Economic Research Institute on Innovation and Technology (CATI-MERIT) (Link and Vonortas 2001). The first two cover U.S.-based alliances recorded in the *Federal Register*, pursuant to the provisions of NCRA.[27] Trends in either database are illustrative only of the technical and organizational characteristics of joint ventures in the United States because the registry is not intended to be a comprehensive count of cooperative activity by U.S.-based firms. The CATI-MERIT database covers international collaborations based on announcements of alliances and tabulated according to the country of ownership of the parent companies involved.[28]

Domestic Public and Private Collaborations, Including Federal Programs

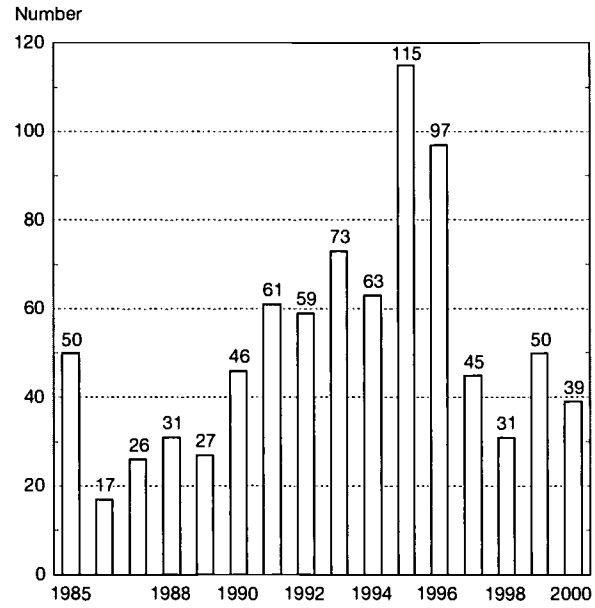
Research Joint Ventures

More than 800 RJVs were registered in the NCRA-RJV database from 1985–2000.[29] According to Vonortas (2001), from 1985 to 1999 these collaborations involved more than 4,200 unique businesses and organizations. Of these participating organizations, more than 3,000 (about three-fourths) were U.S. based; 88 percent of these domestic participants were for-profit firms, 9 percent were nonprofit institutions (including universities), and 3 percent were government units. Two-thirds of the organizations represented in these alliances participated in only one collaboration over the 15-year period ending in 1999; another 27 percent participated in two to five alliances.

The CORE database (Link 2001), based on collaborations as a unit, shows the following trends:

- In 2000, there were 39 new RJVs compared with 50 in 1999. New filings peaked in 1995 at 115 after increasing successively since 1986. (See figure 4-17.) Brod and Link (2001) estimated a statistical model to explain the trends in RJVs filings, including the decline since the 1995 peak. They find that filings are likely to be countercyclical. In particular, they argue that "[w]hen the economy is strong and...R&D is growing, firms may rely less on cooperative research arrangements...than when the economy is weak and internal resources are more constrained."
- Half of the research joint ventures in 1985–2000 involved companies in three industries: electronic and electrical equipment (148 of 829, or 18 percent), communications (135, or 16 percent), and transportation equipment (127, or 15 percent).

Figure 4-17.
Domestic research joint ventures: 1985–2000



NOTE: Data are annual counts of new research joint ventures registered under the National Cooperative Research and Production Act.

SOURCE: Based on data from Link, A. 2001. *Federal Register Filings: The 2000 Update of the CORE Database*. Report submitted to the National Science Foundation, Arlington, VA.

Science & Engineering Indicators – 2002

In terms of the composition of these joint ventures, petroleum refining (SIC 29) and related oil and gas extraction each had a median of eight members, the highest among individual industries over 1989–99. Chemicals (SIC 28) and electronic and electrical equipment and components (SIC 36) had a median of six and five, respectively.[30] Participation of universities and Federal agencies in these colaborative activities is discussed next.

[27]Domestic data come from *Federal Register* filings of RJVs. Restrictions on multifirm cooperative research relationships were loosened by NCRA in 1984 (Public Law 98-462) after concerns over the technological leadership and international competitiveness of American firms in the early 1980s. This law was enacted to encourage U.S. firms to collaborate on generic, precompetitive research. However, to gain protection from antitrust litigation, NCRA requires firms engaging in RJVs to register them with the Department of Justice. In 1993, the National Cooperative Research and Production Act (NCRPA, Public Law 103-42) extended legal protection to collaborative production activities.

[28]The CATI database is compiled by the Maastricht Economic Research Institute on Innovation and Technology in the Netherlands. The data consist of thousands of interfirm cooperative agreements. These counts are restricted to strategic technology alliances, such as joint ventures for which R&D or technology sharing is a major objective, research corporations, and joint R&D pacts. CATI is a literature-based database. Its key sources are newspapers, journal articles, books, and specialized journals that report on business events. Because data are limited to activities publicized by the firm, agreements involving small firms and certain technology fields are likely to be underrepresented. Another limitation is that the database draws primarily from English-language materials.

[29]Note that data from the *Federal Register*, while illustrative, are based on a specific legislative intent focused on antitrust concerns, as opposed to a dedicated survey activity. This fact may bias the RJVs counts and/or their composition in several ways. In one respect, the counts may fall short of the true extent of the phenomenon depending on the (perceived) antitrust climate over time. On the other hand, some joint ventures may register an excessive number of members, even if actual research activity is limited to few R&D active partners.

[30]In some SICs, the average number of members is inflated by several consortia with as many as several hundred members. These large groupings may not represent actual collaborative research activity but agreements to share results by providing funding, facilities, or other type of support, while joining a legally sanctioned umbrella. In particular, there are at least 19 consortia with more than 100 members in this database, many of which have multiple university members, as well as government participation.

Public-Private Collaborations

Collaborative S&T activities may involve public institutions, such as government agencies and universities, as well as other nonprofit research organizations. Activities include transfer of technology from Federal laboratories and universities, small business S&T programs, and the Advanced Technology Program. See sidebar, "The Advanced Technology Program: 1990–2000 Trends."

Federal Technology Transfer Programs. In general, technology transfer can be defined as the exchange or sharing of technology or technical knowledge across different organizations. It can take place in a number of scenarios: in public or private research collaborations (the focus of this section), in fee-based transactions (licensing and trade), and in training or hiring activities. The role of Federal agencies and laboratories, either as a source of technology to be commercialized by private parties or as a research partner, is considerable given substantial Federal R&D activity, as described earlier in the chapter. Public policy objectives for Federal cooperative research and technology transfer activities include the support of mission objectives such as defense, public health, and the promotion of competitiveness and economic growth (Bozeman 2000). One common technology transfer mechanism is a license that confers rights to exploit commercially a patented or otherwise proprietary technology. Other technology transfer mechanisms include cooperative agreements, personnel exchange, user facility agreements, and technical assistance.

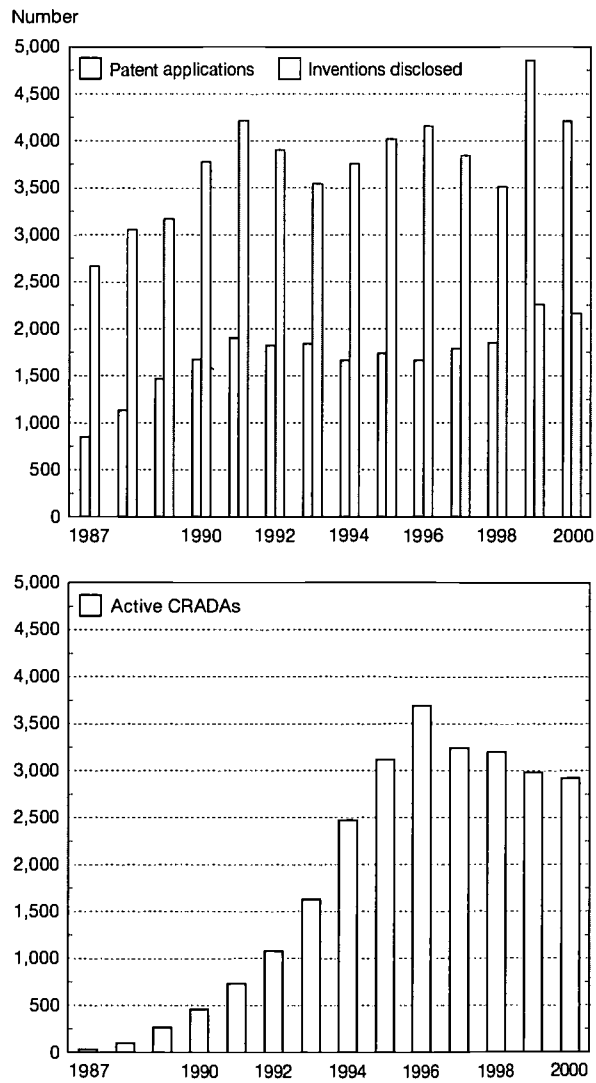
In the early 1980s, Federal technology transfer became widely regarded as a means of addressing Federal concerns about U.S. industrial strength and world competitiveness. The Stevenson-Wydler Technology Innovation Act of 1980 added technology transfer of Federally-owned or originated technology as an explicit mission of Federal laboratories. In the same year, the Bayle-Dole Act specified the authority of Federal agencies to obtain patents, grant licenses, and transfer custody of patents with the explicit purpose of promoting the utilization and marketing of inventions under Federally-funded R&D by nonprofit organizations and small businesses. Subsequent amendments repealed the restriction to grant an exclusive license only to small firms (Schacht 2000). Later in the decade, the Federal Technology Transfer Act of 1986 authorized government-owned and government-operated laboratories to enter into Cooperative Research and Development Agreements (CRADAs)[31] with private industry and gave all companies, regardless of size, the right to retain title to inventions (Schacht 2000). The 1989 passage of the National Competitiveness Technology Transfer Act extended this authority to contractor-operated labs (including DOE's FFRDCs). More recently, the Technology Transfer Commercialization Act of 2000 (Public Law 106-404) improved the ability of Federal agencies to license federally owned inventions.

[31]The statute defines CRADAs as any agreement between one or more laboratories and one or more non-Federal parties in which the government shares personnel, facilities, equipment, or other resources (but not funding) with non-Federal parties for the purpose of advancing R&D efforts consistent with the missions of the laboratories.

Data on technology transfer activities from Federal agencies are reported to the Department of Commerce and include inventions disclosed, Federally-owned patents, licenses of patented inventions, income from those patented inventions, and the number of CRADAs. In 2000, Federal agencies involved in R&D and technology transfer activities reported 4,209 invention disclosures, 2,159 patent applications, and 1,486 patents issued. (See figure 4-18 and appendix table 4-35.) Since fiscal year 1997, a total of 5,655 patents have been issued to Federal agencies.

A total of 2,924 CRADAs involving 10 Federal agencies and their laboratories were active in 2000. The largest participants by far are DOD laboratories (1,364 active CRADAS or 47 percent of the total) and DOE (687 or 23 percent). The number of active CRADAs increased rapidly in the early and

Figure 4-18.
Federal technology transfer indicators: 1987–2000



CRADA = Cooperative Research and Development Agreement

See appendix table 4-35.

Science & Engineering Indicators – 2002

The Advanced Technology Program: 1990–2000 Trends

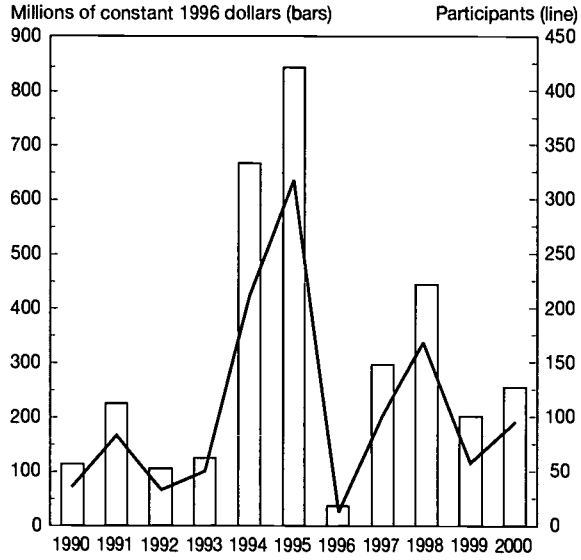
The Advanced Technology Program (ATP), National Institute of Standards and Technology, U.S. Department of Commerce, has funded the development of high-risk enabling technologies since 1990. Proposals are submitted to a peer review process based on technical and economic criteria. Awards are made on a cost-share basis for both single applicants and joint ventures.

During the 1990–2000 period, over 1,100 companies, nonprofit institutions, and universities participating in the program received $3.3 billion in R&D funding—divided about equally between ATP and industry funds. (See appendix table 4-38.) These participants pursued 522 projects in five technology areas: biotechnology, electronics, information technology, advanced materials and chemistry, and manufacturing. In terms of project structure, 350 projects (67 percent) were single-company projects and 172 (33 percent) were joint ventures; 812 participants (70 percent) were members of joint ventures over this 11-year period.

In 2000, funding for projects increased 27 percent to $256 million in constant 1996 dollars after declining more than 50 percent in 1999. (See figure 4-19.) The funding in 2000 included $135 million (53 percent) from ATP and $122 million (47 percent) from industry. At the same time, the number of awards increased 46 percent to 54, whereas the number of participants increased by 67 percent. Funding for the ATP program peaked in the last two years of the first Clinton administration, declined drastically in 1996, and has ranged between one-fourth and one-third of the 1995 peak ever since.

The ups and downs in ATP funding over the 1990s reflect, in part, an ongoing debate over the program's goals. On one hand, the inherent technical and market risks and the inability of private firms to fully capture the benefits in some enabling technologies are recognized by most observers as generating underinvestment in certain R&D areas. However, the role and effectiveness of ATP and similar technology partnership programs as policy tools to answer this challenge are still under debate.* At the time of this writing, the Bush administration's FY 2002 budget calls for the suspension of new awards and for an evaluation of the program to assess long-term funding (U.S. OMB 2001b).

Figure 4-19.
ATP funding and number of participants: 1990–2000



ATP = Advanced Technology Program

NOTE: Constant dollars based on fiscal year GDP implicit price deflators (appendix table 4-1).

See appendix table 4-38.

Science & Engineering Indicators – 2002

*For empirical studies related to this debate see David, Hall, and Toole (2000). For public policy analysis of the program, see Wessner (2001) and references therein.

mid-1990s, reached a peak of 3,688 in fiscal year 1996, and stabilized around 3,000 since. (See figure 4-18.) For a comprehensive review of licensing and other policy issues in CRADAS using data on the above indicators to fiscal year 1998, see U.S. OTP (2000). Other data on CRADAs such as internal structure (membership profiles, organizational structure), activities, and research outputs (licensing, commercial and agency mission impacts) have been explored by a number of case studies but are unavailable from more comprehensive survey data.[32]

Industry-University Collaboration. Even though the Federal Government still provides the bulk of university research funding, universities have adjusted to the decreasing role of the Federal Government in R&D funding by relying increasingly on non-federal funding sources[33] and by engaging in collaborations with nonacademic organizations (Jankowski 1999). Universities have also increased their patenting and technology transfer activities, notably since the Bayh-Dole Act of 1980 (and subsequent amendments) allowed them to patent federally funded research (Mowery et al. 2001; Nelson 2001).[34] From the perspective of industry, joint research activities with academia support industrial research objectives and comple-

[32]See Mowery, David, C. *Using Cooperative Research and Development Agreements as S&T Indicators: What Do We Have and What Would We Like?* in NSF (2001g) and references therein.

[33]For a discussion of funding of academic R&D in the U.S. and other advanced economies, see "International Comparisons of National R&D Trends" later in the chapter.

[34] For more on university patenting activity and technology transfer see 'Outputs of Scientific and Engineering Research' in Chapter 5, Academic Research and Development, of this volume. See also the special issue of the *Journal of Technology Transfer* on the Symposium on University-Industry Technology Transfer (vol. 26, no. 5, January 2001).

ment other aspects of industry-university relations, including most notably the hiring of graduates.

Federal assistance for cooperative research centers between industry and academia, including NSF's Cooperative Research Centers, was specified in the Federal Technology Transfer Act of 1986.[35] A paper based on a survey of NSF's Industry-University Cooperative Research Centers (IUCRCs) suggests that these centers have had a positive impact on joint authorship with university scientists, contract research, licensing of university patenting, and hiring of graduate studies (Adams, Chiang, and Starkey 2001).

The CORE database on research alliances (described earlier) provides some indication of the extent of these public-private collaborations. For the 1985–2000 period, universities participated in 15 percent of these RJVs, and 11 percent had at least one Federal laboratory member. However, eight percent of domestic alliances had at least one university as a research member in 2000, down from 16 percent in 1999 and below the 30 percent peak in 1996.

From 1985–2000, 30 percent of RJVs in electronic and electrical equipment (SIC 36) and 19 percent of industrial machinery RJVs (including computer manufacturing) had at least one U.S. university as a partner, topping all industries in this category (see figure 4-20). Collaborations in these two industries also had the highest level of participation by Federal laboratories.

Small Business S&T Programs. Small businesses have a long-recognized role in fostering local and national economic growth. In the S&T arena, this recognition translates into the effort to increase the participation of small business in Federal R&D and technology transfer. Although economic activity and R&D performance tend to be performed by large firms in the manufacturing sector and small firms in the nonmanufacturing sector, as discussed earlier in the chapter, economists have debated over the years whether smaller or larger firms are more likely to engage or succeed in innovative activities. Further studies have shown that their relative incentives and efficiencies in research and commercialization depend on a number of institutional and technological characteristics over the life cycle of products or industries. Furthermore, alliances between small or startup firms and established companies may fare better than either type of business individually.

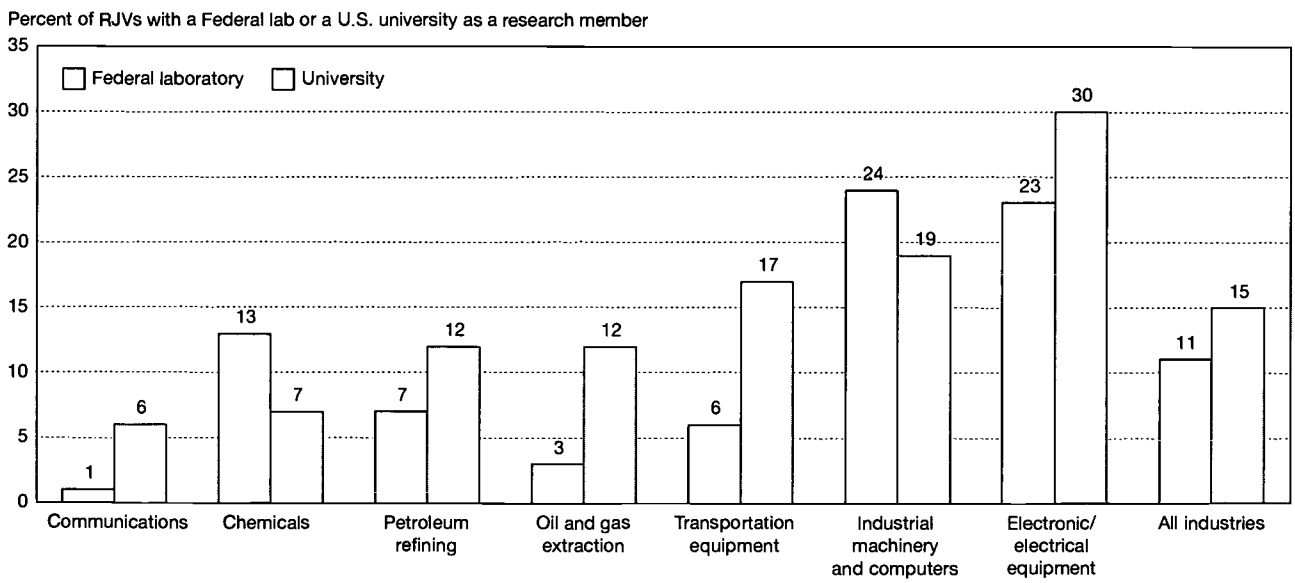
Nevertheless, smaller firms are more likely than larger or more established companies to be affected by a number of financing and other market constraints. Internal funds have been shown to significantly affect R&D activity conducted by small high-technology firms.[36] Larger firms may be able to produce cash flows above investment needs and generally have better access to capital markets. Smaller or younger firms in high-technology sectors have the additional burden of being engaged in riskier technological activities with unproved market records.

SBIR. The Small Business Administration (SBA) has a key role helping small and disadvantaged firms obtain financing, government R&D contracts, or technology transfer opportu-

[35]Sections 3705, 3706, and 3707 of Title 15, United States Code.

[36]In particular, R&D has a stronger relationship with the permanent or long-term component of cash flows. For example, permanent funding is required for R&D personnel, who are costly to hire and train (Himmelberg and Petersen 1994).

Figure 4-20.
Participation of public organizations in industry RJVs: 1985–2000



RJVs = research joint ventures

SOURCE: Based on data from Link, A. 2001. *Federal Register Filings: The 2000 Update of the CORE Database.* Report submitted to the National Science Foundation, Arlington, VA.

Science & Engineering Indicators – 2002

nities, and providing technical support for R&D and commercialization activities.[37] A major tool of this policy objective is the Small Business Innovation Research (SBIR) program, created by the Small Business Innovation Development Act of 1982 (Public Law 97-219), coordinated by SBA. Ten years into the program, it was reauthorized with an emphasis on commercialization "as an explicit criterion when evaluating proposals" (Public Law 102-564).[38] The same bill created the Small Business Technology Transfer (STTR) program, a smaller program emphasizing cooperative R&D and technology transfer.[39]

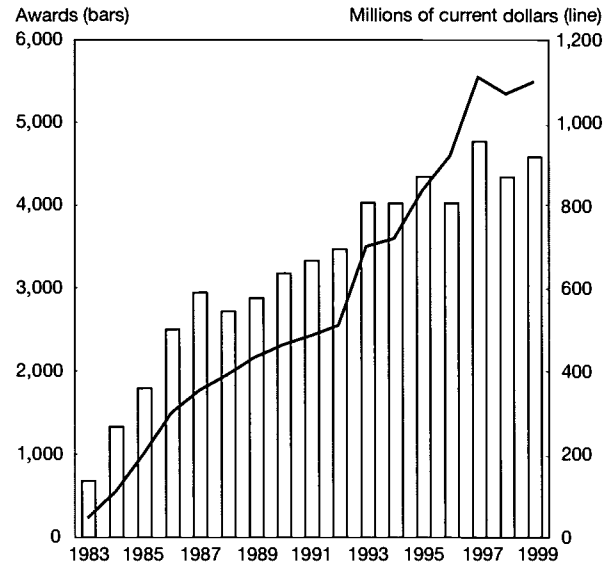
The programs do not represent separate funding from SBA but, rather, redirect other Federal agencies' R&D funds to small firms (those with 500 or fewer employees). Projects are administered by participating agencies. Specifically, Federal agencies with extramural R&D obligations above $100 million must set aside a fixed percentage of such obligations for SBIR projects. This set-aside has been at 2.5 percent since FY 1997. To obtain this Federal funding, a company applies for a Phase I SBIR grant. The proposed project must meet an agency's research needs and have commercial potential. If approved, grants of up to $100,000 are made. If the concept shows further potential, the company can receive a Phase II grant of up to $750,000. In Phase III, the innovation must be brought to market with private-sector investment and support; no SBIR funds may be used for Phase III activities.

From 1983 to 1999, SBIR awarded $9.7 billion to over 55,000 projects. Projects included research in computers, information processing and electronics, materials, energy, environmental protection, and life sciences. In 1999, the program awarded $1.1 billion in R&D money to 4,590 projects. (See figure 4-21.) Ten agencies participated in FY 1999; DOD is the largest participant with $514 million (47 percent), followed by HHS with $314 million (29 percent), funding 1,962 (43 percent) and 1,236 (27 percent) projects, respectively, in 1999. (See appendix table 4-36.) Given the design of the program, its overall size and agency participation mirror the size and composition of the Federal extramural R&D budget.

On average, approximately three-fourths of the awards are for Phase I, but they use only about 30 percent of the funds. There are many more projects in the first exploratory phase because only the most worthy projects (in terms of technical and commercialization prospects) move to the second phase. At the same time, these second-phase projects have used an increasing share of the funds from all agencies combined. This reflects an increase in dollars per Phase II project from the low $300,000s at the beginning of the program to $635,000 in 1999.[40]

The geographic distribution of SBIR awards reflects the overall concentration of total Federal R&D funding. In particular, in FY 1998, the top five states (California, Massachusetts, Virginia, Maryland, and Colorado) received one-half of both awards and SBIR dollars. Several agencies have used the SBIR program in conjunction with other outreach programs to increase participation of states with traditionally low levels of Federal R&D funding. For example, according to the U.S. GAO (1999b) report, NSF has used its Experimental Program to Stimulate Competitive Research (EPSCoR) to increase assistance to SBIR participants in EPSCoR states and the Commonwealth of Puerto Rico.[41] Assistance includes a "Phase Zero" award to help in the preparation of SBIR proposals.

Figure 4-21.
Growth in SBIR awards and funding: 1983–99



SBIR = Small Business Innovation Research

See appendix table 4-36. *Science & Engineering Indicators – 2002*

STTR. The STTR program pairs eligible small businesses with either nonprofit institutions or an FFRDC to perform joint R&D projects. The purpose is to leverage the technical resources of these research institutions (mostly universities) with small businesses for technology development, transfer, and commercialization. Participating small businesses must perform at least 40 percent of the work and be in overall control of the project. The program is structured, much like the SBIR program, in three phases. The first phase studies technical and commercial feasibility with funding not to exceed $100,000 for one year; further development occurs in the second phase with a maximum of $500,000 in funds over two years. In the last phase, the participants engage in commercial applications with no Federal STTR funds.

Five Federal agencies with more than $1 billion in extramu-

[37]See text of Public Law 106-554, December 2000. For analysis of small business research programs as public venture capital programs, see Lerner and Kegler (2000) and references therein.

[38]See also U.S. GAO (1999a).

[39]SBIR was reauthorized in December 2000 by the Small Business Reauthorization Act of 2000 (Public Law 106-554) through FY 2008 (September 30, 2008). A bill to reauthorize the STTR program, scheduled to expire in September 2001, was introduced in the Senate in May 2001 and placed on the Senate Legislative Calendar in late August 2001 (S. 856, 107th Congress).

[40]The average dollar amount per project is $61,800 for Phase I and $434,370 for Phase II over the life of the program through FY 1999.

[41]The states are Alabama, Arkansas, Idaho, Kansas, Kentucky, Louisiana, Maine, Mississippi, Montana, Nebraska, Nevada, North Dakota, Oklahoma, South Carolina, South Dakota, Vermont, West Virginia, and Wyoming.

ral R&D participate in the program: DOD, NSF, DOE, NASA, and HHS. Since FY 1996, the required set-aside has been 0.15 percent compared with 2.5 percent for the SBIR program.[42] From FY 1994 to FY 1999, the STTR program has awarded more than $300 million to more than 1,700 projects. In 1999, STTR awarded $65 million to 329 projects. (See appendix table 4-37.) Three-fourths of the projects were in Phase I. The largest participant by far is DOD. The majority of the research institutions participating were universities (283 of 329, or 86 percent). The remainder were divided between FFRDCs (22) and hospitals and other nonprofit organizations (24).[43]

International Private and Public Collaborations

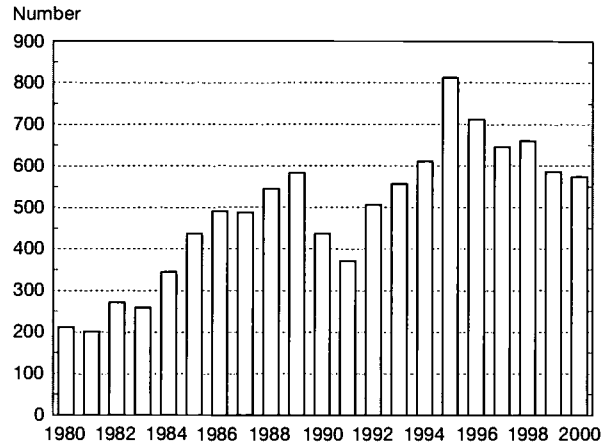
International Business Alliances

In 2000, 574 new technology or research alliances were formed worldwide in six major sectors: information technology (IT), biotechnology, advanced materials, aerospace and defense, automotive, and (nonbiotech) chemicals, according to the data available from MERIT-CATI (Hagerdoon 2001). Over the past two decades, the formation of international technology alliances has grown considerably. In particular, there were 6,477 technology alliances formed between 1990 and 2000 compared with 3,826 over 1980–89. However, international alliances peaked at 812 in 1995, the same year, domestic collaborations peaked in the CORE database. This is not surprising given the significant role of alliances involving U.S. companies. (See figure 4-22.)

The majority of the alliances involved companies from the United States, Japan, and countries of Western Europe. Fully 80 percent (5,187) of the 1990–2000 alliances involved at least one U.S.-owned company (see text table 4-12), compared with 64 percent in the 1980s. At the same time, European firms participated in 2,784 technology alliances. Japanese companies were involved in 910 partnerships, down slightly from the earlier period.[44] The dominance of U.S. companies in this database is also clear by noting that among the alliances involving at least one U.S. company, the share of alliances involving *only* U.S. firms increased from 37 percent in the 1980s to more than 50 percent in 1990–2000. (See figure 4-23.) On the other hand, European and Japanese companies engaged in more interregional collaborations compared with U.S. companies. As discussed below, these geographic patterns were driven by IT and biotechnology R&D activity.

Technology Focus. The share of biotechnology partnerships reached an all-time high of 35 percent in 2000 (199 of 574), continuing an increasing trend that began in 1991. (See figure 4-24.) Furthermore, this is the first time that biotech alliances have outnumbered IT partnerships in any given year in the database, dating back to the 1960s. In 2000, there were 184 (32

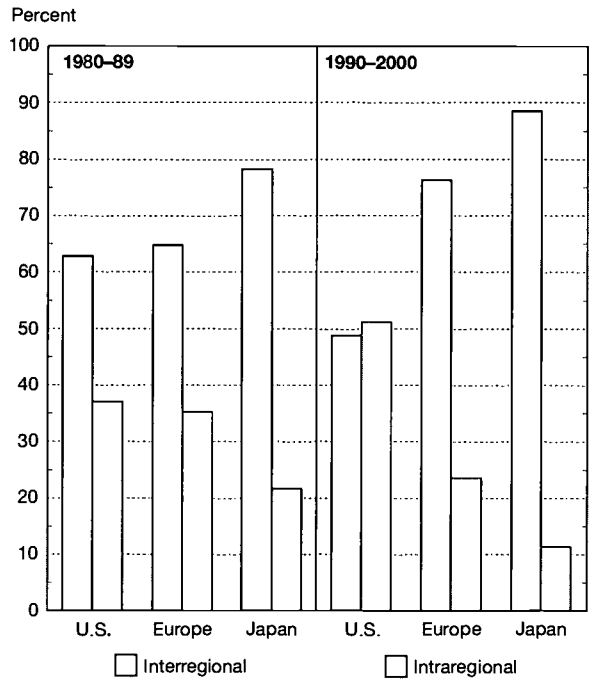
Figure 4-22.
International strategic technology alliances: 1980–2000



NOTE: Data are annual counts of new international strategic technology alliances.

See appendix table 4-39. *Science & Engineering Indicators – 2002*

Figure 4-23.
Shares of international strategic technology alliances: 1980–89 and 1990–2000



NOTES: Interregional share refers to the share of alliances formed by companies from different countries or regions. Intraregional shares consider only alliances among companies from the same country or region. Total alliances: 1980–89: U.S. = 2,445; Europe = 1,904; Japan = 1,073. 1990–2000: U.S. = 5,187; Europe = 2,784; Japan = 910.

See text table 4-12 and appendix table 4-39.

Science & Engineering Indicators – 2002

[42]The initial set-aside percentages were 0.05 percent in FY 1994 and 0.1 percent in FY 1995.

[43]For a survey of companies receiving STTR awards see U.S. GAO (2001b and 2001c).

[44]As discussed previously, technology partnerships announced in non-English publications, such as those based in Asia, are likely to be undercounted.

Text table 4-12.
International strategic technology alliances: 1990–2000

Region	All alliances	Information technology	Biotechnology	All other technologies
		Counts		
All regions	6,477	2,687	1,553	2,237
USA-Europe	1,654	536	525	593
USA-Japan	511	292	82	137
USA-Others	364	158	71	135
Europe-Japan	239	92	37	110
Europe-Others	234	64	49	121
Japan-Others	56	30	6	20
Intra-USA	2,658	1,299	629	730
Intra-Europe	657	169	147	341
Intra-Japan	104	47	7	50
		Regional shares (percentages)		
All regions	100	100	100	100
USA-Europe	26	20	34	27
USA-Japan	8	11	5	6
USA-Others	6	6	5	6
Europe-Japan	4	3	2	5
Europe-Others	4	2	3	5
Japan-Others	1	1	0	1
Intra-USA	41	48	41	33
Intra-Europe	10	6	9	15
Intra-Japan	2	2	0	2
		Technology shares (percentages)		
All regions	100	41	24	35
USA-Europe	100	32	32	36
USA-Japan	100	57	16	27
USA-Others	100	43	20	37
Europe-Japan	100	38	15	46
Europe-Others	100	27	21	52
Japan-Others	100	54	11	36
Intra-USA	100	49	24	27
Intra-Europe	100	26	22	52
Intra-Japan	100	45	7	48

SOURCE: Based on data from the Cooperative Agreements and Technology Indicators (CATI) database, Maastricht Economic Research Institute on Innovation and Technology (MERIT), Maastricht, the Netherlands.

Science & Engineering Indicators – 2002

percent) new IT partnerships, less than the 225 partnerships in 1999. The number of new IT alliances peaked in 1995 at 338, reaching a maximum share of 55 percent in 1991. More important, the combined shares of these two technologies increased from 55 percent in the 1980s to 66 percent in the 1990s.

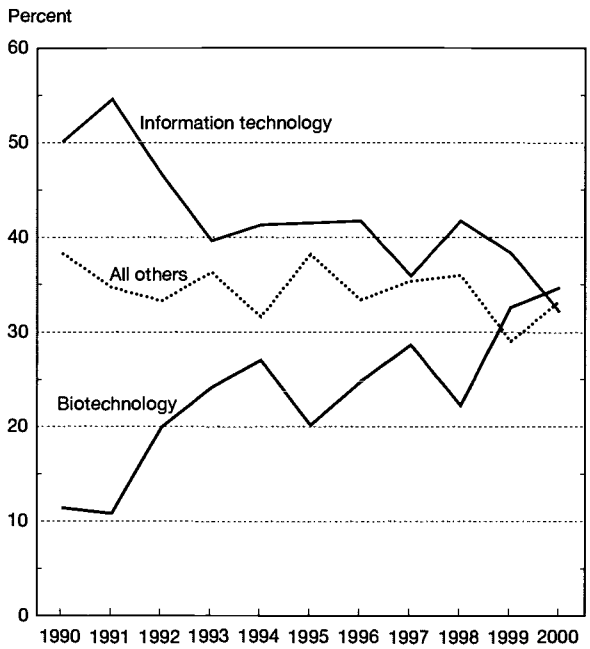
The United States and Europe were prime locales for biotechnology alliances during the 1990s, attracting the interest of venture capital and stimulating high-profile projects such as the decade-long effort to map the human genome. Of the 1,500 biotechnology alliances in the past decade, 41 percent involved U.S. companies only and another 34 percent involved pairings of U.S. and European companies (see text table 4-12). This partnering is likely to intensify in coming years as biotechnology startups and pharmaceutical firms collaborate with instrument, software, and bioinformatic companies for the next research step dubbed "proteomics," which involves mapping the structure and function of proteins based on gene expression databases (Hamilton and Regaldo 2001).

Interregional IT alliances have become less frequent in the MERIT-CATI database. In 1990–2000, a majority of IT partnerships (56 percent) were within countries or regions (United States, Japan, or the European region), as opposed to alliances across regions (44 percent). This compares with an even split between these two types of IT alliances in the 1980s. Furthermore, U.S.-only partnerships represent about one-half of IT alliances, up from 29 percent in the 1980s.

Government-to-Government Cooperation

Nation-to-nation cooperation constitutes a special case of international research collaboration. In addition to the rationale for collaborative projects discussed earlier, these projects often have an added dimension in terms of foreign policy objectives and security issues. Some so-called megaprojects are characterized by extremely high costs, key national stakes, and often multiple international stakeholders. Forms of international government collaboration include

Figure 4-24.
International strategic technology alliances, by technology shares



See appendix table 4-39.

Science & Engineering Indicators – 2002

joint construction, operation, and use of large facilities for research or exploration (e.g., space and nuclear physics) and joint research activities.[45]

At least three organizational forms of government-to-government S&T collaboration can be identified. An individual U.S. agency may collaborate with sister agencies abroad to pursue common R&D interests, leveraging funds and technical expertise. U.S. agencies may also form a research umbrella to work together among themselves and then engage in joint activities with overseas organizations as needed. Governments also may use international organizations to advance scientific or technical objectives, often in conjunction with complementary national goals. See sidebar, "Collaborative R&D Projects in Selected International Organizations."

Looking at agency-specific activities, the U.S. GAO (1999b) estimated that 575 international S&T agreements existed between seven U.S. agencies (DOE, NASA, NIH, NIST, NSF, National Oceanic and Atmospheric Administration (NOAA), and the State Department) and other countries in FY 1997. However, not all of these S&T agreements included cooperative R&D activities. At the same time, cooperative R&D projects also occur outside such formal international interagency agreements. Funding data are particularly scarce. A report by RAND's Science and Technol-

[45]Projects in this category can cost as much as several billion U.S. dollars over many years of planning and development. See Boesman (1994) and U.S. Congress, Office of Technology Assessment (1995).

Collaborative R&D Projects in Selected International Organizations

In addition to national agencies, governments also use international organizations to promote, study, and coordinate scientific collaboration. The following is a sample of scientific activities coordinated by international organizations.

- **Global Forum on Agricultural Research.** The activities of the Global Forum on Agricultural Research (GFAR) include the promotion of research partnerships in agricultural R&D as well as the exchange of scientific and technical information. GFAR is fostering global and regional research partnerships in the areas of biotechnology, plant genetics, biodiversity, agroecology, and natural resources management (website: <http://www.egfar.org/>).
- **North Atlantic Treaty Organisation (NATO) Science Program—Cooperative Science and Technology Program.** This program supports conferences, workshops, and collaborative grants for scientists of NATO and some partner countries. Four scientific areas are covered: life sciences, physics and engineering, environmental and earth sciences, and security-related civil S&T (website: <http://www.nato.int/science/e/cst.htm>).
- **Organisation for Economic Co-operation and Development (OECD) Global Science Forum.** The OECD's Global Science Forum identifies opportunities for international cooperation in basic scientific research. The forum establishes special- purpose working groups and workshops to perform technical analyses. Activities include workshops on structural genomics, compact ultrahigh-power lasers, a consultative group on high-energy physics, a working group on neuroinformatics, and a task force on radio astronomy and the radio spectrum (website: <http://www.oecd.org >).
- **World Health Organization's Special Program for Research and Training in Tropical Diseases.** The World Health Organization's (WHO's) Special Program for Research and Training in Tropical Diseases was established in 1975 and is cosponsored by the United Nations Development Program, the World Bank, and WHO. The program supports global efforts to combat a portfolio of major diseases affecting developing countries (website: <http://www.who.int/tdr/about/mission.htm>).

ogy Policy Institute tries to fill this gap by compiling R&D spending data on international cooperative projects sponsored by U.S. agencies (Wagner, Yezril, and Hassell 2001).

The RAND report finds that approximately $4.4 billion in R&D spending by Federal agencies involved a significant international content in FY 1997 compared with $70 billion in total Federal obligations for R&D work in that year. The vast majority of the spending involves scientist-to-scientist collaboration in joint research projects. Technical support to aid a foreign country was a distant second. The largest spending for binational R&D cooperation was identified in projects involving Russia, Canada, the United Kingdom, Germany, and Japan. Spending in collaborative R&D with Russia increased considerably since the dissolution of the Soviet Union, especially in aerospace and aeronautics. Other scientific and policy interests in this area of the world include containing nuclear materials and aiding the transition of Russian scientists from weapons to civilian research.

Spending in aerospace and aeronautics accounted for more than one-half of the U.S. R&D dollars committed to a single field of collaboration across all countries. Biomedical and other life sciences, engineering, and energy fields also received significant international support. In part, the preeminence of aerospace research in international research spending is due to the disproportionate share of NASA in these statistics, fully $3.1 billion of the reported $4.4 billion, including funding for large multicountry projects such as the International Space Station and the Earth Observing Satellite System. Undoubtedly, international R&D support provided by other agencies is somewhat undercounted. For example, DOD figures reported at $263 million are likely to be an underestimate due to data validation problems, according to RAND. NIH, NSF, and DOE also perform key international work with projects in human genetics, infectious diseases, geosciences, and other basic research and energy sciences.

In another approach, U.S. agencies have formed interagency research groups that subsequently pursue international activities. For example, the U.S. Global Change Research Program (USGCRP), in place since 1989, studies climate change and Earth ecosystems and performs some of its research and data gathering on an international basis.[46] The program authorized research funds of $758 million in FY 2000 from NASA, NSF, DOE, NOAA, USDA, and other agencies (Executive Office of the President 2001). Another $937 million was authorized in support of NASA's development of Earth-observing satellites and related data systems as part of USGCRP activities. (For a summary of recent efforts to more fully integrate the use of collaborative activities in the international S&E arena, see sidebar, "The NSB Task Force on International Issues in Science and Engineering.")

The NSB Task Force on International Issues in Science and Engineering

The National Science Board (NSB) is responsible for monitoring the health of the national research and education enterprise. In recent years, the importance of science and technology in the global context has grown. As a result, both private sector and government cooperation in international science and engineering have become more prominent.

The NSB took note of these developments in preparing its strategic plan (NSB-98-215), in which it observed that one of the most important challenges confronting the United States is how to deal with science and engineering in the global context. The National Science Board expressed the need for a fresh assessment of the roles and needs of science and engineering in the international arena, and for a coherent strategy that supports a productive relationship between scientific and foreign policy objectives.

The Board subsequently established the Task Force on International Issues in Science and Engineering to undertake this assessment. The task force was charged with examining the Federal policy role and the institutional framework that supports international cooperation in research and education, as well as NSF's leadership role in international S&E in the 21st century. The task force has organized symposia, workshops, and panel discussions with a broad array of experts and stakeholders and has conducted an extensive review of relevant policy documents and reports. Two interim reports will be followed shortly by a comprehensive National Science Board report on international science and engineering.

Further information about the work of the task force can be found on the Board's website at <http://www.nsf.gov/nsb/>.

International Comparisons of National R&D Trends

Absolute levels of R&D expenditures are indicators of the breadth and scope of a nation's S&T activities and are a harbinger of future growth and productivity. Indeed, investments in the R&D enterprise strengthen the technological base on which economic prosperity increasingly depends worldwide. The relative strength of a particular country's current and future economy and the specific scientific and technological areas in which a country excels, are further revealed through comparison with other major R&D-performing countries. This section provides comparisons of international R&D spend-

[46]For a description of international activities of the program, see <http://www.usgcrp.gov/usgcrp/links/relintpr.html>.

ing patterns.[47] It examines absolute and relative expenditure trends, contrasts performer and source structural patterns, reviews the foci of R&D activities within sectors, and looks at government research-related priorities. Although R&D performance patterns by sector are broadly similar across countries, national sources of support differ considerably. In nearly all OECD countries, government has provided a declining share of all R&D funding during the past decade, whereas the industrial share of the funding total has increased considerably. The relative emphasis of industrial R&D efforts, however, differ across countries, as do governmental R&D priorities and academic S&E field research emphases. Reflecting an overall pattern of R&D internationalization, foreign sources of R&D funding have been increasing in many countries.

Absolute Levels of Total R&D Expenditures

The worldwide distribution of R&D performance is concentrated in relatively few industrialized nations. Of the $518 billion in estimated 1998 R&D expenditures for the 30 OECD countries, fully 85 percent is expended in only 7 countries (Organisation for Economic Co-operation and Development 2000a).[48] These estimates are based on reported R&D investments (for defense and civilian projects) converted to U.S. dollars with purchasing power parity (PPP) exchange rates.[49] See sidebar, "Purchasing Power Parities: Preferred Exchange Rates for Converting International R&D Data."

The United States accounts for roughly 44 percent of all OECD member countries' combined R&D investments; U.S. R&D investments continue to outdistance by 150 percent R&D investments made in Japan, the second largest R&D-performing country. The United States not only spent more money on R&D activities in 1999 than any other country but also spent as much by itself as the rest of the G-7 countries (Canada, France, Germany, Italy, Japan, and the United Kingdom) combined. (See figure 4-26 and appendix table 4-40 for inflation-adjusted PPP R&D totals for OECD and G-7 countries.) In terms of other large R&D performers, only South Korea accounts for a substantial share of the OECD total (a remarkable 3.8 percent in 1998, which is higher than the amounts expended in either Canada or Italy). In only four other countries (the Netherlands, Australia, Sweden, and Spain) do R&D expenditures exceed 1 percent of the OECD R&D total (OECD 2000a).[50]

In terms of relative shares, U.S. R&D spending in 1985 reached historical highs of 53 percent of the G-7 total and 48 percent of all OECD R&D.[51] As a proportion of the G-7 total, U.S. R&D expenditures declined steadily to a low of 49 percent in 1992. Since then, U.S. R&D has climbed to its 1999 level, a 53 percent G-7 share. (See figure 4-26 for actual expenditure totals.) Conversely, R&D spending in the United States was equivalent to 112 percent of spending in non-U.S. G-7 countries and to approximately 80 percent of all other OECD countries' R&D expenditures in 1999.

Initially, most of the U.S. improvement since 1993 relative to the other G-7 countries resulted from a worldwide slowing in R&D performance that was more pronounced in other countries. Although U.S. R&D spending stagnated or declined for several years in the early to mid-1990s, the reduction in real R&D spending in most of the other large R&D-performing countries was more striking. In Japan, Germany, and Italy, inflation-adjusted R&D spending fell for three consecutive years (1992, 1993, and 1994) at a rate of decline that exceeded similarly falling R&D spending in the United States.[52] In fact, large and small industrialized countries worldwide experienced substantially reduced R&D spending in the early 1990s (OECD 2000a). For most of these countries, economic recessions and general budgetary constraints slowed both industrial and government sources of R&D support. More recently, R&D spending has rebounded in several G-7 countries, as has R&D spending in the United States. Yet since annual R&D growth generally has been stronger in the United States than elsewhere and has even slowed to a standstill in Japan according to the most recently available statistics (see figure 4-27), the difference between the United States and the other G-7 countries' combined R&D spending has continued to widen.

Concurrent with the latest years' increase in the U.S. share of the G-7 countries' R&D performance, a similar increase has been seen in the U.S. share of all OECD countries' R&D spend-

[47]Most of the R&D data presented here are from reports to OECD, the most reliable source of such international comparisons. A high degree of consistency characterizes the R&D data reported by OECD, with differences in reporting practices among countries affecting their R&D/GDP ratios by no more than an estimated 0.1 percentage point (International Science Policy Foundation 1993). Nonetheless, an increasing number of non-OECD countries and organizations now collect and publish internationally comparable R&D statistics, which are reported at various points in this chapter.

[48]Current OECD members are Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, South Korea, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.

[49]Although PPPs technically are not equivalent to R&D exchange rates, they better reflect differences in countries' research costs than do market exchange rates.

[50]Although countries other than members of the OECD also fund and perform R&D, with the exception of just a handful, most of these national R&D efforts are comparatively small. For example, in 1997 total R&D expenditures in China and Russia were $24.7 billion and $10.3 billion (PPP dollars) and nondefense R&D in Israel totaled $2.5 billion PPP (OECD 2000c). Among non-OECD members of Red Iberomericana de Indicadores de Ciencia y Tecnologia (RICYT), the largest R&D expenditures are reported for Brazil ($9.2 billion U.S. at market exchange rates), Argentina ($1.1 billion), Chile ($0.5 billion), and Colombia ($0.4 billion) (RICYT 2001). The combined R&D expenditures of these seven countries (approximately $50 billion) would raise the OECD world total by about 10 percent, and about one-half would be derived from China alone.

[51] OECD maintains R&D expenditure data that can be divided into three periods: (1) 1981 to the present, which are properly annotated and of good quality; (2) 1973 to 1980, which are probably of reasonable quality, for which some metadata are available; and (3) 1963 to 1972, about which there are serious doubts for most OECD countries (with notable exceptions of the United States and Japan), many of which launched their first serious R&D surveys in the mid-1960s. The analyses in this chapter are limited to data for 1981 and later years.

[52]The United Kingdom similarly experienced three years of declining real R&D expenditures, but its slump took place in 1995, 1996, and 1997. The falling R&D totals in Germany were partly a result of specific and intentional policies to eliminate redundant and inefficient R&D activities and to integrate the R&D efforts of the former East Germany and West Germany into a united German system.

Purchasing Power Parities: Preferred Exchange Rates for Converting International R&D Data

Comparisons of international R&D statistics are hampered because each country's R&D expenditures are denominated in its home currency. Two approaches are commonly used to normalize the data and facilitate aggregate R&D comparisons: dividing R&D by gross domestic product, which results in indicators of relative effort according to total economic activity and circumvents the problem of currency conversion, and converting all foreign-denominated expenditures to a single currency, which results in indicators of absolute effort. The first method is a straightforward calculation that permits only gross national comparisons. The second method permits absolute-level comparisons and analyses of countries' sector- and field-specific R&D investments, but it entails choosing an appropriate currency conversion series.

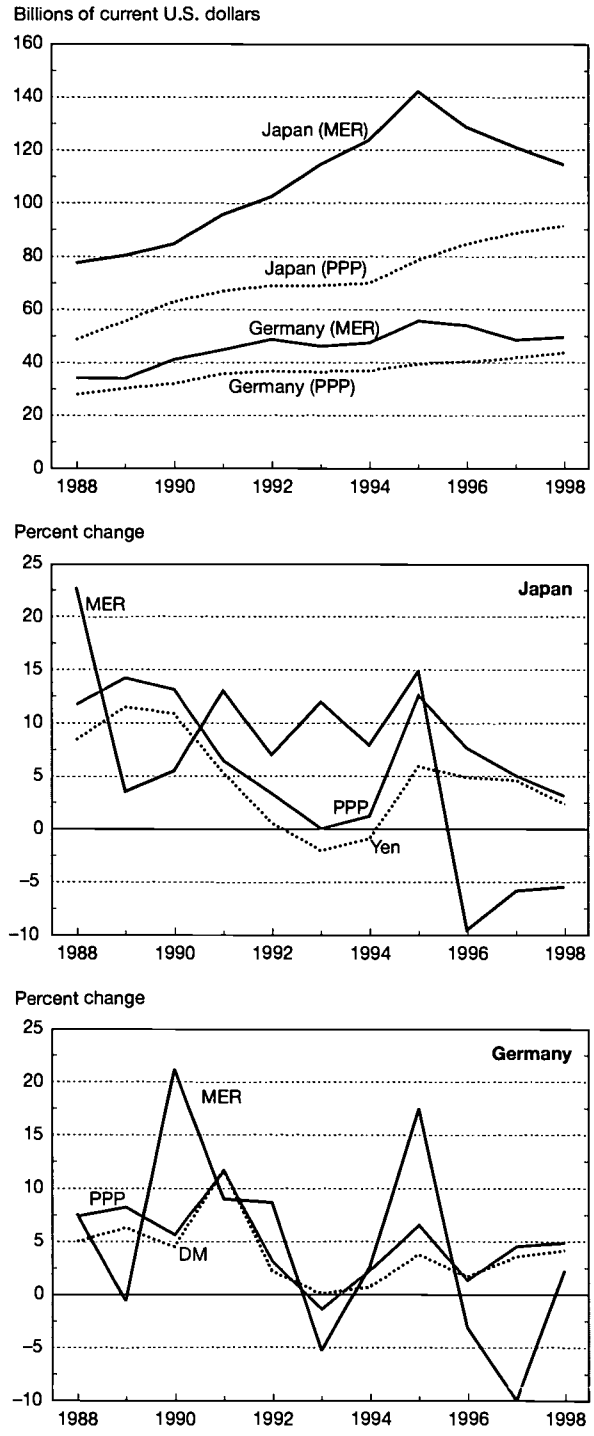
Market Exchange Rates Versus Purchasing Power Parity Rates

Because (for all practical purposes) no widely accepted R&D-specific exchange rates exist, the choice is between market exchange rates (MERs) (International Monetary Fund 1999) and purchasing power parities (PPPs) (OECD 2000a). These rates are the only series consistently compiled and available for a large number of countries over an extended period of time.

Market Exchange Rates—At their best, MERs represent the relative value of currencies for goods and services that are traded across borders; that is, MERs measure a currency's relative international buying power. Sizable portions of most countries' economies do not engage in international activity, however, and major fluctuations in MERs greatly reduce their statistical utility. MERs also are vulnerable to a number of distortions, including currency speculation, political events such as wars or boycotts, and official currency intervention, which have little or nothing to do with changes in the relative prices of internationally traded goods.

Purchasing Power Parity Rates—Because of the MER shortcomings described above, the alternative currency conversion series of PPPs has been developed (Ward 1985). PPPs take into account the cost differences across countries of buying a similar basket of goods and services in numerous expenditure categories, including nontradables. The PPP basket is, therefore, representative of total GDP across countries. When the PPP formula is applied to current R&D expenditures of other major performers, such as Japan and Germany, the result is a substantially lower estimate of total R&D spending than that given by MERs. (See figure 4-25.) For example, Japan's R&D in 1998 totaled $92 billion based on PPPs and $115 billion based on MERs, and the

Figure 4-25.
R&D expenditures and annual changes in R&D estimates, Japan and Germany



MER = market exchange rate; PPP = purchasing power parity; DM = deutsche mark

See appendix tables 4-2 and 4-40.

Science & Engineering Indicators – 2002

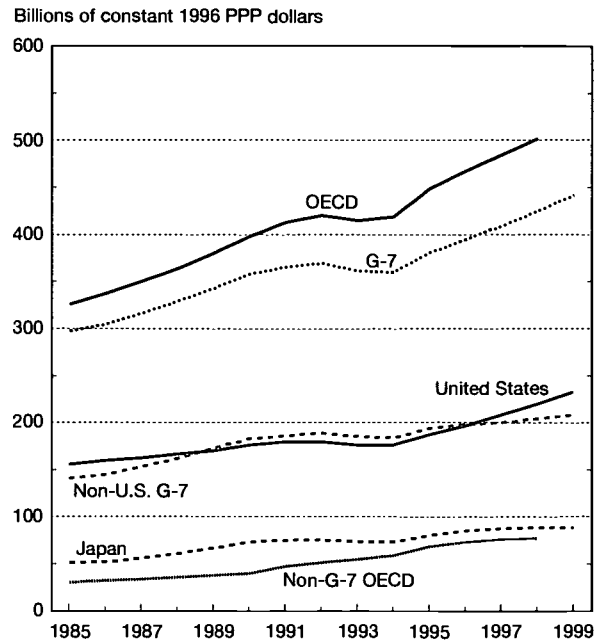
German R&D expenditure was $44 billion on PPPs and $50 billion on MERs. (By comparison, the U.S. R&D expenditure was $227 billion in 1998.)

PPPs are the preferred international standard for calculating cross-country R&D comparisons wherever possible and are used in all official OECD R&D tabulations. Unfortunately, they are not available for all countries and currencies. They are available for all OECD countries, however, and are therefore used in this report.

Exchange Rate Movement Effects

Although the difference is considerable between what is included in GDP-based PPP items and R&D expenditure items, the major components of R&D costs, fixed assets and the wages of scientists, engineers, and support personnel, are more suitable to a domestic converter than to one based on foreign trade flows. Exchange rate movements bear little relationship to changes in the cost of domestically performed R&D. (See figure 4-25.) When annual changes in Japan's and Germany's R&D expenditures are converted to U.S. dollars with PPPs, they move in tandem with such funding denominated in their home currencies. Changes in dollar-denominated R&D expenditures converted with MERs exhibit wild fluctuations that are unrelated to the R&D purchasing power of those investments. MER calculations indicate that, between 1988 and 1998, German and Japanese R&D expenditures each increased twice by 15 percent or more. In reality, nominal R&D growth was only one-fourth to one-third those rates in either country during this period. PPP conversions generally mirror the R&D changes denominated in these countries' home currencies.

Figure 4-26.
U.S., G-7, and OECD countries' R&D expenditures



OECD = Organisation for Economic Co-operation and Development; PPP = purchasing power parity

NOTE: Non-U.S. G-7 countries are Canada, France, Germany, Italy, Japan, and the United Kingdom.

See appendix table 4-40. *Science & Engineering Indicators – 2002*

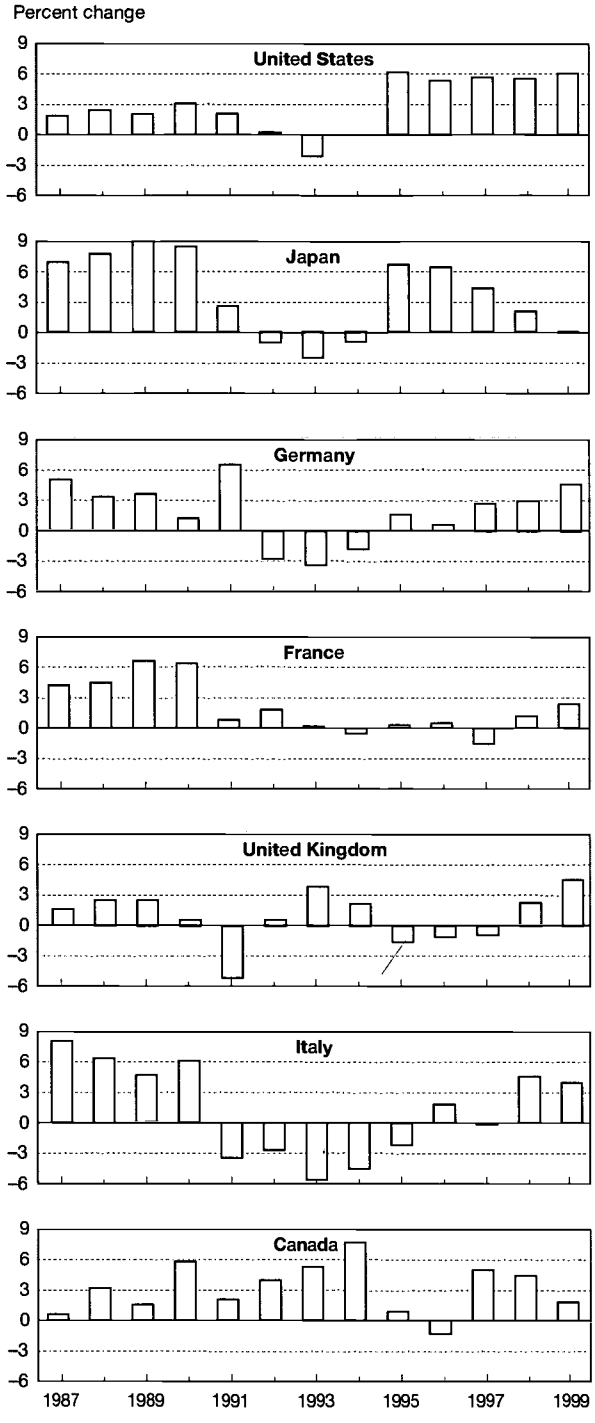
ing. In 1985, the United States accounted for 48 percent of the R&D reported by OECD countries; by 1995, the U.S. share had dropped to 42 percent of the OECD R&D total. Part of this share reduction (perhaps up to 2 percentage points) resulted from the addition of several countries to OECD membership (thereby increasing the OECD R&D totals); worldwide growth in R&D activities, however, was a greater contributing factor to the loss of R&D share experienced by the United States. Since then, the U.S. share has climbed back to 44 percent of the OECD total in 1999, more a result of robust R&D growth in the United States than a result of the significant changes under way in the other OECD countries.

Trends in Total R&D/GDP Ratios

One of the first (Steelman 1947) and now most widely used indicators of a country's commitment to growth in scientific knowledge and technology development is the ratio of R&D spending to GDP. (See figure 4-28.) For most of the G-8 countries (that is, the G-7 countries plus the Russian Federation), the latest R&D/GDP ratio is no higher now than it was at the start of the 1990s, which ushered in a period of slow growth or decline in their overall R&D efforts. The ways in which different countries have reached their current ratios vary considerably, however.[53] The United States and Japan reached 2.7 and 2.8 percent, respectively, in 1990–91. As a result of reduced or level spending by industry and government in both countries, the R&D/GDP ratios declined several tenths of a percentage point, to 2.4 and 2.6, respectively, in 1994 before rising again to 2.6 and 3.0 percent. Growth in industrial R&D accounted for much of the recovery in each of these countries. Electrical equipment, telecommunications, and computer services companies have reported some of the strongest R&D growth since 1995 in the United States. Growth in pharmaceutical R&D also has been substantial. In Japan, spending increases were highest in the electronics, machinery, and automotive sectors and appear to be associated mainly with a wave of new digital technologies (Industrial Research Institute 1999). However, the steady increase in Japan's R&D/GDP ratio since 1994 is also partially a result of anemic economic conditions overall: GDP fell in both 1998 and 1999,

[53] A country's R&D spending and therefore its R&D/GDP ratio is a function of several factors in addition to its commitment to supporting the R&D enterprise. Especially because the majority of R&D is performed by industry in each of these countries, the structure of industrial activity can be a major determinant of a country's R&D/GDP ratio. For example, economies with high concentrations in manufacturing (which traditionally have been more R&D intensive than nonmanufacturing or agricultural economies) have different patterns of R&D spending. See "Industry Sector" for further discussion of such considerations.

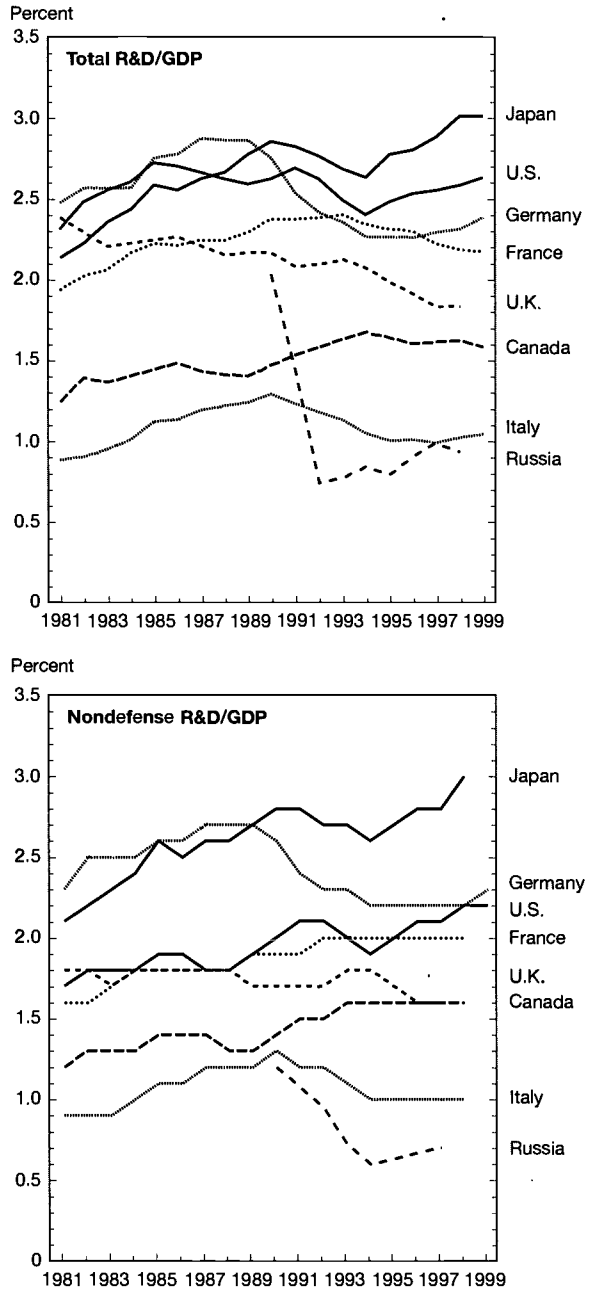
Figure 4-27.
Rates of change in total inflation-adjusted R&D spending



NOTE: The inflation-adjusted R&D expenditures reflected in this graph are denominated in foreign currencies deflated by the countries' own GDP price deflators and therefore are not distorted by exchange rate conversions.

See appendix table 4-40. *Science & Engineering Indicators – 2002*

Figure 4-28.
R&D as percentage of GDP, G-8 countries



See appendix tables 4-40 and 4-41.

Science & Engineering Indicators – 2002

so that even level R&D spending resulted in a slight increase in its R&D ratio (OECD 2000a).

Among the remaining six G-8 countries, two (Germany and Russia) display recent increases in their economies' R&D intensity, and four (the United Kingdom, France, Italy, and Canada) report an R&D/GDP ratio that has remained stagnant or continues to decline. In Germany, the R&D/GDP ratio fell from 2.9 percent at the end of the 1980s, before reunification, to 2.3 percent in 1993 before rising to its current level of 2.4 percent. By comparison, this macro-R&D

indicator continues to slip slightly in France and the United Kingdom to their current levels of 2.2 and 1.9 percent, respectively, and has fluctuated narrowly at 1.0 and 1.6 percent in Italy and Canada, respectively, for the past five years or longer. The end of the cold war and collapse of the Soviet Union had a drastic effect on Russia's R&D enterprise. R&D spending in Russia was estimated at 2.0 percent of GDP in 1990; that figure plummeted to 1.4 percent in 1991 and then tumbled further to 0.7 percent in 1992. Moreover, the severity of this R&D decline is masked somewhat: although the R&D share was falling, it also was a declining share of a declining GDP. By 1999, the R&D/GDP ratio in Russia had inched back to about 1.0 percent, although the country continues to experience severe reductions in its R&D spending.

Overall, the United States ranked fifth among OECD countries in terms of reported R&D/GDP ratios for the 1996–99 period. (See text table 4-13.) Sweden leads all countries with 3.7 percent of its GDP devoted to R&D, followed by Japan (3.0 percent), Finland (2.9 percent), and Switzerland (2.7 percent). In general, nations in Southern and Eastern Europe tend to have R&D/GDP ratios below 1.5 percent, whereas Nordic nations and those in Western Europe report R&D spending shares greater than 1.5 percent. In a broad sense, the reason for such patterns has much to do with overall funding patterns and macroeconomic structures. In practically all OECD countries, the business sector finances most of the R&D. However, OECD countries with relatively low R&D/GDP ratios tend to be relatively low-income countries, and government funding tends to provide a larger proportion of the R&D support than it provides in the high R&D/GDP ratio countries. Furthermore, the private sector in such low-income countries often consists of low-technology industries, resulting in low overall R&D spending and, therefore, low R&D/GDP ratios. Indeed, a strong link exists between countries with high incomes that emphasize the production of high-technology goods and services and those that invest heavily in R&D activities (OECD 2000e).[54]

Text table 4-13.
R&D percentage of gross domestic product

Sweden (1997)	3.70	Brazil (1996)	0.91
Japan (1999)	3.01	Spain (1999)	0.89
Finland (1998)	2.89	Slovak Republic (1998)	0.86
Switzerland (1996)	2.73	Cuba (1999)	0.83
United States (1999)	2.63	Poland (1999)	0.75
South Korea (1998)	2.55	China (1998)	0.69
Israel (1997)	2.54	South Africa (1998)	0.69
Germany (1999)	2.38	Hungary (1999)	0.68
France (1999)	2.17	Chile (1997)	0.63
Denmark (1999)	1.99	Portugal (1997)	0.62
Belgium (1999)	1.98	Romania (1998)	0.54
Taiwan (1998)	1.97	Greece (1997)	0.51
Netherlands (1998)	1.95	Turkey (1997)	0.49
Iceland (1999)	1.88	Argentina (1999)	0.47
United Kingdom (1999)	1.87	Colombia (1997)	0.41
Canada (1999)	1.85	Mexico (1997)	0.34
Austria (1999)	1.82	Panama (1998)	0.33
Norway (1999)	1.73	Bolivia (1999)	0.29
Australia (1998)	1.49	Uruguay (1999)	0.26
Singapore (1997)	1.47	Malaysia (1996)	0.22
Slovenia (1997)	1.42	Trinidad and Tobago (1997)	0.14
Ireland (1997)	1.39	Nicaragua (1997)	0.13
Czech Republic (1999)	1.27	Ecuador (1998)	0.08
Costa Rica (1996)	1.13	El Salvador (1998)	0.08
New Zealand (1997)	1.13	Peru (1997)	0.06
Italy (1999)	1.04	**Total OECD** (1998)	2.18
Russian Federation (1999)	1.06	**European Union** (1998)	1.81

NOTES: Civilian R&D only for Israel and Taiwan. Data are presented for the latest available year in parentheses.

SOURCES: Organisation for Economic Co-operation and Development (OECD), Main Science and Technology Indicators database (April 2001); Pacific and Economic Cooperation Council (1999); OECD, *R&D Efforts in China, Israel, and Russia: Some Comparisons With OECD Countries*, (CCNM/DSTI/EAS, Paris, 2000); Centre for Science Research and Statistics (CSRS), *Russian Science and Technology at a Glance: 2000* (Moscow 2001); Red Iberomericana de Indicadores de Ciencia y Tecnologia (Iberomerican Network of Science & Technology Indicators) (RICYT), *Principales Indicadores de Ciencia y Tecnologia 2000* (Buenos Aires, Argentina 2001); and national sources.

Science & Engineering Indicators – 2002

Outside the European region, R&D spending has intensified considerably since the early 1990s. Several Asian countries, most notably South Korea and China, have been particularly aggressive in expanding their support for R&D and S&T-based development. In Latin America and the Pacific region, other non-OECD countries also have attempted to increase R&D investments substantially during the past several years. Even with recent gains, however, most non-European (non-OECD) countries invest a smaller share of their economic output on R&D than do OECD members (with the exception of Israel, whose reported 2.5 percent nondefense R&D/GDP ratio ranks seventh in the world). With the apparent exception of Costa Rica, all Latin American countries for which such data are available report R&D/GDP ratios below 1 percent. (See text table 4-13.) This distribution is consistent with broader indicators of economic growth and wealth. However, many of these countries also report additional S&T-related expenditures on human resources training and S&T infrastructure development that are not captured in R&D and R&D/GDP data (Red Iberomericana de Indicadores de Ciencia y Tecnologia 2001).

Nondefense R&D Expenditures and R&D/GDP Ratios

As a result of concerns related to national scientific progress, standard-of-living improvements, economic competitiveness, and commercialization of research results, attention has shifted from nations' total R&D activities to nondefense R&D expenditures as indicators of scientific and technological strength. Indeed, conclusions about a country's relative standing may differ dramatically, depending on whether total R&D expenditures are considered or defense-related expenditures are excluded from the totals; for some countries, the relative emphasis has shifted over time. Among

[54] See OECD (1999b) for further discussion of these and other broad R&D indicators for OECD countries.

G-8 countries, the inclusion of defense R&D has little impact on R&D totals for Japan, Germany, Italy, and Canada, where defense R&D represents 5 percent or less of the national total. In other countries, defense has accounted for a more significant, although since the end of the cold war declining, proportion of the national R&D effort. Between 1988 and 1998, the defense share of the R&D total:

- has fallen from 31 to 15 percent in the United States,
- has fallen from 21 to 7 percent in France,
- has fallen from 17 to 12 percent in the United Kingdom, and
- accounts for approximately 25 percent of the 1998 Russian R&D total.

Consequently, if current trends persist, the distinction between defense and nondefense R&D expenditures in international comparisons may become less important. In absolute dollar terms, the U.S. nondefense R&D spending is still considerably larger than that of its foreign counterparts. In 1998 (the latest year for which comparable international R&D data are available from most OECD countries), U.S. nondefense R&D was more than twice that of Japan and was equivalent to 94 percent of the non-U.S. G-7 countries' combined nondefense R&D total. (See appendix table 4-41.)

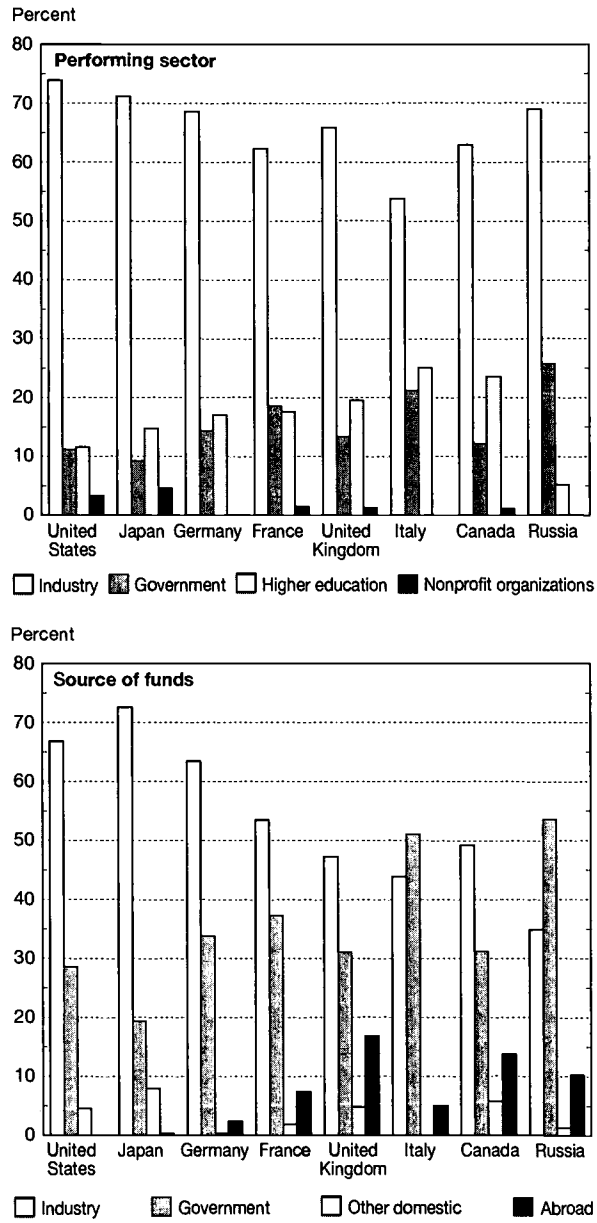
In terms of R&D/GDP ratios, the relative position of the United States is somewhat less favorable for this nondefense metric compared with those ratios for all R&D combined. Japan's nondefense R&D/GDP ratio (3.0 percent) exceeded that of the United States (2.2 percent) in 1998, as it has for years. (See figure 4-28 and appendix table 4-41.) The nondefense R&D ratio of Germany (2.3 percent in 1999) slightly exceeded that of the United States (again, in contrast to total R&D). The 1998 nondefense ratio for France (2.0 percent) was slightly below the U.S. ratio; ratios for the United Kingdom and Canada (each at 1.6 percent) and for Italy (1.0 percent) were considerably lower. The nondefense R&D/GDP ratio for Russia was nearly one-third (0.7 percent) the U.S. ratio.

International R&D by Performer, Source, and Character of Work

Broad Sector Patterns

Although marked differences are observed in the financing and performance of R&D among both OECD and non-OECD countries, similarities also are observed in R&D patterns for the G-8 countries. Government and industry account for roughly 80 percent or more of the R&D funding in each of these eight countries, although the respective contributions vary substantially across countries.[55] The industrial sector provided more than 70 percent of R&D funds in Japan, 67 percent in the United States, 64 percent in Germany, 54 percent in France; and between 44 and 49 percent in the United Kingdom, Italy, and Canada. (See figure 4-29.) In Russia, industry provided approximately 35 percent of the nation's R&D funding. Government provided the largest share (54 percent) of Russia's R&D total, as it did in Italy (at 51 percent of the national R&D effort). In the remaining six countries, government was the second largest source of R&D funding, ranging between 19 percent (in Japan) and 37 percent (in France) of the total. In each of these eight countries, government provided the largest share of the funds used for academic R&D performance. (See appendix table 4-42.)

Figure 4-29.
R&D expenditures by performer and source, G-8 countries



NOTES: Japan, France, United Kingdom, and Russia data for 1998. U.S., Germany, Italy, and Canada data for 1999.

See appendix table 4-42. *Science & Engineering Indicators – 2002*

[55] In accordance with international standards, sources of funding are attributed to the following sectors: all levels of government combined, business enterprises, higher education, private nonprofit organizations, and funds from abroad. The taxonomy used in presenting U.S. R&D expenditures elsewhere in this chapter differs somewhat.

The industrial sector dominates R&D performance in each of the G-8 countries. (See figure 4-29.) Industry performance shares for the 1998–99 period ranged from a little more than 70 percent in the United States and Japan to less than 54 percent in Italy. Industry's share was between 62 and 69 percent in France, Canada, the United Kingdom, Germany, and Russia. Most of the industrial R&D performance in these countries was funded by industry. Government's share of funding for industry R&D performance ranged from as little as 2 percent in Japan to 43 percent in Russia. (See appendix table 4-42.) In the other G-8 countries, the government funding share of industrial R&D ranged narrowly between 5 and 13 percent.

In most of these countries, the academic sector was the next largest R&D performer (at about 12 to 25 percent of the performance total in each country).[56] Academia often is the primary location of research (as opposed to R&D) activities, however. Government was the second largest R&D performing sector in France (which included spending in some sizable government laboratories), as it was in Russia (accounting for 26 percent of that nation's R&D effort).

[56] The national totals for Europe, Canada, and Japan include the research component of general university fund (GUF) block grants (not to be confused with basic research) provided by all levels of government to the academic sector. Therefore, at least conceptually, the totals include academia's separately budgeted research and research undertaken as part of university departmental R&D activities. In the United States, the Federal Government generally does not provide research support through a GUF equivalent, preferring instead to support specific, separately budgeted R&D projects. On the other hand, a fair amount of state government funding probably does support departmental research at public universities in the United States. Data on departmental research, considered an integral part of instructional programs, generally are not maintained by universities. U.S. totals are most certainly underestimated relative to the R&D effort reported for other countries.

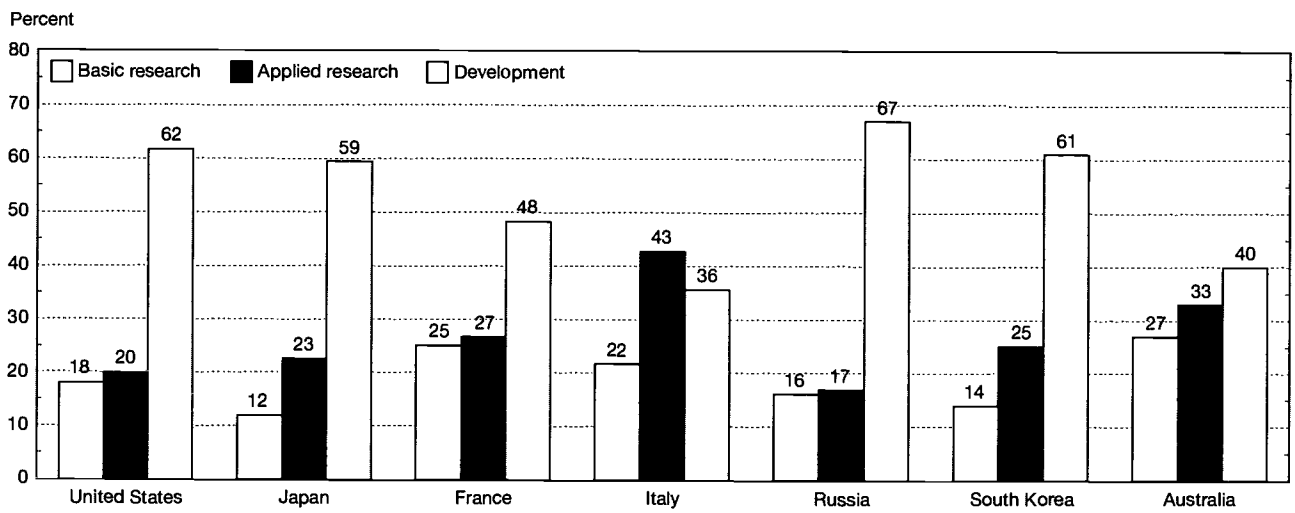
Character of R&D Effort

Not all of the G-8 countries categorize their R&D expenditures into basic research, applied research, or development categories, and for several countries that do use this taxonomy, the data are somewhat dated (OECD 2000b). In fact, only 6 of the 30 OECD members (and Russia) have reported their countries' character of work shares for 1998 or later. R&D classification by character of work probably involves a greater element of subjective assessment than other R&D indicators. See sidebar, "Choice of the 'Right' R&D Taxonomy Is a Historical Concern." Rather than resulting from surveys, the data often are estimated in large part by national authorities.[57] Nonetheless, where these data exist, they indicate the relative emphasis that a country places on supporting fundamental scientific activities—the seed corn of economic growth and technological advancement.

The United States expends approximately 18 percent of its R&D on activities that performers classify as basic research. (See figure 4-30.) About one-half of this research is funded by the Federal Government and performed in the academic sector. The largest share of this basic research effort is conducted in support of life sciences. Basic research accounts for comparatively smaller amounts of the national R&D per-

[57] The magnitude of the amounts estimated as basic research also is affected by how R&D expenditures are themselves estimated by national authorities. International R&D survey standards recommend that both capital and current expenditures be included in the R&D estimates, including amounts expended on basic research. Each of the non-U.S. countries displayed in figure 4-30 includes capital expenditures on fixed assets at the time they took place (OECD 1999b). All U.S. R&D data reported in the figure include depreciation charges instead of capital expenditures. U.S. R&D plant data (not shown in the figure) are distinct from current fund expenditures on R&D.

Figure 4-30.
Distribution of R&D expenditures by character of work in selected countries: 1998



NOTES: The character of work for 6 percent of Japan's R&D is unknown. Details may not sum to total because of rounding.

SOURCES: Organisation for Economic Co-operation and Development (OECD), 2000b; Centre for Science Research and Statistics (CSRS), 2001.

Science & Engineering Indicators – 2002

Choice of the "Right" R&D Taxonomy Is a Historical Concern

With the following words, written more than 50 years ago, Vannevar Bush (1945) laid the basis in his seminal report, *Science—The Endless Frontier,* for what eventually became known (and perhaps was unfairly derided) as the linear model of innovation:

"Scientific research may be divided into the following broad categories: (1) pure research, (2) background research, and (3) applied research and development. The boundaries between these categories are by no means clear-cut and it is frequently difficult to assign a given investigation to any single category. On the other hand, typical instances are easily recognized, and study reveals that each category requires different institutional arrangements for maximum development." (p. 81.)... "Basic research...creates the fund from which the practical applications of knowledge must be drawn. New products and new processes do not appear full-grown. They are founded on new principles and new conceptions, which in turn are painstakingly developed by research in the purest realms of science." (p. 19.)

Bush's model somewhat simplistically depicts innovation as a three-step process whereby (1) scientific breakthroughs from the performance of basic research (2) lead to applied research, which (3) leads to the development or application of applied research to commercial products, processes, and services. Although it is quite unlikely that either scientific or statistical experts ever really believed that such a model captured the complex relationships between science, technology, and innovation, it did (and still does) lend itself to the collection and analysis of data for policymaking purposes.

Most of the criticism surrounding the inappropriateness of the basic research, applied research, and development categories that are used in practically all R&D data collection efforts (see sidebar, "Definitions of Research and Development," at the beginning of this chapter) focus on the lack of clear boundaries between basic research and applied research.* This debate took form ever since Bush first differentiated "basic research" (a term he used interchangeably with "pure research") as that which is performed without thought of specific practical ends from applied research, the function of which is to provide "complete answers" to practical problems. A number of proposals have arisen over the years to replace, or supplement, the basic/applied research taxonomic categories, including fundamental versus strategic research, exploratory versus programmatic research, curiosity-driven versus mission-oriented research—to name just a few.†

Indeed, in the last published version (OECD 1994) of the *Frascati Manual* (international standards and guidelines for conducting R&D surveys), the option of collecting separate data on "pure basic research" and "oriented basic research" was introduced. To date, few countries have chosen to collect research expenditure data with these, or similar, reporting refinements. More generally, none of the proposed alternatives has gained a consensus in either the scientific, political, or statistical communities; each proposed alternative suffers from its own shortcomings which are as least as problematic as the taxonomic categories that would be replaced. On a more historical note, Bush himself was not particularly concerned about the precision of the definitions he used. Rather, he simply wanted to establish a framework that offered the best chance for basic research to receive special protection and, more important, ensured government financial support.

*It is just as likely, however, that the distinctions between applied research and development and between development and related (for example, routine testing and evaluation) and downstream (for example, preproduction) activities are subject to their own reporting complexities.

†One of the more recent well-known alternative taxonomy paradigms was developed by the late David Stokes (1997) and depicted in *Pasteur's Quadrant: Basic Science and Technological Innovation.* Stokes suggested multiple research categories: pure basic research (work inspired by the quest for basic understanding but not by potential use), purely applied research (work motivated only by potential use), and strategic research (work inspired by both potential use and fundamental understanding). Stokes characterized Louis Pasteur's research on the microbiological process of disease in the late 19th century as strategic research.

formance efforts in the Russian Federation (16 percent); South Korea (14 percent), which is currently the sixth largest R&D-performing member of OECD; and Japan (12 percent). Compared with patterns in the United States, however, a considerably greater share is funded for engineering research activities in each of these three countries. Conversely, basic research accounts for more than 20 percent of total R&D performance reported in Italy, France, and Australia.[58]

In contrast to spending patterns reported for most countries, spending on applied research activities accounts for the largest proportion (43 percent) of Italy's R&D total. In each of the other countries shown here, development accounted for the largest share of national totals (approximately 60 percent but as little as 40 percent of total in Australia), with most of the experimental development work under way in their respective industrial sectors.

Higher Education Sector

Source of Funds. In many OECD countries, the academic sector is a distant second to industry in terms of the national R&D performance effort. Among G-8 countries, universities

[58]The most current character of work data available from OECD sources for Germany are for 1993. The United Kingdom compiles such data only for the industry and government sectors, not for higher education or its nonprofit sector, the traditional locus of basic research activities.

account for as little as 5 percent of Russia's R&D total to upward of a 25 percent share in Italy.[59] For most of these countries, the government is now, and historically has been, the largest source of academic research funding. However, in each of these countries for which historical data exist (the exception being Russia), the government financing share has declined during the past 20 years, and industry as a source of university R&D funding has increased. Specifically, the government share, including both direct government support for academic R&D and the R&D component of block grants to universities,[60] has fallen by 8 percentage points or more in six of the G-7 countries since 1981 (the exception being Italy, in which the government share has dipped from 96 to 94 percent of the academic R&D total). By comparison, and as an indication of an overall pattern of increased university-firm interactions (often intending to promote the commercialization of university research), the funding proportion from industry sources for these seven countries combined climbed from 2.5 percent of the academic R&D total in 1981, to 5.4 percent in 1990, to 6.4 percent in 1998. In Germany and Canada, almost 11 percent of university research is now funded by industry. (See text table 4-14.)

S&E Fields. As noted in the discussion on the character of the R&D effort, the national emphases in particular S&E fields differ across countries. Where they are collected at all, most of the internationally comparable data on field-specific R&D are reported for the higher education sector. Although difficult to generalize, it would appear that most countries supporting a substantial level of academic R&D (defined at $1 billion PPPs in 1998) devote a relatively larger proportion of their R&D for engineering, social sciences, and humanities than does the United States. (See text table 4-15.) Conversely, the U.S. academic R&D effort emphasizes the medical sciences and natural sciences relatively more than do many other OECD countries.[61] The latter observation is consistent with the overall U.S. relative R&D emphases in health and biomedical sciences for which NIH and U.S. pharmaceutical companies are known.

Text table 4-14.
Academic R&D expenditures, by country and source of funds
(Percentages)

Country and source of funds	1981	1990	1999
Canada			
Government	79.8	73.2	66.4
Other	16.4	20.9	22.8
Industry	3.9	5.9	10.8
France			
Government	97.7	92.9	88.9
Other	1.0	2.2	7.7
Industry	1.3	4.9	3.4
Germany			
Government	98.2	92.1	87.5
Other	0.0	0.0	2.0
Industry	1.8	7.9	10.6
Italy			
Government	96.2	96.7	94.4
Other	1.1	0.9	0.9
Industry	2.7	2.4	4.8
Japan			
Government	57.7	51.2	49.1
Other	41.3	46.5	48.5
Industry	1.0	2.3	2.3
United Kingdom			
Government	81.3	73.5	64.4
Other	15.9	19.0	28.3
Industry	2.8	7.6	7.3
United States			
Government	74.1	66.9	65.6
Other	21.5	26.2	26.9
Industry	4.4	6.9	7.3

NOTES: Canada data are for 1983; France, Japan, and United Kingdom data are for 1998.

SOURCE: Organisation for Economic Co-operation and Development (OECD), *Basic Science and Technology Statistics* (Paris, March 2000).

Science & Engineering Indicators – 2002

Industry Sector

Sector Focus. Industrial firms account for the largest share of the total R&D performance in each of the G-8 countries. However, the purposes to which the R&D is applied differ somewhat, depending on the overall industrial composition of the economy. Furthermore, the structure of industrial activity can itself be a major determinant of the level and change in a country's industrial R&D spending. Variations in such spending can result from differences in absolute output, industrial structure, and R&D intensity. Countries with the same size economy could have vastly different R&D expenditure levels (and R&D/GDP ratios). Differences might depend on the share of industrial output in the economy, on whether the industries that account for the industrial output are traditional

[59]Country data are for 1998 or 1999. (See appendix table 4-42.)

[60]Whereas GUF block grants are reported separately for Japan, Canada, and European countries, the United States does not have an equivalent GUF category. In the U.S., funds to the university sector are distributed to address the objectives of the Federal agencies that provide the R&D funds. Nor is GUF equivalent to basic research. The treatment of GUF is one of the major areas of difficulty in making international R&D comparisons. In many countries, governments support academic research primarily through large block grants that are used at the discretion of each individual higher education institution to cover administrative, teaching, and research costs. Only the R&D component of GUF is included in national R&D statistics, but problems arise in identifying the amount of the R&D component and the objective of the research. Government GUF support is in addition to support provided in the form of earmarked, directed, or project-specific grants and contracts (funds for which can be assigned to specific socioeconomic categories). In the United States, the Federal Government (although not necessarily state governments) is much more directly involved in choosing which academic research projects are supported than are national governments in Europe and elsewhere. In each of the European G-7 countries, GUF accounts for 50 percent or more of total government R&D to universities and for roughly 40 percent of the Canadian government academic R&D support. Thus, these data indicate not only relative international funding priorities but also funding mechanisms and philosophies regarding the best methods for financing research.

[61]In international S&E field compilations, the natural sciences comprise math and computer sciences, physical sciences, environmental sciences, and all life sciences other than medical and agricultural sciences. Also note that the U.S. academic R&D effort is considerably larger than in any other country and the U.S. total ($25 billion PPP) is comparable with the combined R&D total ($29 billion PPP) of the other seven countries listed in text table 4-15.

Text table 4-15.
Shares of academic R&D expenditures, by country and S&E field: 1998
(Percentages)

Field	United States	Japan	Germany	Australia	South Korea	Spain	Sweden	Russia
Total academic R&D (billions of 1995 PPP dollars)	24.8	13.4	7.3	2.0	1.8	1.8	1.4	1.4
Percent of total academic R&D								
Natural science and engineering	92.7	66.1	78.5	73.0	91.5	77.9	81.7	88.3
Natural sciences	41.0	11.5	30.3	27.5	18.5	40.8	22.3	59.0
Engineering	15.6	24.4	20.5	16.2	49.0	18.0	23.6	26.7
Medical sciences	28.6	25.5	23.3	22.8	17.0	13.9	29.0	1.7
Agricultural sciences	7.6	4.6	4.4	6.6	7.0	5.2	6.7	0.9
Social sciences and humanities	7.3	33.9	21.5	27.0	8.5	22.1	18.3	11.7
Social sciences	6.0	NA	8.6	19.5	NA	14.2	12.2	6.6
Humanities	1.3	NA	12.9	7.6	NA	7.8	6.1	5.1
Percent of academic NS&E R&D								
Natural science and engineering	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Natural sciences	44.2	17.4	38.6	37.7	20.2	52.4	27.3	66.8
Engineering	16.8	37.0	26.1	22.1	53.6	23.1	28.9	30.2
Medical sciences	30.8	38.6	29.6	31.2	18.6	17.8	35.5	1.9
Agricultural sciences	8.2	7.0	5.6	9.0	7.6	6.6	8.3	1.1

PPP = purchasing power parity; NA = detail not available, but included in totals

NOTES: These are the only OECD countries that report more than $1 billion (1995 PPPs) in higher education R&D and that provide S&E field data. Data for Sweden are for 1997.

SOURCES: Organisation for Economic Co-operation and Development (OECD), Main Science and Technology Indicators database (April 2001); Centre for Science Research and Statistics (CSRS), *Russian Science and Technology at a Glance: 2000* (Moscow, 2001); and National Science Foundation, Division of Science Resources Statistics (NSF/SRS).

Science & Engineering Indicators – 2002

sites of R&D activity (e.g., food processing firms generally conduct less R&D than pharmaceutical firms), and on whether individual firms in the same industries devote substantial resources to R&D or emphasize other activities (i.e., firm-specific intensities). Text table 4-16 provides the distribution of industrial R&D performance in the G-8 countries and in Sweden and Finland, which have the first and third highest R&D/GDP ratios in the world, respectively.[62]

The level of industrial R&D in the United States far exceeds the level reported for any and all other of these countries, and therefore, the data are reported as shares of countries' industrial R&D totals. Most of these countries perform R&D in support of a large number of industry sectors. The sector distribution of the U.S. industrial R&D effort, however, is among the most widespread and diverse. This perhaps indicates a national inclination and ability to invest in becoming globally competitive in numerous industries rather than specializing in just a few industries or niche technologies. No U.S. industry sector accounts for more than 13 percent of the industry R&D total (the electrical equipment industry representing the highest level), and only two others (office machinery, including computers, and aerospace) account for 10 percent or more of the industry total. By comparison, most of the other countries display somewhat higher sector concentrations, including 20 percent or higher industry R&D shares for electrical equipment firms in Finland (at 44 percent of its industry total), Canada, Italy, and Sweden. Indeed, the electrical equipment sector is among the largest performers of the industrial R&D effort in 8 of the 10 countries shown (exceptions are the United Kingdom and Russia). Among other manufacturing sectors, 20 percent or higher shares are reported for motor vehicles in Germany and for pharmaceuticals in the United Kingdom, which is consistent with general economic production patterns.[63]

As indicated earlier, one of the more significant trends in U.S. industrial R&D activity has been the growth of the R&D effort within the nonmanufacturing sector. According to the internationally harmonized data in text table 4-16, such growth accounted for 20 percent of the U.S. 1997 industry R&D total, with computer services, R&D services, and trade each accounting for the largest individual shares (about 5 percent). A number of other countries also report substantial increases in their service sector R&D expenditures during the past 25 years. Among G-7 countries, nonmanufacturing R&D shares have increased by about 5 percentage points in France and Italy and by 13 percentage points in the United States, United Kingdom, and Canada since the early 1980s (Jankowski 2001b). In each of these three English-speaking countries, computer and related services account for a substantial share of the service R&D totals. Furthermore, R&D services appear to be an important locus of industry activity in several countries, reflecting in part the growth in outsourcing and

[62]Similar industrial R&D details for Switzerland and South Korea (which report the fourth and sixth highest R&D/GDP ratios in the world, respectively) were not available from OECD harmonized databases (OECD 2000a).

[63] See OECD (1999a) for a harmonized historical series on industry R&D expenditures in several OECD countries.

Text table 4-16.
Shares of industrial R&D, by industry sector for selected countries
(Percentages)

Industry	United States (1997)	Canada (1998)	Germany (1997)	France (1997)	Italy (1998)	Japan (1997)	United Kingdom (1998)	Russian Federation (1997)	Sweden (1997)	Finland (1998)
Total (billions of PPP dollars)	157.5	7.6	28.2	16.6	6.7	66.1	15.5	5.7	5.1	2.2
				Percent of total						
Total business enterprise	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total manufacturing	79.9	63.8	93.5	87.3	85.6	92.6	80.5	36.8	85.9	87.2
Food, beverages, and tobacco	1.2	1.1	0.7	1.8	1.3	2.5	2.4	0.1	1.0	2.1
Textiles, fur, and leather	0.3	0.7	0.7	0.6	0.4	0.7	0.3	0.1	0.1	0.6
Wood, paper, printing, and publishing	1.4	1.6	0.4	0.4	0.3	1.1	0.5	0.2	3.4	4.2
Coke, ref. petroleum products, and nuclear fuel	1.1	1.2	0.3	1.4	0.6	0.6	3.5	0.5	0.2	0.6
Chemicals (less pharmaceuticals)	4.6	2.3	12.2	6.3	5.5	8.9	6.7	1.8	1.3	4.3
Pharmaceuticals	7.6	6.8	6.5	12.8	8.3	5.9	21.9	0.2	15.2	3.4
Rubber and plastic products	0.9	0.6	1.7	2.7	1.8	2.4	0.6	0.3	0.9	2.1
Nonmetallic mineral products	0.4	0.1	0.9	1.2	0.3	2.0	0.5	0.2	0.5	0.8
Basic metals	0.6	1.8	1.0	1.7	1.1	3.5	0.7	1.1	1.0	1.2
Fabricated metal products	1.2	1.0	1.5	1.2	4.4	1.2	0.9	0.2	1.1	1.9
Machinery, NEC	3.7	2.2	11.0	4.5	5.7	8.6	6.3	11.9	9.8	10.4
Office, accounting and computing machinery	11.6	4.0	2.3	2.4	1.8	9.7	1.2	0.0	0.8	0.7
Electrical machinery	2.9	0.9	3.0	3.6	5.5	10.5	4.1	1.3	1.5	5.2
Electronic equipment (radio, TV, and communications)	13.0	25.1	11.3	11.8	19.9	16.3	7.5	3.2	21.9	43.6
Instruments, watches, and clocks	8.8	1.2	5.2	9.9	1.7	3.9	3.3	0.8	5.2	3.5
Motor vehicles	9.6	1.6	24.2	12.1	15.3	12.8	8.9	3.2	18.2	0.5
Other transport equipment (less aerospace)	0.3	0.1	1.6	0.6	1.5	0.4	0.7	3.0	0.5	1.5
Aerospace	10.3	10.8	8.5	11.5	9.9	1.0	10.2	8.7	3.1	0.0
Furniture, other manufacturing NEC	NA	0.7	0.5	0.6	0.4	0.8	0.2	0.0	0.2	0.6
Recycling	0.3	NA	0.0	0.0	0.0	NA	0.0	0.0	NA	0.1
Electricity, gas, and water	0.2	2.7	0.3	3.0	1.7	0.9	1.4	0.5	0.8	1.6
Construction	0.2	0.3	0.3	1.0	0.3	2.1	0.4	0.9	0.6	0.8
Agriculture and mining	0.1	2.9	0.5	1.8	0.0	0.0	1.4	3.3	1.1	0.7
Total services	19.7	30.3	5.4	7.0	12.3	4.4	16.4	58.5	11.6	9.8
Wholesale, retail trade, motor vehicle repair, etc.	5.2	7.2	0.1	NA	0.4	NA	0.1	0.0	NA	0.1
Hotels and restaurants	0.1	NA	NA	NA	0.0	NA	NA	0.0	NA	NA
Transport and storage	0.4	0.1	0.2	2.8	0.1	0.1	0.2	0.5	0.3	0.2
Communications	1.3	1.3	NA	NA	0.7	2.7	4.4	0.7	2.3	5.4
Financial intermediation (incl. insur.)	1.0	2.8	0.0	NA	0.8	NA	NA	0.0	NA	NA
Computer and related activities	5.6	6.9	1.7	2.4	2.2	1.6	6.7	1.1	3.2	3.0
Research and development	4.5	9.5	1.4	NA	5.8	NA	3.4	44.9	5.2	NA
Other business activities NEC	NA	2.5	1.4	1.8	2.0	NA	1.5	0.4	0.5	0.8
Community, social and personal service activities, etc.	NA	NA	0.1	NA	0.2	NA	0.1	10.9	0.1	0.3

PPP = purchasing power parity; NA = not available separately; NEC = not elsewhere classified

NOTE: Analytical Business Enterprise Research and Development (ANBERD) data not available for Switzerland and South Korea. Data are for the years listed under country names.

SOURCES: Organisation for Economic Co-operation and Development (OECD), Analytical Business Enterprise Research and Development (ANBERD) database (DSTI/EAS Division), (Paris, 2000); and OECD, *R&D Efforts in China, Israel, and Russia: Some Comparisons With OECD Countries* (CCNM/DSTI/EAS, Paris, 2000).

Science & Engineering Indicators – 2002

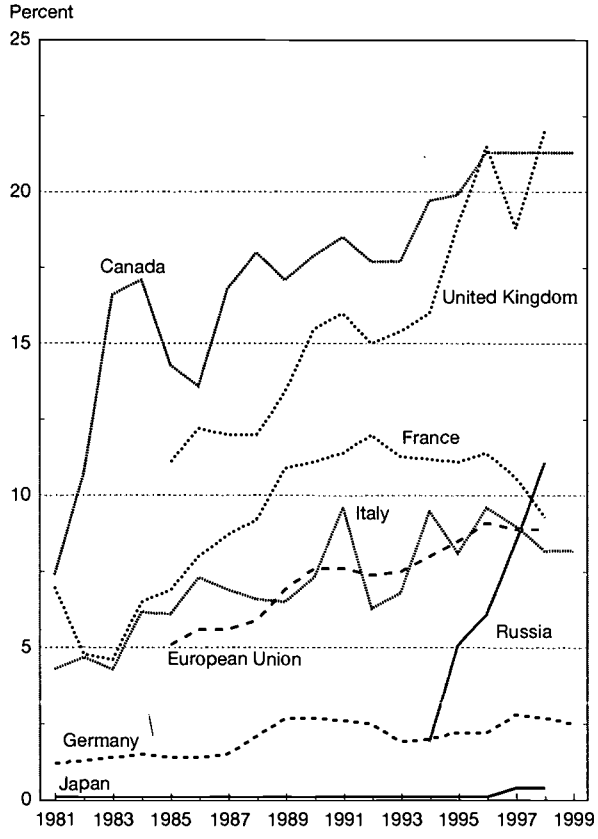
greater reliance on contract R&D in lieu of in-house performance, as well as intramural R&D in these industries.

According to the national statistics, only in Germany and Japan do the nonmanufacturing sectors currently account for less than 10 percent of the industry R&D performance total. Among the countries listed in text table 4-16, services R&D shares range from as little as 4 percent in Japan to 59 percent in Russia. The latter figure, however, primarily occurs because specialized industrial research institutes perform a large portion of Russia's industry and federal government R&D and are classified under the "research and development" sector within the service sector. Apart from these institutes, the manufacturing-nonmanufacturing split in Russia's industrial R&D would be similar to ratios in the United States (American Association for the Advancement of Science (AAAS) and Centre for Science Research and Statistics (CSRS) 2001).

Source of Funds. Most of the industrial R&D in each of these eight countries is provided by industry itself. As is the situation for OECD countries overall, government financing accounts for a small and declining share of the industry R&D performance total within G-7 countries. See "Government Sector" for further discussion. Government financing shares range from as little as 2 percent of the industry R&D in Japan to 13 percent of Italy's industry R&D effort. (See appendix table 4-42.) (For recent historical reasons, Russia is the exception to this pattern among the G-8 countries, with government accounting for 43 percent of its industry total.) In the United States, the Federal Government currently provides about 11 percent of the R&D funds used by industry, and the majority of that funding is obtained through contracts from DOD.

As shown in figure 4-31, funds from abroad accounted for as little as 0.4 percent of Japan's R&D expenditure total to almost 22 percent of total R&D expenditures in the United Kingdom. Foreign funding, predominantly from industry for R&D performed by industry but also including some small amounts of foreign funding provided to other nonindustry sectors, is an important and growing funding source in several countries. Growth in this funding source primarily reflects the increasing globalization of industrial R&D activities overall. For European countries, however, the growth in foreign sources of R&D funds may also reflect the expansion of coordinated European Community (EC) efforts to foster cooperative shared-cost research through its European Framework Programmes.[64] Although the growth pattern of foreign funding has seldom been smooth, it now accounts for more than 20 percent of industry's domestic performance totals in Canada and the United Kingdom and approximately 10 percent of industry R&D performed in Italy, France, and Russia. (See figure 4-31.) Such funding takes on even greater importance in many of the smaller OECD countries as well as in less industrialized countries (OECD 1999b).

Figure 4-31.
Proportion of industrial R&D financed by foreign sources



See appendix table 4-45.

Science & Engineering Indicators – 2002

In the United States, approximately 13 percent of funds spent on industry R&D performance in 1998 are estimated to have come from majority-owned affiliates of foreign firms investing domestically. This amount was considerably more than the 3 percent funding share provided by foreign firms in 1980 and their 8 percent share reported as recently as 1991.[65]

Government Sector

Government R&D Funding Totals. In most countries, the government sector makes its strongest impact on the R&D enterprise not by conducting R&D but, rather, by financing R&D. The government sector accounts for only 11 percent of OECD members' combined R&D performance in 1998 (OECD 2000a) and for 26 percent or (usually much) less in each of the G-8 countries. (See appendix table 4-42.) Government accounted for 13 percent of the OECD performance total as recently as 1995.

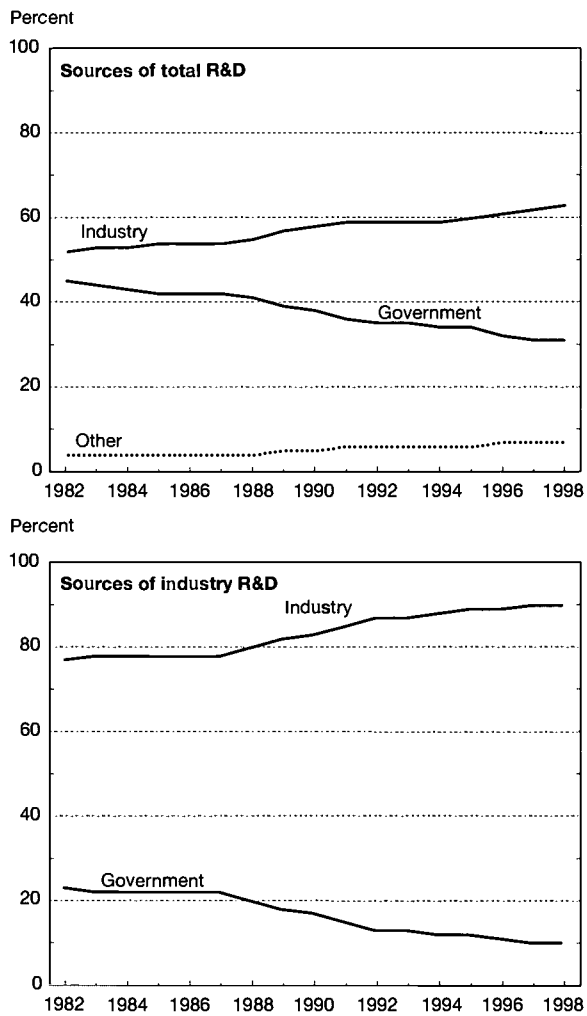
The decline in governments' share of the R&D performance totals, however, pales in comparison with their shrinking share of the R&D financing total. Indeed, the most significant trend among the G-7 and other OECD countries has been the relative decline in government R&D funding in the 1990s. In 1998, less than one-third of all R&D funds were derived from government sources, down considerably from the 45 percent share reported 16 years earlier. (See figure 4-32.) Among all OECD countries, government accounts for the highest funding share in Portugal (68 percent

[64]Since the mid-1980s, EC funding of R&D has become increasingly concentrated in its multinational Framework Programmes for Research and Technological Development (RTD), which were intended to strengthen the scientific and technological bases of community industry and to encourage it to become more internationally competitive. EC funds distributed to member countries' firms and universities have grown considerably. The EC budget for RTD activities has grown steadily from 3.7 billion European Currency Units (ECU) in the First Framework Programme (1984–87) to an estimated 15 billion ECU for the Fifth Framework Programme that runs from 1998 to 2002. The institutional recipients of these would tend to report the source as "foreign" or " funds from abroad" (Eurostat 2001).

[65]Unlike for other countries, there are no data on foreign sources of U.S. R&D performance. The figures used here to approximate foreign involvement are derived from the estimated percentage of U.S. industrial performance undertaken by majority-owned (i.e., 50 percent or more) nonbank U.S. affiliates of foreign companies. In short, the U.S. foreign R&D totals represent industry funding based on foreign ownership regardless of originating source, whereas the foreign totals for other countries represent flows of foreign funds from outside the country to any of its domestic performers. See the extensive coverage of industrial foreign R&D investments in the following sections of this chapter.

of its 1997 R&D total) and the lowest share in Japan (19 percent in 1998). Part of the relative decline reflects the effects of budgetary constraints, economic pressures, and changing priorities in government funding (especially the relative reduction in defense R&D in several of the major R&D-performing countries, notably France, the United Kingdom, and the United States). Another part reflects the absolute growth in industrial R&D funding as a response to increasing international competitive pressures in the marketplace, irrespective of government R&D spending patterns, thereby increasing the relative share of industry's funding as compared with government's funding. Both of these considerations are reflected in funding patterns for industrial R&D performance alone. In 1982, government provided 23 percent of the funds used by industry in conducting R&D within OECD countries, whereas by 1998 government's share of the industry R&D total had fallen by more than half, to 10 percent of the total. In most OECD countries (as in the United States), government support for business R&D is skewed toward large firms.

Figure 4-32.
Sources of R&D expenditures in OECD countries



OECD = Organisation for Economic Co-operation and Development

See appendix table 4-44.

Science & Engineering Indicators – 2002

Government R&D Priorities. A breakdown of public expenditures by major socioeconomic objectives provides insight into government priorities that as a group have changed over time and that individually differ considerably across countries.[66] Within OECD, the defense share of governments' R&D financing total has declined annually since the mid-1980s. Accounting for 44 percent of the government total in 1986, defense-related activities now garner a much smaller 31 percent share. (See text table 4-17.) Much of this decline is driven by the U.S. experience: 53 percent of the U.S. Government's $78 billion R&D investment during 1999 was devoted to national defense, down from its 69 percent share in 1986. Nonetheless, defense still accounts for a relatively larger government R&D share in the United States than elsewhere. This share compares with the 35 percent defense share in the United Kingdom (of a $9 billion government total), 30 percent in Russia (of $4 billion), 23 percent in France (of $13 billion), and less than 10 percent each in Germany, Italy, Canada, and Japan. (See figure 4-33 and appendix table 4-43.) As in the United States, these recent figures represent substantial cutbacks in defense R&D in the United Kingdom and France, where defense accounted for 44 and 40 percent, respectively, of government R&D funding in 1990. However, defense-related R&D also seems particularly difficult to account for in many countries' national statistics. See sidebar, "Tracking R&D: Gap Between Performer- and Source-Reported Expenditures."

Concurrent with the changes in overall defense/nondefense R&D shares, notable shifts have occurred in the composition of OECD countries' governmental nondefense R&D support during the past two decades. In terms of the broad socioeconomic objectives to which government programs are classified in various international reports (OECD 1999a, 2000f), government R&D shares have increased most for health and the environment and for various nondirected R&D activities (identified in text table 4-17 as "other purposes").[67] Growth in health-related R&D financing has been particularly strong in the United States, whereas many of the other OECD countries have reported relatively greater growth for environmen-

[66]Data on the socioeconomic objectives of R&D funding are rarely obtained by special surveys; they are generally extracted in some way from national budgets. Because those budgets already have their own methodology and terminology, these R&D funding data are subject to comparability constraints not placed on other types of international R&D data sets. Notably, although each country adheres to the same criteria for distributing their R&D by objective as outlined in OECD's *Frascati Manual* (OECD 1994), the actual classification may differ among countries because of differences in the primary objective of the various funding agents. Note also that these data reflect government R&D funds only, which account for widely divergent shares and absolute amounts of each country's R&D total.

[67]Health and environment programs include human health, social development, protection of the environment, and exploration and exploitation of the Earth and its atmosphere. R&D for "other purposes" in text table 4-17 includes nonoriented programs, advancement of research, and primarily GUF (e.g., the estimated R&D content of block grants to universities described in note 56).

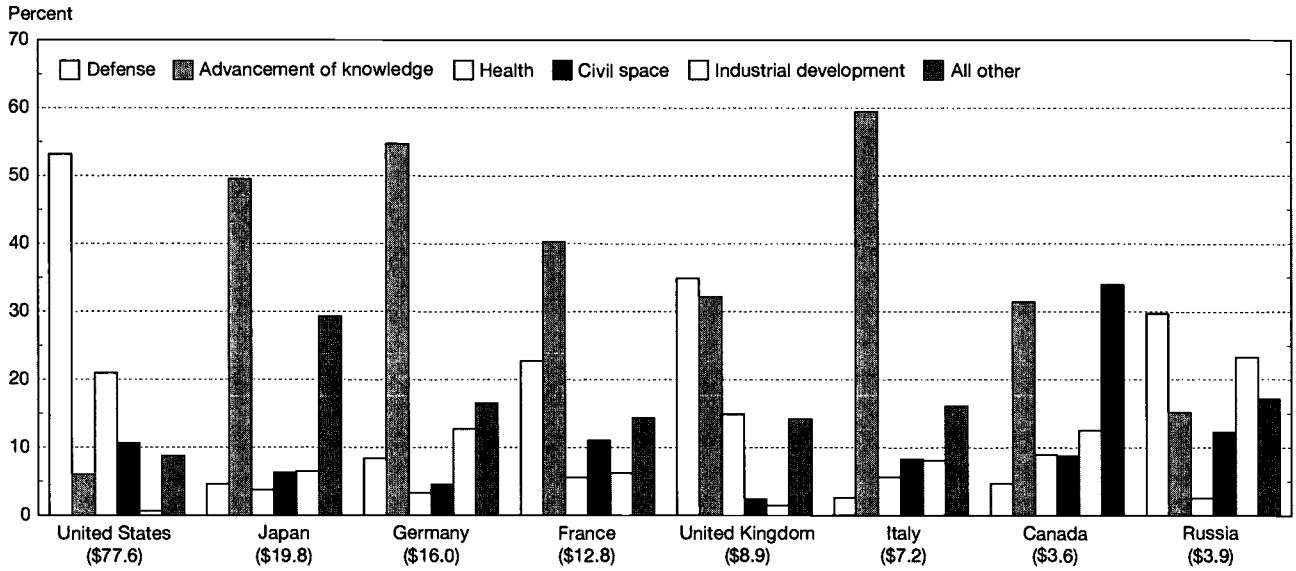
Text table 4-17.
Government R&D support for defense and nondefense purposes, all OECD countries
(Percentages)

Year	Government R&D budget shares		Government nondefense R&D budget shares			
	Defense	Nondefense	Health and environment	Economic development programs	Civil space	Other purposes
1981	35.6	64.4	19.7	37.5	9.9	32.9
1982	38.1	61.9	19.4	37.7	8.6	34.3
1983	39.9	60.1	19.3	36.8	7.7	36.2
1984	41.8	58.2	20.1	35.9	7.9	36.1
1985	43.4	56.6	20.5	35.6	8.6	35.3
1986	44.4	55.6	20.5	34.5	8.8	36.2
1987	44.1	55.9	21.2	32.3	9.8	36.7
1988	43.4	56.6	21.5	30.7	10.2	37.6
1989	42.0	58.0	21.8	29.9	11.0	37.3
1990	40.2	59.8	22.3	29.0	12.1	36.6
1991	37.3	62.7	22.3	28.6	12.2	36.9
1992	36.0	64.0	22.6	27.5	12.3	37.6
1993	36.0	64.0	22.5	26.6	12.5	38.4
1994	33.5	66.5	22.7	25.6	12.6	39.1
1995	31.6	68.4	22.7	24.6	12.3	40.4
1996	31.3	68.7	22.8	24.5	12.0	40.7
1997	31.3	68.7	23.1	24.7	11.6	40.6
1998	30.5	69.5	23.9	22.7	11.5	41.9

SOURCE: Organisation for Economic Co-operation and Development (OECD), Main Science and Technology Indicators database (Paris, November 2000).

Science & Engineering Indicators – 2002

Figure 4-33.
Government R&D support by socioeconomic objectives, G-8 countries



NOTES: The amounts listed under country names represent total government R&D support in billions of U.S. purchasing power parity (PPP) dollars. Data for Italy, Russia, and Canada are for 1998; data for all other countries are for 1999. R&D is classified according to its primary government objective, although it may support any number of complementary goals. For example, defense R&D with commercial spinoffs is classified as supporting defense, not industrial development. R&D for the advancement of knowledge is not equivalent to basic research.

See appendix table 4-43.

Science & Engineering Indicators – 2002

Tracking R&D: Gap Between Performer- and Source-Reported Expenditures

In many OECD countries, including the United States, total government R&D support figures reported by government agencies differ substantially from those reported by performers of R&D work. Consistent with international guidance and standards (OECD 1994), however, most countries' national R&D expenditure totals and time series are based primarily on data reported by performers. This convention is preferred because performers are in the best position to indicate how much they spent in the actual conduct of R&D in a given year and to identify the source of their funds. Although funding and performing series may be expected to differ for many reasons such as different bases used for reporting government obligations (fiscal year) and performance expenditures (calendar year), the gap between the two R&D series has widened during the past several years. Additionally, the divergence in the series is most pronounced in countries with relatively large defense R&D expenditures (National Science Board (NSB) 1998).

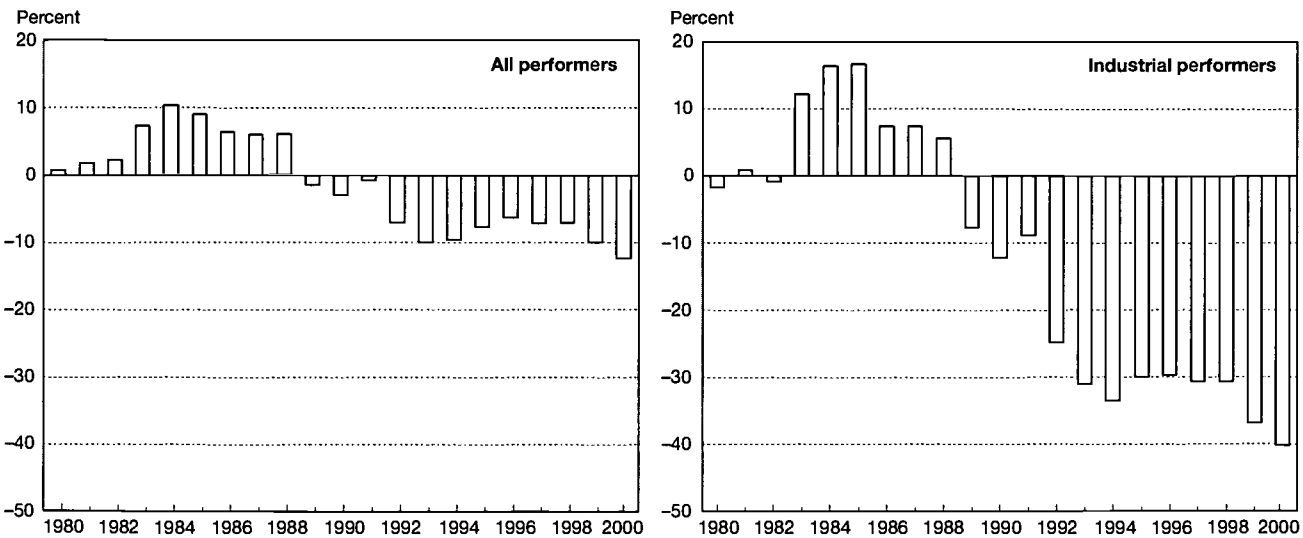
Data Gap Trends

For the United States, the reporting gap has become particularly acute over the past several years. In the mid-1980s, performer-reported Federal R&D exceeded Federal reports by $3 to $4 billion annually (5–10 percent of the government total). This pattern reversed itself toward the end of the decade; in 1989, the government-reported R&D total exceeded performer reports by $1 billion. The gap has since grown to about $8 billion. In other words, approximately 10 percent of the government total in 1999 is unaccounted for in performer surveys. (See figure 4-34.) The difference in Federal R&D totals is primarily in Department of Defense (DOD) development funding of industry (principally aircraft and missile firms). For 1999, Federal agencies reported $31.9 billion in total R&D obligations provided to industrial performers compared with an estimated $20.2 billion in Federal funding reported by industrial performers. (DOD reports industry R&D funding of $24.6 billion, whereas industry reports using $11.7 billion of DOD's R&D funds.) Overall, industrywide estimates equal a 37 percent paper "loss" of federally reported 1999 R&D support. (See figure 4-34.)

Reasons for Data Gaps

Interviews with industry representatives have helped the National Science Foundation (NSF) identify possible reasons that performer-reported R&D totals might differ from funding agency-reported totals. Generally, since the end of the cold war, numerous changes have occurred in the defense contracting environment and DOD's budgeting process. These have been accompanied by major shifts in the composition of R&D, test, and evaluation contracts, which may account for some of the statistical discrepancies. In ways unknown a decade earlier, new types of defense contractors and nontraditional forms of R&D expenditures apparently play a major role in complicating the collection of R&D data. (A complete summary of the NSF study appeared in NSB 2000.)

Figure 4-34.
Difference in U.S. performer-reported versus agency-reported Federal R&D



NOTE: Difference is defined as percentage of federally reported R&D.

See appendix table 4-34.

Science & Engineering Indicators – 2002

More recently, however, Federal agencies and representatives from firms and universities (recipients of Federal R&D funding) gathered at a Congressional Research Service (CRS) workshop to discuss these R&D data issues. Not surprisingly, participants were unable to reach a consensus on the reasons for the growing data gaps. According to the CRS summary (Davey and Rowberg 2000), participants generally agreed that agency downsizing in recent years has left fewer resources to collect, process, and report R&D data to NSF. Because agencies do not place a high priority on such data reporting, those who report data are likely to be the early victims of downsizing. Nonetheless, the agencies with the largest discrepancy between their reported R&D obligations and the R&D expenditures reported by industry performers receiving those funds (DOD, Department of Energy, and National Aeronautics and Space Administration) believe that the source of the discrepancy lies almost exclusively with the performers. Those agencies have reviewed their data collection and reporting methods and contend that they have been stable and consistent over the period during which the discrepancies have grown.

On the other hand, the U.S. Bureau of the Census, which collects the industry R&D data for NSF, stated that it has not seen any significant shifts in the character of that data since at least 1992. In particular, no significant changes have appeared that could correlate with the rise in mergers and acquisitions among the surveyed firms. Industry participants questioned why agencies were not solely responsible for reporting these Federal R&D funding data to NSF rather than sharing the burden with industry. And according to an even more recent U.S. General Accounting Office (2001a) investigation, "Because the gap is the result of comparing two dissimilar types of financial data [Federal obligations and performer expenditures], it does not necessarily reflect poor quality data, nor does it reflect whether performers are receiving or spending all the Federal R&D funds obligated to them. Thus, even if the data collection and reporting issues were addressed, a gap would still exist." In summary, users should expect no quick resolution to the issue of why performer-reported R&D data differ from the data reported by the funding Federal agencies, nor perhaps should they be overly concerned about the discrepancy.

tal research programs. Indeed, as is indicated from a variety of R&D metrics, the emphasis on health-related research is much more pronounced in the United States than in other countries, although the importance of tracking the R&D contribution to improving human health has become widely accepted (OECD 2001a). In 1999, the Federal Government devoted 21 percent of its R&D investment to health-related R&D, making such activities second only to defense. (Direct comparisons between health and defense R&D are complicated because most of the health-related R&D is research, and about 90 percent of defense R&D is development.)

The relative shift in emphasizing nondirected R&D reflects government priority setting during a period of fiscal austerity and constraint. With fewer discretionary funds available to support R&D, governments have tended to conduct activities that are traditionally in the government sphere of responsibility and for which private funding is less likely to be available. For example, basic research projects are inextricably linked to higher education.[68] Conversely, the relative share of government R&D support provided for economic development programs has declined considerably, from 38 percent of total in 1981 to 23 percent in 1999. Economic development programs include the promotion of agriculture, fisheries and forestry, industry, infrastructure, and energy, all activities for which privately financed R&D is more likely to be provided without public support, although the focus of such private and public support would undoubtedly differ somewhat.

Different activities are emphasized in individual countries' governmental R&D support statistics. Japan committed 19 percent of its total governmental R&D support ($20 billion) to energy-related activities, reflecting the country's historical concern about its high dependence on foreign sources of energy. (See appendix table 4-43.) In Canada, 11 percent of the government's $4 billion in R&D funding was directed toward agriculture. Space R&D received considerable support in the United States and France (11 percent of the total in each country), while industrial development accounted for 8 percent or more of governmental R&D funding in Canada, Germany, Italy, and Russia. In fact, industrial development is the leading socioeconomic objective for R&D in Russia, accounting for 23 percent of all government R&D, funding for which is primarily oriented toward the development of science-intensive industries and is aimed at increasing economic efficiency and technological capabilities (AAAS and CSRS 2001).[69] Industrial development programs accounted for 7 percent of the Japanese total but for less than 1 percent of U.S. R&D. (See figure 4-33.) The latter figure, which includes mostly R&D funding by NIST of the U.S. Department of Commerce, is understated relative to most other countries as a result of data compilation differences. In part, the low U.S. industrial development share reflects the expectation that firms will finance industrial R&D activities with their own funds; in part, government R&D that may be indirectly useful to in-

[68]See Kaiser et al. (1999) for a description on recent efforts to make higher education R&D data more internationally comparable.

[69]As an added indication of evolving government priorities in Russia, fully 27 percent of the government's 1998 R&D budget appropriations for economic programs were used to assist in the conversion of the country's defense industry to civil applications (AAAS and CSRS 2001).

dustry is often funded with other purposes in mind such as defense and space (and is therefore classified under other socioeconomic objectives).

Japanese, German, and Italian government R&D appropriations in 1998–99 were invested relatively heavily in advancement of knowledge (50 percent or more of the $20 billion total for Japan, 55 percent of Germany's $16 billion total, and 59 percent of the $7 billion total in Italy). "Advancement of knowledge" is the combined support for advancement of research and GUF.[70] Indeed, the GUF component of advancement of knowledge, for which there is no comparable counterpart in the United States, represents the largest part of government R&D expenditure in most OECD countries.

R&D Tax Policies. In many OECD countries, government not only provides direct financial support for R&D activities but also uses indirect mechanisms such as tax relief to promote national investment in S&T. Indeed, tax treatment of R&D in OECD countries is broadly similar, with some variations in the use of R&D tax credits (OECD 1996, 1999a). The main features of the R&D tax instruments are as follows:

- Almost all OECD countries (including the United States) allow 100 percent of industry R&D expenditures to be deducted from taxable income in the year they are incurred.
- About one-half of OECD countries (including the United States) provide some type of additional R&D tax credit or incentive with a trend toward using incremental credits. A few countries also use more targeted approaches, such as those favoring basic research.
- Several OECD countries have special provisions that favor R&D in small and medium-size enterprises. (In the United States, credit provisions do not vary by firm size, but direct Federal R&D support is provided through grants to small firms.)

A growing number of R&D tax incentives are being offered in OECD countries at the subnational (provincial and state) levels, including in the United States. See Poterba (1997) for a discussion of international elements of corporate R&D tax policies.

International Industrial R&D Investments

International R&D investments refer to R&D and related long-term activities by private companies outside of the home country. Broadly speaking, these activities include the acquisition or establishment of R&D facilities abroad, R&D spending in foreign subsidiaries (in manufacturing, services, or research facilities), international R&D alliances, licensing agreements, and contract research overseas. These activities fulfill different objectives in corporate R&D strategies and exhibit various degrees of managerial and financial commitment from the parties involved. Although public data on these international business activities are key for S&T policy analysis and design, their availability varies considerably, even within advanced economies.

In this section, the focus is on R&D spending trends to and from the United States, with a brief overview of overseas and foreign-owned domestic R&D facilities.[71] In principle, trends in R&D facilities are tied to overall foreign direct investment (FDI) trends, especially in high-technology industries. However, comprehensive FDI data on acquired and established facilities by type of major activity (i.e., manufacturing versus research) are not available in most countries.[72] On the other hand, R&D spending by multinational corporations are readily available from financial and operating data collected in FDI statistics.

By definition, R&D spending in subsidiaries abroad is preceded by the acquisition or establishment of foreign facilities. More fundamentally, however, the economics of these two activities have become increasingly intertwined in advanced economies. For one, FDI flows are becoming a key element in understanding the overall corporate R&D strategy of global companies. Conversely, knowledge-based assets are becoming an increasingly important factor in FDI decisions by multinational companies. However, empirical links are elusive with the available data. For example, mere changes in ownership can affect R&D spending statistics without representing changes in the actual performance of R&D domestically.

Foreign Direct Investments and R&D Facilities

Total foreign direct investments have increased steadily in recent years in the United States and elsewhere, according to data from the Bureau of Economic Analysis (BEA). Recent increases worldwide have been fueled by motives ranging from market liberalization efforts leading to privatization drives in some emerging markets, proximity to existing or potential large consumer markets, and regional technological advantages. Foreign direct investment flows into the United States are dominated by the lure of a large domestic market and by the technological sophistication of many of its firms. Technology-related factors driving FDI include an educated and skilled workforce, a favorable regulatory environment, and the need for complementary technologies in an increasingly complex and rapid innovation process.

According to an OECD study, as much as 85 percent of FDI activity worldwide consists of mergers and acquisitions (M&As), compared to the establishment of new industrial facilities or so-called greenfield investments (Kang and Johansson

[70] In the United States, "advancement of knowledge" is a budgetary category for research unrelated to a specific national objective. Furthermore, although GUF are reported separately for Japan, Canada, and European countries, the United States and Russia do not have an equivalent GUF category. In the United States, funds to the university sector are distributed to address the objectives of the Federal agencies that provide the R&D funds. GUF is not equivalent to basic research. For 1999, the GUF portion of total national governmental R&D support was 48 percent in Italy, 39 percent in Germany, 37 percent in Japan, and between 18 and 24 percent in the United Kingdom, Canada, and France.

[71] Data limitations preclude the inclusion of contract R&D with (or grants to) foreign organizations, whereas international technology alliances are discussed earlier in this chapter.

[72] As discussed below, a DOC survey with 1997 and 1998 data provides the latest available indicators of overseas and foreign-owned domestic R&D facilities.

2000). M&As involving high-technology facilities supply not only vital research infrastructure (such as specialized facilities and equipment) but also an existing base of intangible assets key in the development and marketing of new technologies including technical know-how and skilled workers, organizational knowledge, marketing networks, and trademarks.

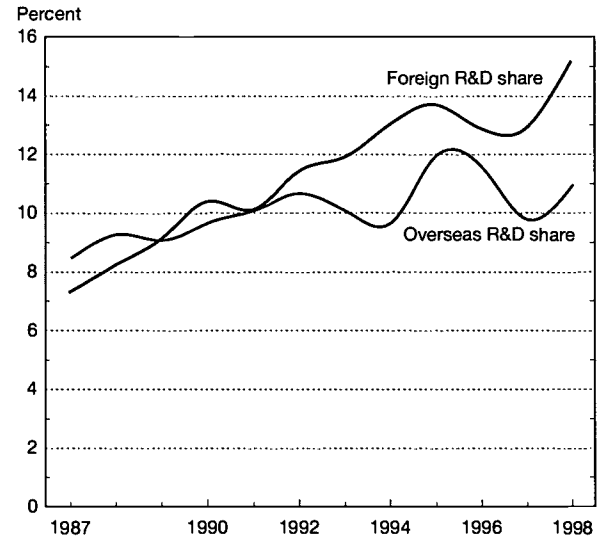
In the United States, data on foreign-owned research facilities are available only to 1998 from a DOC survey (Dalton, Serapio, and Yoshida 1999). In 1998, 715 U.S. R&D facilities were operated by 375 foreign-owned companies, including 251 facilities (35 percent) owned by Japanese parent companies. Other countries with a major presence were Germany 107 (15 percent) and the United Kingdom 103 (14 percent). One-third of the facilities were chemicals/rubber, drugs, and biotechnology centers, most with German, Japanese, or British parent companies. Another 10 percent (74) were computer and semiconductor R&D facilities, and 7 percent (53) conducted software research. Almost two-thirds of these computer and software research centers were Japanese owned, with a good share located in California. On the other hand, by 1997 U.S. companies had established at least 186 R&D facilities overseas. Two-thirds of these facilities were located in five countries: Japan (43), United Kingdom (27), Canada (26), France (16), and Germany (15).[73]

Foreign R&D and R&D Expenditure Balance

R&D spending by U.S. affiliates of foreign companies in the United States (or foreign R&D spending) increased 28 percent in 1997–98, from $17 billion to $22 billion, the largest single-year increase since 1990, as compiled by BEA (2000).[74] (See appendix table 4-50.) This pushed foreign R&D as a proportion of company-funded industrial R&D in the United States to a record 15 percent in 1998, after fluctuating around 13 percent since 1994. (See figure 4-35.)

When combined with the $15 billion of R&D spent abroad by U.S.-based companies, this yields a "net inflow" of R&D expenditures of more than $7 billion in 1998 compared with $3 billion a year earlier.[75] (See figure 4-36.) However, this record increase in net U.S. inflows needs to be put in perspective. In particular, data on foreign R&D spending in the United States are affected by changes in ownership involving domestic and foreign companies, as in cross-country M&As. In 1998, two of the largest M&As included the Daimler-Benz (Germany) merger with Chrysler and the British Petroleum (United Kingdom) merger with Amoco. Acquisition of Ameri-

Figure 4-35.
Ratio of foreign and overseas R&D spending to company-funded industrial R&D

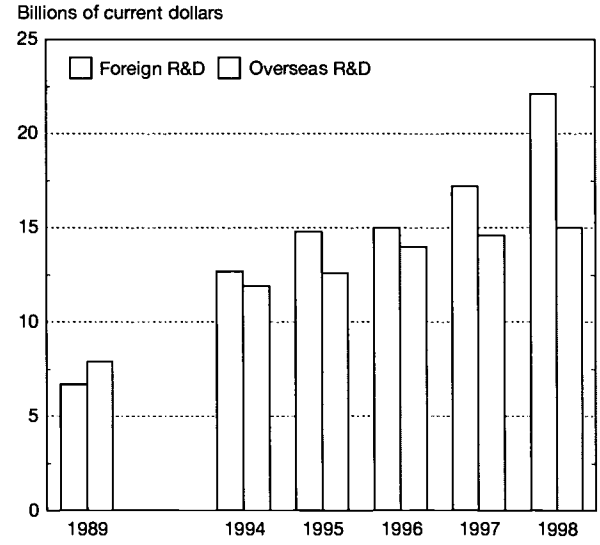


NOTES: Foreign R&D refers to R&D performed in the United States by U.S. affiliates of foreign parent companies. Overseas R&D refers to R&D performed abroad by foreign affiliates of U.S. parent companies.

See appendix tables 4-32, 4-46, and 4-50.

Science & Engineering Indicators – 2002

Figure 4-36.
Globalization of U.S. industrial R&D



NOTES: Foreign R&D refers to R&D performed in the United States by U.S. affiliates of foreign parent companies. Overseas R&D refers to R&D performed abroad by foreign affiliates of U.S. parent companies.

See appendix tables 4-48 and 4-50.

Science & Engineering Indicators – 2002

[73]For a detailed discussion of the results of the DOC survey, see NSB (2000), pages 2–65/66.

[74]Data are for R&D performed in the United States by majority-owned (more than 50 percent) nonbank U.S. affiliates of foreign parent companies. See appendix tables 4-50 and 4-51. Appendix table 4-49 has R&D spending data based on 10 percent foreign ownership. Data are based on the concept of an ultimate beneficial owner, which is the person "proceeding up the U.S. affiliate's ownership chain beginning with and including the foreign parent, that is not owned more than 50 percent by another person." For more details and definitions, see Quijano (1990).

[75]Note that the BEA data used here are based on R&D performance, not funding source (domestic or foreign). Still, these R&D spending trends do provide an indication of the industrial and R&D strategies of multinational companies based in, or with activities in, the United States.

can R&D-performing companies increases reported R&D funded by foreign affiliates that may or may not represent actual changes in research activities beyond a change in ownership. Difficulties in the valuation of purchased in-process R&D, the cumulative (and more difficult to track) effect of smaller acquisitions, and the offsetting effects of divestitures also make it difficult to assess the effect of cross-border M&A activity in international R&D spending flows.

Chemical manufacturing and the new NAICS sector of computer and electronic product manufacturing had the largest single-industry shares of foreign R&D in 1998 (33 and 20 percent, respectively). They include the largest subsectors attracting foreign R&D funding: pharmaceuticals and communications equipment (see appendix table 4-51). As detailed below, more than one-half of foreign-owned chemicals and pharmaceuticals R&D in the United States is performed by Swiss and German subsidiaries. Transportation equipment (mostly motor vehicles and bodies) had a 12 percent share in 1998, up sharply from the 1997 share, in part due to cross-border M&A activity. The most notable nonmanufacturing sectors are professional, scientific, and technical services (NAICS sector 54), which include R&D services, with a 3 percent share, and information services (NAICS sector 51), with 2 percent share. The latter includes such R&D-intensive industries as telecommunications and data processing services.

Comparable to statistics on high-technology trade and FDI flows, European, Japanese, and Canadian companies make the largest R&D investments in the United States. (See figure 4-37.) In 1998, American affiliates of European parent companies represented 72 percent of the $22 billion R&D spending in the United States, down slightly from 75 percent in 1996, Asia-Pacific (14.4 percent, including Japan at 11.7 percent), and Canada (10.7 percent). Among the European countries, the largest shares correspond to Germany (22.1 percent), the United Kingdom (16.7 percent), and Switzerland (14.0 percent).

Furthermore, specific countries dominate foreign majority-owned R&D expenditures in certain U.S. industries. Swiss subsidiaries performed 34 percent of foreign-owned R&D in chemicals as well as 26 percent of foreign-owned industrial machinery R&D in 1998. German subsidiaries performed 20 percent of foreign-owned chemical R&D. At the same time, more than 90 percent of R&D spending by foreign-owned transportation equipment affiliates is performed by European subsidiaries.[78] On the other hand, 25 percent of the Japanese-owned $2.6 billion R&D spending in the United States is performed in the area of computers and other electronic products. (See text table 4-18.)

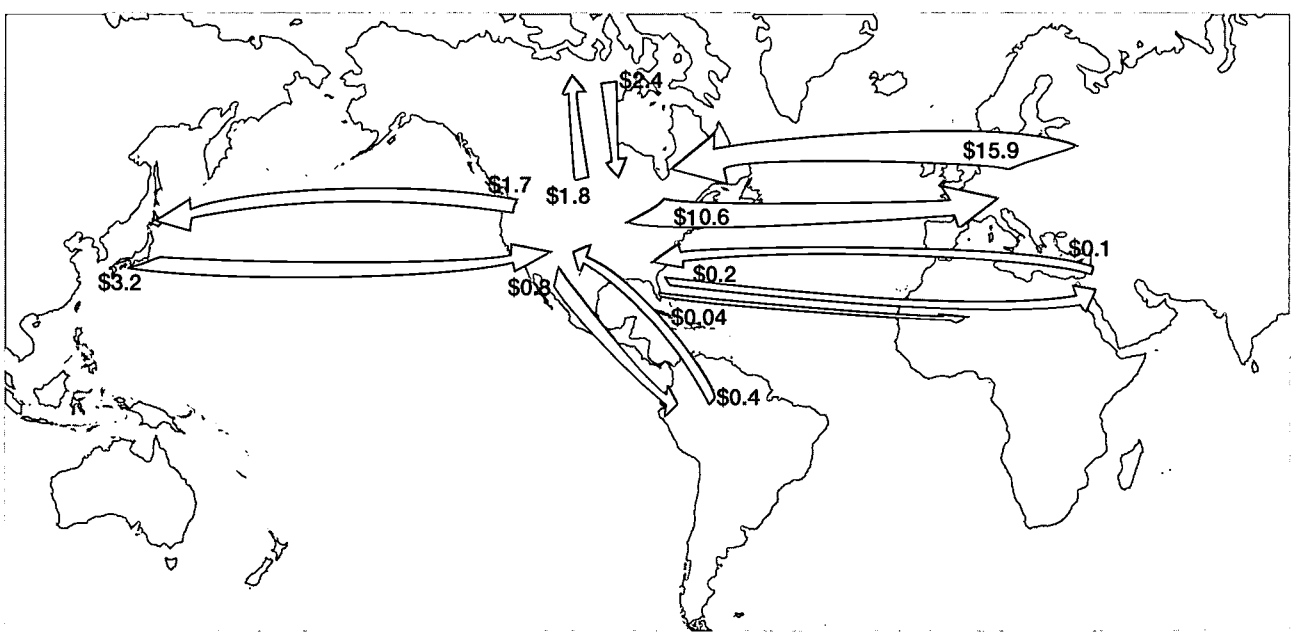
Overseas R&D Spending

According to data from the NSF Industrial R&D survey (NSF 2001e), R&D performed abroad by foreign affiliates of U.S. parent companies (or overseas R&D spending) reached

[78]Disclosure limitations preclude further country-specific analysis.

Figure 4-37.
Industrial R&D spending of U.S. and foreign affiliates, by world region: 1998

Billions of current dollars



See appendix tables 4-48 and 4-50.

Science & Engineering Indicators – 2002

Text table 4-18.
R&D performed by majority-owned U.S. affiliates of foreign companies in the United States, by NAICS industry of affiliate and country: 1998
(Millions of U.S. dollars)

Country	All industries	Manufacturing						Non-manufacturing
		Total	Chemicals	Machinery	Computers	Electrical equipment	Transportation equipment	
Total	22,073	18,256	7,193	725	4,509	898	2,678	3,817
Canada	2,353	2,127	12	5	D	D	D	226
Europe	15,904	14,197	6,749	D	D	D	2,416	1,707
France	1,905	1,807	712	3	535	123	88	98
Germany	4,880	4,570	1,387	D	77	D	D	310
Netherlands	985	941	359	D	D	1	D	44
Switzerland	3,083	2,956	2,443	189	28	3	0	127
United Kingdom	3,685	3,005	D	177	220	72	128	680
Asia and Pacific	3,180	1,600	408	D	664	D	224	1,580
Japan	2,578	1,470	D	D	637	7	171	1,108
Western hemisphere	393	D	—	0	5	0	8	D
Middle East	129	116	D	4	91	0	0	13
Africa	D	D	0	0	0	0	0	D

NAICS = North American Industry Classification System; D = withheld to avoid disclosing operations of individual companies; — = less than $500,000

NOTES: Data are for majority-owned (more than 50 percent ownership) non–bank affiliates of foreign parents by country of ultimate beneficial owner (UBO). Industry of affiliate based on NAICS industrial classification system. Data include expenditures for R&D conducted by affiliates, whether for themselves or for others under contract. Data exclude expenditures for R&D conducted by others for affiliates under contract. See also appendix tables 4-50 and 4-51.

SOURCE: U.S. Bureau of Economic Analysis, *Foreign Direct Investment in the United States: Operations of U.S. Affiliates of Foreign Companies*, Preliminary 1998 Estimates (Washington, DC, 2000).

Science & Engineering Indicators – 2002

$17 billion in 1999. (See appendix table 4-47.)[79] In the three-year period for which NAICS-based data are available from this survey (1997 to 1999) this spending grew 28 percent (25 percent after adjusting for inflation).[80] Although the manufacturing share in R&D spending by American subsidiaries abroad declined from 90 percent in 1997 to 74 percent in 1999,[81] the largest single-industry shares in 1999 are all in this sector: transportation equipment (24 percent), chemicals (19 percent), pharmaceuticals, (17 percent), and computer and electronic products (11 percent). The nonmanufacturing information sector represented 8 percent of spending by foreign affiliates of American companies in 1999, up from a 5 percent share in 1997. Professional, scientific, and technical services had a 3 percent share in 1999 compared to 2 percent in 1998 and 1 percent in 1997.

Data on overseas R&D spending are available with country detail from a separate BEA survey but only through 1998. BEA data show that R&D expenditures overseas by majority-owned foreign affiliates (MOFAs) of U.S. multinationals increased from $12 billion in 1994 to $15 billion in 1998, for an annual growth rate of 4.8 percent.[82] The 1998 figure represents an increase of 2.7 percent over 1997 (1.4 percent after adjusting for inflation). However, this increase in R&D overseas did not keep pace with domestic industrial R&D, as shown in figure 4-35, where overseas R&D spending is presented relative to domestic company-funded industrial R&D.

More than two-thirds ($10.3 billion) of R&D performed overseas in 1998 took place in five countries: the United Kingdom, Germany, Canada, France, and Japan. (See appendix table 4-48.) This concentration of R&D spending abroad corresponds with other overseas activities by U.S. multinational companies. In particular, Mataloni (2000) notes an increase in new or acquired MOFAs by U.S. multinationals in large markets with high wages, especially to the United Kingdom, as opposed to low-wage countries. Not surprisingly, R&D expenditures by majority-owned foreign affiliates of U.S. parent companies were also the highest in the United Kingdom ($3 billion, or 21 percent of overseas R&D). Cultural and economic similarities with the United States, such as the low level of market regulation, as well as the duty-free access to customers in other European Union members, makes the United Kingdom a prime target for new MOFA operations.[83] In addition, advanced economies offer U.S. affiliates either large or high-income markets, and technological know-how

[79]The 1998 NSF figure for R&D abroad is $16 billion, higher than the BEA tally of $15 billion in 1998 discussed below. At the time this report was written, 1999 BEA data were not available.

[80]For historical data, see appendix table 4-46.

[81]Note that manufacturing shares for 1997–99 are not completely comparable with previous years based on the SIC system. For example, some of the new nonmanufacturing sectors in NAICS contain activities previously classified in manufacturing.

[82]In constant 1996 dollars, the annual growth rate was 3.3 percent, reaching $14.5 billion in 1998.

[83]U.S. MNCs acquired or established 84 of 477 foreign affiliates in the United Kingdom in 1998, the largest single-country figure. These new MOFAs in the United Kingdom accounted for the largest share (44 percent) of the gross product of all new MOFAs in 1998, the latest figure available from BEA. Other key locations for new U.S. affiliates in 1998 were Canada (38), Germany (36), the Netherlands (36), and France (27).

that complements or expands the parents' capabilities.

As a region, majority-owned European subsidiaries of American companies performed $10.6 billion (71 percent) of overseas R&D in 1998, the highest regional share. (See first data column in text table 4-19.) Canadian subsidiaries had a 12 percent share in 1998 but more than doubled R&D spending over 1994–98. On the other hand, Japanese subsidiaries performed 7 percent of U.S.-owned R&D abroad in 1998, down from a 10 percent share in 1994, reflecting the impact of the decade-long recession in that Asian economy. In fact, Canadian subsidiaries have been spending more than the Japanese units on R&D activities since 1996, something that had not happened since 1982. (See appendix table 4-48.)

According to the BEA data, about three-fourths of all R&D performed overseas by majority-owned affiliates in 1998 was undertaken in four manufacturing sectors: transportation equipment (30 percent), chemicals (27 percent), industrial machinery, including computers (7 percent), and electronic equipment and components, except computers (8 percent). (See text table 4-19.) Almost one-fourth of the $4 billion spent by majority-owned U.S. affiliates overseas in chemicals research (which includes pharmaceuticals and some biotechnology research) was performed in the United Kingdom; another 16 percent was performed in France.

On the other hand, of the $4.5 billion in automotive and other transportation equipment research overseas in 1998, 42 percent was performed in Germany and another 21 percent in Canada. This is not surprising, given the strong presence of American automobile factories and related technical centers in both countries. For industrial machinery, 31 percent of research abroad was performed in the United Kingdom and 22 percent in Germany. For electronic equipment, the countries with the largest shares were Germany (16 percent) and Japan (11 percent).

Text table 4-19.
R&D performed overseas by majority-owned foreign affiliates of U.S. parent companies, by SIC industry of affiliate and country: 1998
(Millions of U.S. dollars)

Country	All industries	Manufacturing					Non-manufacturing
		Total	Chemicals	Industrial machinery	Electronic equipment	Transportation equipment	
Total	14,986	12,746	4,002	1,116	1,212	4,465	2,240
Canada	1,771	1,569	395	23	124	917	202
Europe	10,580	9,154	2,988	874	724	3,084	1,426
Belgium	326	232	173	3	5	15	94
France	1,321	1,143	656	75	52	151	178
Germany	3,042	2,908	258	250	194	1,872	134
Italy	586	521	275	50	71	60	65
Netherlands	501	301	D	9	61	63	200
Spain	198	181	75	8	41	45	17
Sweden	448	385	D	23	8	D	63
Switzerland	234	164	35	66	17	0	70
United Kingdom	3,144	2,610	956	342	104	D	534
Rest of Europe	780	709	D	48	171	D	71
Asia and Pacific	1,690	1,267	445	162	237	139	423
Australia	302	240	54	9	1	D	62
Japan	1,030	722	317	76	132	5	308
Rest of Asia/Pacific	358	305	74	77	104	D	53
Western hemisphere	753	662	137	18	119	322	91
Brazil	448	435	72	13	D	D	13
Mexico	191	140	21	5	D	D	51
Middle East (Israel)	157	62	13	D	8	0	95
Africa	35	32	23	D	—	3	3

SIC = Standard Industrial Classification System; D = withheld to avoid disclosing operations of individual companies; — = less than $500,000

NOTES: Data are for majority-owned (more than 50% ownership) non-bank affiliates of nonbank U.S parents by SIC industry of affiliate. Data include expenditures for R&D conducted by foreign affiliates, whether for themselves or for others under contract. Data exclude expenditures for R&D conducted by others for affiliates under contract. Industrial machinery includes computer equipment.

See also appendix table 4-48.

SOURCE: U.S. Bureau of Economic Analysis, *U.S. Direct Investment Abroad: Operations of U.S. Parent Companies and Their Foreign Affiliates*, Preliminary 1998 Estimates (Washington, DC, 2000).

Science & Engineering Indicators – 2002

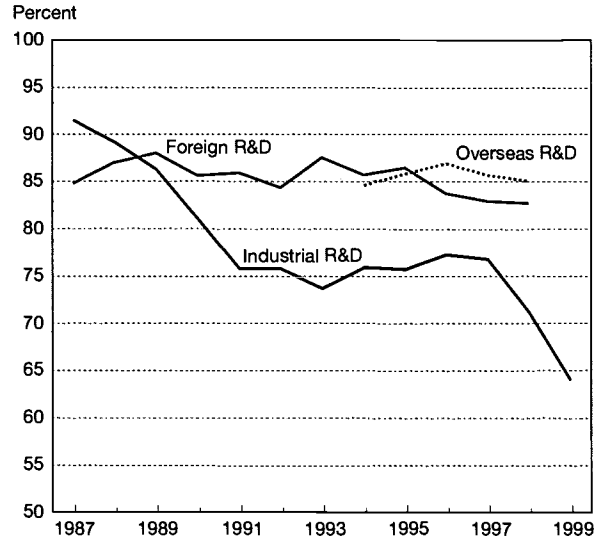
Industrial Structure of International R&D Spending and the IGRD Index

Manufacturing activity still dominates trends in total domestic, foreign, and overseas R&D spending, but such dominance has declined in recent years. Of these indicators, overseas R&D continue to have the heaviest concentration of manufacturing activity, followed by foreign R&D and total domestic industrial R&D. (See figure 4-38.)

Different industries dominate these three categories of R&D spending, revealing diverse technological and financial opportunities across U.S. borders. For example, 27 percent of R&D spending by foreign affiliates of U.S. companies was performed in transportation equipment, the highest proportion among all major R&D performing industries in 1998. (See figure 4-39 and appendix table 4-52.) However, this proportion is more than twice its 12 percent share of foreign R&D spending in the United States. On the other hand, chemicals research, which includes pharmaceuticals and some biotechnology, represented 33 percent of foreign R&D in the United States, twice its 17 percent overseas R&D share. Furthermore, the proportion of chemicals R&D in either foreign or overseas R&D spending is higher than its domestic company-funded R&D share of 13 percent, reflecting a high degree of globalization of R&D activity in this industry.

Another interesting pair of industries is computer manufacturing and information services (software publishing and data processing services). They represent the manufacturing

Figure 4-38.
Manufacturing shares in foreign, overseas, and total domestic industrial R&D

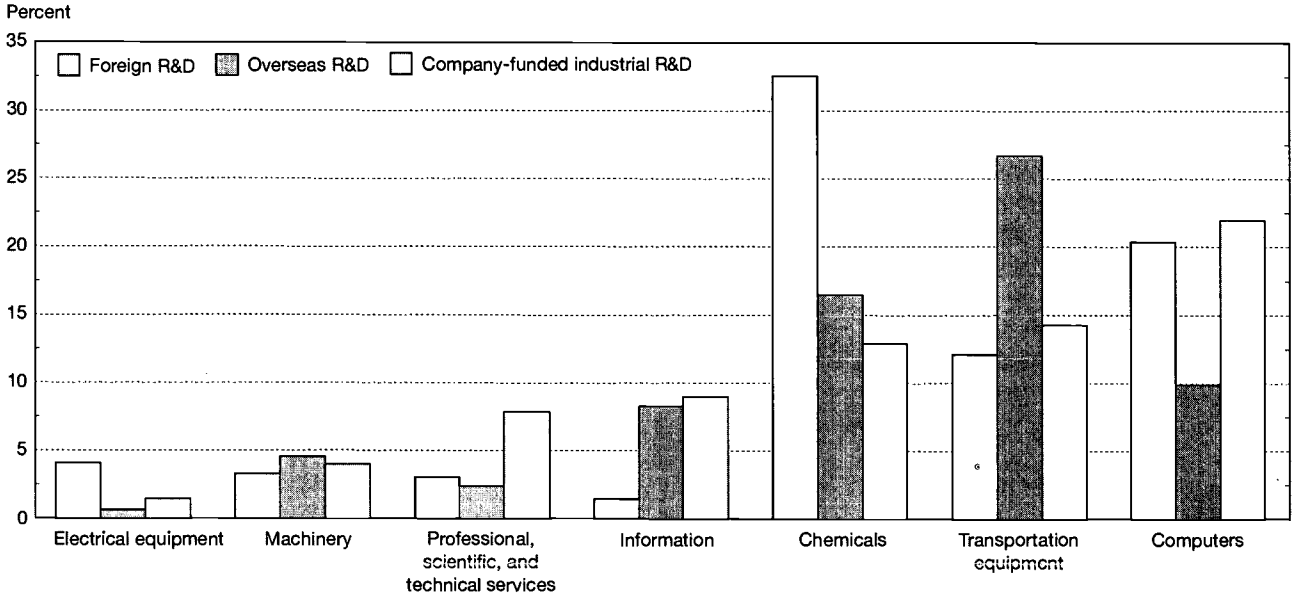


NOTES: Foreign R&D refers to R&D performed in the U.S. by United States affiliates of foreign parent companies. Overseas R&D refers to R&D performed abroad by foreign affiliates of U.S. parent companies. The industrial classification system used in industrial R&D and foreign R&D data changed from SIC to NAICS in 1997.

See appendix tables 4-31, 4-48, and 4-50.

Science & Engineering Indicators – 2002

Figure 4-39.
Share of selected industries in foreign, overseas, and company-funded industrial R&D in the United States: 1998



NOTES: Foreign R&D refers to R&D performed in the United States by U.S. affiliates of foreign parent companies. Overseas R&D refers to R&D performed abroad by foreign affiliates of U.S. parent companies. The seven industries in this figure account for 77 percent, 69 percent, and 72 percent of foreign, overseas, and domestic company-funded R&D, respectively.

See appendix table 4-52.

Science & Engineering Indicators – 2002

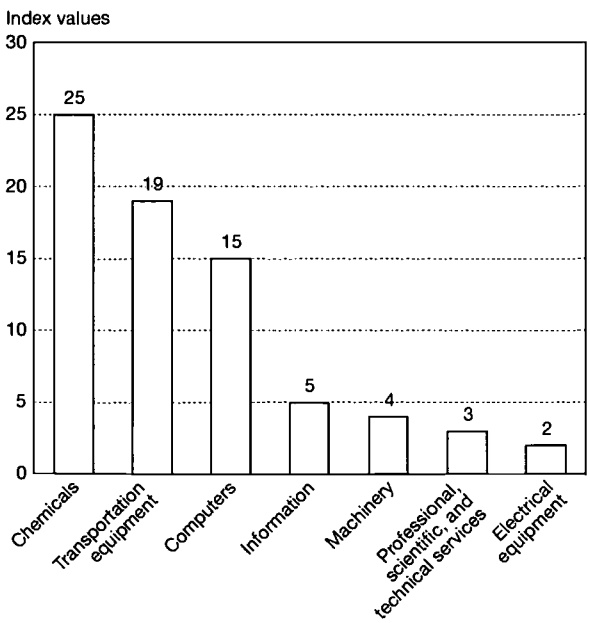
and services sides, respectively, of information technology activity. Remarkably, the share of information services in R&D spending abroad (8.3 percent) is five times larger than that industry's foreign R&D share (1.5 percent) in 1998. The opposite is true for computer and electronic products. The computer industry accounts for 20 percent of total foreign R&D in the United States, twice as large as its 10 percent share in R&D funds spent abroad. However, more data based on the newly established NAICS classification system would be needed over time to form a more accurate picture of the R&D flows in these two components of IT R&D.

Another measure of the degree of globalization of R&D activity is obtained by combining these R&D spending shares. Specifically, the Industrial Globalization R&D (IGRD) index is defined as the average of foreign and overseas R&D spending shares for a given industry.[84] This average indicates how open an industrial innovation system is to R&D flows, not unlike the sum of exports and imports, which quantifies the openness of national economies to the flow of goods. By this measure, chemical manufacturing in the U.S. exhibit the highest degree of internationalization with an IGRD index of 25, followed by transportation equipment (19), and computer manufacturing (15). (See figure 4-40.)

Several implications may be drawn from this indicator. An industry with a high IGRD index may be less constrained by national R&D expenditure trends. Furthermore, such an industry is more likely to have the institutional setup required to take advantage of technological opportunities elsewhere. The index could be used in conjunction with other international S&T indicators discussed in this volume, including bibliometric indicators, foreign-origin patents, international alliances and R&D facilities, and high-technology trade.[85]

[84]In principle, the IGRD index has a range of [0, 100]. However, reasonable index values for R&D-intensive industries in advanced economies are not likely to exceed or even be close to 50.

Figure 4-40.
Industrial Globalization R&D index for selected U.S. industries



NOTE: The Industrial Globalization R&D (IGRD) index is the average of foreign and overseas R&D spending shares for a given industry.

See appendix table 4-52. *Science & Engineering Indicators – 2002*

Conclusion

A resurgence in R&D investment in the United States in the mid-1990s has continued through to the beginning of 2000. A prosperous economy invigorated companies in both the manufacturing and service sectors, enabling them to allocate more resources toward the discovery of new knowledge and the application of that knowledge toward the development of new products, processes, and services. An upsurge in innovation is further contributing to a buoyant economy.

At the same time that the private sector's role in maintaining the health of U.S. R&D enterprise has been expanding, the Federal Government's contribution has been receding, as the Federal share has become less prominent in both the funding and the performance of R&D. Similar developments have been seen in many countries throughout the world. As a result of these two divergent funding trends in the United States, the composition of the nation's R&D investment is slowly shifting. For example, a growing percentage of the nation's R&D total has been directed toward nondefense activities.

Concurrent with these broad patterns of change, the locus of R&D activities is also shifting as a reflection of broad technological changes and new scientific research opportunities. For example, a growing amount of industrial R&D is now undertaken in services (versus manufacturing) industries, and much of the industry R&D growth has been in biotechnology and information technology. Reflecting the political reality of tremendous increases in research funding for NIH relative to other Federal agencies, the composition of these Federal funds has shifted markedly toward the life sciences during the past several years. Whereas industry has focused its R&D on new product development, the Federal Government historically has been the primary funding source for basic research activities.

As part of the changing composition of R&D activities, the organizational process of conducting R&D also has undergone substantial change. Greater reliance is being placed on the academic research community, and all sectors have expanded their participation in a variety of domestic and international partnerships both within and across sectors. The rapid rise in global R&D investments is evident from the expansion of industry's overseas R&D spending and the even more rapid rise in foreign firms' R&D spending in the United States. These domestic and foreign collaborations permit performers to pool and leverage resources, reduce costs, and share the risks associated with research activities. In addition, such alliances and international investments open a host of new scientific opportuni-

[85]See earlier sections in this chapter, as well as chapters 5 and 6 in this volume.

ties for R&D performers that undoubtedly will continue to redefine the R&D enterprise into the future.

Each of these developments creates further challenges in terms of data measurement and indicator improvement. Indeed, there are a number of specific areas of interest that could benefit from expanded data collections and analyses (National Research Council, 2000). Most notably, better information is needed on structural changes in industrial R&D (including research on the nature of R&D in the service sector and obtaining finer detail by industrial classification and geographic location). More extensive data could improve our understanding of the relationship between R&D and innovation to address the manner in which science and technology are transferred among firms and transformed into new processes and products. Fuller investigations and tracking of the apparent increase in the web of partnerships among firms, universities, and Federal agencies and laboratories in conducting R&D are warranted, as is more research on the extent and role of multidisciplinary research in science and engineering. Both of these latter topics, research that involves multiple partners and multiple fields, illustrate directly the growing complexities that characterize the R&D enterprise.

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Chapter 5
Academic Research and Development

Highlights

Financial Resources for Academic R&D

- **In 2000, U.S. academic institutions spent an estimated $30 billion (in current dollars) on research and development (R&D).** The Federal Government provided $17.5 billion, academic institutions $6.0 billion, state and local governments $2.2 billion, industry $2.3 billion, and other sources $2.2 billion.
- **Over the past half century (between 1953 and 2000), average annual growth in R&D has been stronger for the academic sector than for any other R&D-performing sector.** During this period, academic R&D rose from 0.07 to 0.30 percent of the gross domestic product, more than a fourfold increase. Industrially performed R&D has grown more rapidly in recent years than R&D performed in any other sector.
- **The academic sector, which performs 43 percent of basic research, continues to be the largest performer of basic research in the United States.** Academic R&D activities have been highly concentrated at the basic research end of the R&D spectrum since the late 1950s. In 2000, an estimated 69 percent of academic R&D expenditures went for basic research, 24 percent for applied research, and 7 percent for development.
- **The Federal Government continues to provide the majority of funds for academic R&D, although its share has been declining steadily since 1966.** The Federal Government provided an estimated 58 percent of the funding for R&D performed in academic institutions in 2000, down from its peak of 73 percent in the mid-1960s.
- **After the Federal Government, academic institutions performing R&D provided the second largest share of academic R&D support.** Except for a brief downturn in the first half of the 1990s, the institutional share of academic R&D support has been increasing steadily since the early 1960s, reaching an estimated 20 percent in 2000. Some of the funds directed to research activities by institutions come from Federal, state, or local government sources but are classified as institutional funds because they are not restricted to research and the universities decide how to use them.
- **Industrial R&D support to academic institutions has grown more rapidly (albeit from a small base) than support from all other sources during the past quarter century.** Industry's share was an estimated 7.7 percent in 2000, its highest level since the 1950s. However, industrial support still accounts for one of the smallest shares of academic R&D funding.
- **Three agencies are responsible for more than four-fifths of Federal obligations for academic R&D: the National Institutes of Health (NIH) for 60 percent, the National Science Foundation (NSF) for 15 percent, and the Department of Defense for 9 percent.** Federal agencies emphasize different science and engineering (S&E) fields in their funding of academic research, with some, such as NIH, concentrating their funding in one field and others, such as NSF, having more diversified funding patterns.
- **After increasing steadily between the early 1970s and early 1990s, the number of universities and colleges receiving Federal R&D support began to decline after 1994.** Almost the entire increase during that period, and the recent decrease, occurred among institutions other than those classified by the Carnegie Foundation for the Advancement of Teaching as research and doctorate-granting institutions. Of these institutions, 559 received Federal R&D support in 1999 compared with 676 in 1994, 461 in 1980, and 341 in 1971.
- **The R&D emphasis of the academic sector, as measured by its S&E field shares, changed between 1973 and 1999, with absolute shares increasing for life sciences, engineering, and computer sciences and declining for social sciences, psychology, environmental (earth, atmospheric, and ocean) sciences, and physical sciences.** In 1999, life sciences accounted for 57 percent of total academic R&D expenditures, 56 percent of Federal academic R&D expenditures, and 58 percent of non-Federal academic R&D expenditures.
- **The distribution of Federal and non-Federal funding of academic R&D varies by field.** In 1999, the Federal Government supported more than three-quarters of academic R&D expenditures in both physics and atmospheric sciences but one-third or less of the R&D in economics, political science, and agricultural sciences.
- **Total academic space for S&E research increased by almost 35 percent between 1988 and 1999, up from about 112 million to 151 million net assignable square feet.** When completed, construction projects initiated between 1986 and 1999 are expected to produce more than 72 million square feet of new research space, which will either replace obsolete or inadequate space or be added to existing space.
- **R&D equipment intensity—the percentage of total annual R&D expenditures from current funds devoted to research equipment—has declined dramatically during the past 15 years.** After reaching a high of 7 percent in 1986, R&D equipment intensity declined to 5 percent in 1999.

Doctoral Scientists and Engineers in Academia

- **An estimated 28 percent of doctoral scientists and engineers at U.S. universities and colleges in 1999 were foreign born.** Computer sciences and engineering had the highest percentages (37 and 35 percent, respectively); followed by mathematics (28 percent); physical, life, and social sciences (from 23 to 19 percent); and psychology (8 percent). Many of these scientists and engineers had obtained their doctorates from U.S. institutions. These estimates are conservative and do not reflect the strong rise in immigration during the 1990s.
- **University hiring of young faculty is picking up, but full-time faculty appointments are less available than ever.** Those entering academia with recently earned doctorates are more likely to receive postdoctoral (43 percent) than faculty positions (39 percent). Only half of those with a doctorate earned four to seven years earlier are in tenure track positions, well below the experience of previous decades.
- **Among new hires, the percentage of white males has been cut in half, from 80 percent in 1973 to 40 percent in 1999,** reflecting a declining propensity to earn a S&E doctorate and the relative attractiveness of nonacademic employment. Growth occurred in the hiring of women and young doctorate-holders from minority backgrounds.
- **An academic researcher pool outside the regular faculty ranks has grown over the years.** The faculty share of the academic workforce has declined, as more research activity is being carried out by postdoctorates and others in full-time nonfaculty positions. This change toward nonfaculty research effort was pronounced in the 1990s. A long-term upward trend shows those with primary research activity increasing relative to total employment.
- **Graduate students play a key role in U.S. academic S&E research, and research assistantships were the primary means of support for about one-quarter of them.** The number of research assistants has risen faster than overall graduate enrollment. A shift is evident away from the physical and into the life sciences, reflecting changes in the field distribution of academic research funds.
- **The percentage of academic researchers with Federal support for their work was lower in 1999 than in the late 1980s.** Exceptions were engineering; computer sciences; and earth, atmospheric, and ocean sciences. Full-time faculty were less frequently supported than other full-time employees, especially postdoctorates, 80 percent of whom received Federal funds. Young Ph.D.-holders in full-time faculty positions reported sharply lower rates of Federal support than their counterparts in other positions.
- **In the view of academic researchers, no large shift has taken place during the 1990s in the nature of academic R&D.** Of those with research as their primary work activity, a modestly larger percentage reported applied and development work in 1999 than in 1993. Among all academic researchers, no such effect was evident.

Outputs of Scientific and Engineering Research: Articles and Patents

- **In 1999, authors from around the world published approximately 530,000 articles in a set of refereed journals included in the Science Citation Index since 1985.** This represented an average increase of 1 percent per annum from the prior decade, with very disparate growth patterns by region. Authors from Western Europe, Asia, and Latin America achieved strong growth in papers; authors from the United States, Eastern Europe, and Sub-Saharan Africa showed a decline of articles in absolute terms.
- **The number of U.S.-authored papers (approximately 164,000 articles in 1999) appear to have fallen from the level in the early 1990s.** This phenomenon is not exclusive to the United States; output fell in the United Kingdom, Canada, and the Netherlands during the latter half of the 1990s. The trend in the United States affected all fields of science, except earth and space science, and most sectors. Although the U.S. share of world output has been in a long-term decline due to strong growth in other countries, the absolute U.S. output volume had grown consistently over the prior three decades.
- **The U.S. portfolio of scientific papers is broad and diverse, although it is dominated by life sciences, particularly biomedical research and clinical medicine.** Social and behavioral sciences also are an important component in the U.S. portfolio. As a region, Western Europe has a similar life-science dominated portfolio, but for major European nations the physical sciences shares are larger than in the U.S. A portfolio consisting of physical sciences and engineering is much more prominent for countries in Eastern Europe, Asia, and Latin America.
- **Scientific collaboration between institutions has increased significantly over the past two decades as a result of IT, the growing complexity and scale of scientific research, and economic and political factors.** In the United States, more than half of all articles in 1999 had authors from multiple institutions, primarily due to a significant rise in international collaboration. By 1999, 1 article in 5 had one non-U.S. author compared with 1 article in 10 in the 1980s.

- **The U.S. has the largest share of internationally authored papers, although this share has declined as other countries have increased and expanded their ties with other countries.** U.S. authors partnered with authors from 160 countries in 1999, and those countries ranged from mature scientific producers of OECD to developing countries. Countries with authors with high levels of collaboration included Western European countries, Japan, Russia, and the newly industrialized economies in Asia. Collaboration also increased in other regions, both intraregionally and with other regions, especially the United States, Western Europe, and Asia.

- **In the United States, collaboration between institutions is extensive, accounting for at least 77 percent of multiple-authored papers by all institutions except academia.** Academia is the center of cross-sector collaboration and plays a key role in the life sciences and chemistry fields. Other distinct partnerships include the private sector in life sciences, chemistry, earth and space sciences, and the Federal Government in earth and space science, and physics.

- **The pattern of research cited by scientific papers is underscored by the prominence of U.S. and Western Europe research cited adjusted for their world share of literature.** The United States is the most highly cited on a regional basis and is prominent in the fields of clinical medicine, biomedical research, chemistry, earth and space science, and social and behavioral sciences. Several Western European countries, notably Switzerland, the Nordic countries, Denmark, and the Netherlands, also are highly cited based on their world share of literature.

- **Developing and emerging countries are cited with less frequency than mature science producers are, but several countries are highly cited in specific fields.** In addition, the citation of Latin American literature, adjusted for its world share of literature, has risen markedly. The United States and Western Europe are the most prominently cited by developing regions, but Latin America and sub-Saharan Africa cite each other's literature at a fairly high degree.

- **Academic patenting has continued to increase and now accounts for 5 percent of all U.S.-owned patents.** Academic patenting is more heavily concentrated in particular application areas than U.S. patenting in general, with especially heavy weight on life sciences applications.

- **Universities are increasingly taking equity positions in spinoff companies as a way of capitalizing on their intellectual property.** The number of equity licenses and options executed grew from 99 in 1995 to 272 in 1998 and 243 in 1999. The total number of new licenses and options reached almost 3,300. Gross royalties in 1999 were $641 million, more than double the 1995 amount.

- **The increase in citations of U.S. patents to research suggests the growing importance of science in practical application of technology.** Over the past two decades, the research citations of U.S. patents rose more than 10-fold, largely because of increases in the life sciences. Citations to most other fields also increased, but at a much lower rate.

- **U.S. literature is the most highly cited (on the basis of relative U.S. share of literature) in U.S. patents by both domestic and foreign inventors.** Asian literature in engineering and technology and physics also is prominently cited by Western European and U.S. inventors, respectively.

Introduction

Chapter Background

A strong national consensus supports the public funding of academic research, and although the Federal Government plays a diminishing role, it still provides close to 60 percent of the financial resources. More than half of academic research and development (R&D) funds go to the life sciences, and this share increased during the past quarter century, raising concern about whether the distribution of funds is appropriately balanced. The number of academic institutions receiving Federal support for R&D activities increased dramatically during the past several decades, expanding the base of the academic R&D enterprise. Recently, however, this number began to decline. The Federal Government plays a minor role in providing direct support to universities and colleges for construction of their research facilities. Nevertheless, the amount of academic science and engineering (S&E) research space grew continuously over the past decade. In contrast, the Federal Government accounted for almost 60 percent of direct expenditures of current funds for academic research equipment, but the percentage of total annual R&D expenditures devoted to such equipment declined noticeably during the past decade. Doctoral S&E faculty in universities and colleges play a critical role in ensuring an adequate, diverse, and well-trained supply of S&E personnel for all sectors of the economy. Until recently, positive outcomes and impacts of R&D were taken for granted; however, the system has begun to face demands that it devise means and measures to account for specific Federal R&D investments.

This chapter addresses key issues of the academic R&D enterprise, such as the importance of a Federal role in supporting academic research; the appropriate balance of funding across S&E disciplines; the breadth and strength of the academic base of the nation's S&E and R&D enterprise; the adequacy of research facilities and instrumentation at universities and colleges; the role of doctoral S&E faculty, including both their teaching and their research responsibilities; and accountability requirements, including measuring outputs and larger social outcomes.

Chapter Organization

The first section of this chapter discusses trends in the financial resources provided for academic R&D, including allocations across both academic institutions and S&E fields. Because the Federal Government has been the primary source of support for academic R&D for more than half a century, the importance of selected agencies in supporting individual fields is explored in detail. This section also presents data on changes in the number of academic institutions that receive Federal R&D support and then examines the status of two key elements of university research activities: facilities and instrumentation.

The next section discusses trends in the employment of academic doctoral scientists and engineers and examines their activities and demographic characteristics. The discussion of employment trends focuses on full-time faculty, postdoctorates, graduate students, and other positions. Differences between the nation's largest research universities and other academic institutions are considered, as are shifts in the faculty age structure. The involvement of women and underrepresented minorities, including Asians/Pacific Islanders, is also examined. Attention is given to participation in research by academic doctoral scientists and engineers, the relative balance between teaching and research, and Federal support for research. Selected demographic characteristics of recent doctorate-holders entering academic employment are reviewed.

The chapter concludes with an assessment of two research outputs: scientific and technical articles in a set of journals covered by the Science Citation Index (SCI) and the Social Science Citation Index (SSCI) and patents issued to U.S. universities. (A third major output of academic R&D, educated and trained personnel, is discussed in the preceding section of this chapter and in chapter 2). This section looks specifically at the volume of research (article counts), collaboration in the conduct of research (joint authorship), use in subsequent scientific activity (citation patterns), and use beyond science (citations to the literature on patent applications). It concludes with a discussion of academic patenting and some returns to academic institutions from their patents and licenses.

Financial Resources for Academic R&D

Academic R&D is a significant part of the national R&D enterprise.[1] Enabling U.S. academic researchers to carry out world-class research requires adequate financial support as well as excellent research facilities and high-quality research equipment. Consequently, assessing how well the academic R&D sector is doing, the challenges it faces, and how it is responding to those challenges requires data and information on a number of important issues relating to the financing of academic R&D, including:

- the level and stability of overall funding,
- the sources of funding and changes in their relative importance,
- the distribution of funding among the different R&D activities (basic research, applied research, and development),
- the balance of funding among S&E fields and subfields (or fine fields),
- the distribution of funding among various types of academic R&D performers and the extent of their participation,

[1] Federally funded research and development centers (FFRDCs) associated with universities are tallied separately and are examined in greater detail in chapter 4. FFRDCs and other national laboratories (including Federal intramural laboratories) also play an important role in academic research and education, providing research opportunities for both students and faculty at academic institutions.

- the changing role of the Federal Government as a supporter of academic R&D and the particular roles of the major Federal agencies funding this sector, and
- the state of the physical infrastructure (research facilities and equipment) that is a necessary input to the sector's success.

Individually and in combination, these issues influence the evolution of the academic R&D enterprise and therefore are the focus of this section. For a discussion of the nature of the data used in this section, see the sidebar, "Data Sources for Financial Resources for Academic R&D."

Academic R&D Within the National R&D Enterprise

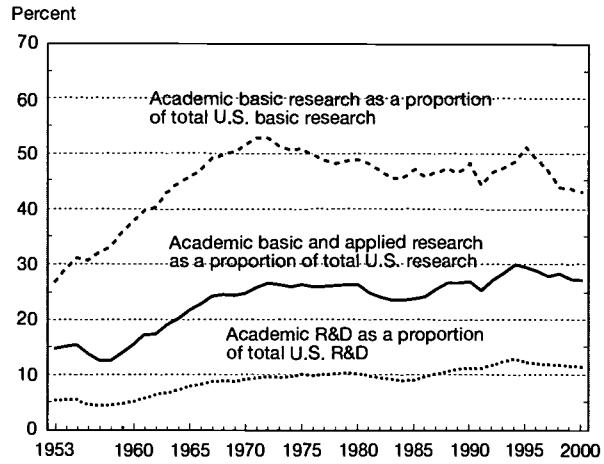
The continuing importance of academia to the nation's overall R&D effort is well accepted today.[2] This is especially true for its contribution to the generation of new knowledge through basic research. During the 1990s, academia accounted for slightly less than half of the basic research performed in the United States.

In 2000, U.S. academic institutions spent an estimated $30 billion, or $28 billion in constant 1996 dollars, on R&D.[3] This was the 26th consecutive year in which constant-dollar spending increased from the previous year. Academia's role as an R&D performer has increased steadily during the past half century, rising from about 5 percent of all R&D performed in the United States in 1953 to almost 11 percent in 2000. (See figure 5-1.) However, since 1994, the sector's performance share has dipped slightly from its high of almost 13 percent. The decline in the academic share is the result of rapid growth in industrial R&D performance. See the section "Growth" below. For a comparison with other industrial countries, see the sidebar, "Comparisons of International Academic R&D Spending."

Character of Work

Academic R&D activities are concentrated at the research (basic and applied) end of the R&D spectrum and do not include much development activity.[4] For academic R&D expenditures in 2000, an estimated 93 percent went for research (69 percent for basic and 24 percent for applied) and 7 percent for development. (See figure 5-2.) From the perspective of national research, as opposed to national R&D, academic institutions accounted for an estimated 27 percent of the U.S. total in 2000. The academic share of research almost doubled, from about 14 percent of the U.S. total in the 1950s to around 26 percent in the first half of the 1970s. (See figure 5-1.) It has since fluctuated between 23 and 30 percent. In terms of basic research alone, the academic sector is the country's largest performer, currently accounting for an estimated 43 per-

Figure 5-1.
Academic R&D, basic and applied research, and basic research as a proportion of U.S. totals: 1953–2000

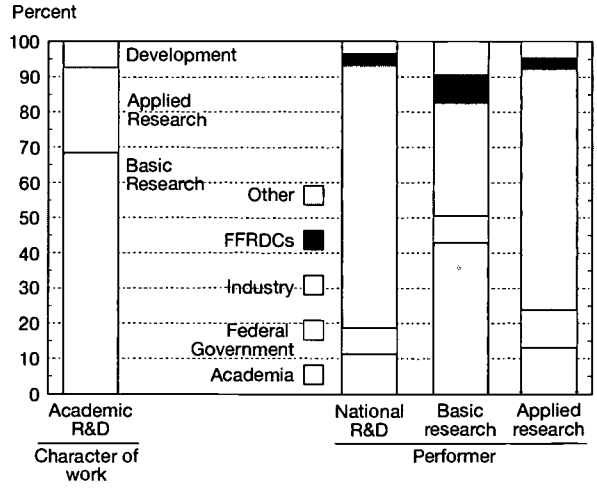


NOTE: Data for 1999 and 2000 are preliminary.

See appendix tables 4-3, 4-7, and 4-11.

Science & Engineering Indicators – 2002

Figure 5-2.
Academic R&D expenditures, by character of work, and national R&D expenditures, by performer and character of work: 2000



FFRDC = Federally Funded Research and Development Center

NOTE: Data are preliminary.

See appendix tables 4-3, 4-7, 4-11 and 5-1.

Science & Engineering Indicators – 2002

[2] For more detailed information on national R&D expenditures, see "R&D Performance in the United States" in chapter 4.

[3] For this discussion, an academic institution is generally defined as an institution that has a doctoral program in science or engineering, is a historically black college or university that expends any amount of separately budgeted R&D in S&E, or is some other institution that spends at least $150,000 for separately budgeted R&D in S&E.

[4] Despite this delineation, the term "R&D" (rather than just "research") is primarily used throughout this discussion because data collected on academic R&D often do not differentiate between research and development. Moreover, it is often difficult to make clear distinctions among basic research, applied research, and development. For the definitions used in NSF resource surveys and a fuller discussion of these concepts, see chapter 4.

Data Sources for Financial Resources for Academic R&D

The data used to describe financial resources for academic R&D are derived from several National Science Foundation (NSF) surveys and one National Center for Education Statistics (NCES) survey. These surveys use similar but not always identical definitions, and the nature of the respondents also differs across the surveys. NSF's four main surveys involving academic R&D are as follows:

1. the Survey of Federal Funds for Research and Development,
2. the Survey of Federal Science and Engineering Support to Universities, Colleges, and Nonprofit Institutions,
3. the Survey of Research and Development Expenditures at Universities and Colleges, and
4. the Survey of Scientific and Engineering Research Facilities.

The NCES survey used is the Integrated Postsecondary Education Data System (IPEDS) Finance Survey. The first two NSF surveys collect data from Federal agencies, whereas the last two NSF surveys and the NCES survey collect data directly from universities and colleges.*

Data presented in the context section, "Academic R&D Within the National Enterprise," are derived from *National Patterns of R&D Resources* (National Science Foundation (NSF) 2000), a report that aggregates NSF survey data on the various sectors of the U.S. economy so that the components of the overall R&D effort are placed in a national context. These data are reported on a calendar-year basis, and the data for 1999 and 2000 are preliminary. Data in subsequent sections are reported on an academic or fiscal-year basis and therefore differ from those reported in this section. Data on major funding sources, funding by institution type, distribution of R&D funds across academic institutions, and expenditures by field and funding source are from the Survey of Research and Development Expenditures at Universities and Colleges. For various methodological reasons, parallel data by field from the NSF Survey of Federal Funds for Research and Development do not necessarily match these numbers.

The data in the section "Emphasis on Research at Universities and Colleges" are drawn from the NCES IPEDS finance survey. Although the definition of research used in this survey is similar to that used in NSF surveys, the data collected include fields other than S&E and do not include many of the indirect costs associated with research; thus, they are not comparable with other data presented in this chapter. The IPEDS Finance Survey reports indirect costs as part of lump sums in other separate expenditure categories, such as academic support, institutional support, and operation and maintenance of plant, rather than distributing these costs to the research, instruction, and public service functions. Data for 1996 were the most recent available at the time this report was prepared. (For more information about indirect costs, see the sidebar, "Recent Developments on the Indirect Cost Front," later in this chapter.)

The data in the "Federal Support of Academic R&D" section come primarily from NSF's Survey of Federal Funds for Research and Development. This survey collects data on R&D obligations from about 30 Federal agencies. Data for fiscal year (FY) 2000 and FY 2001 are preliminary estimates. The amounts reported for FY 2000 reflect congressional appropriation action as of the third quarter of FY 2000, the period in which the last survey was conducted. Data for FY 2001 represent administration budget proposals that had not been acted on. Data on Federal obligations by S&E field are available only for FY 1999, as they are not estimated and refer only to research (basic and applied) rather than to research plus development.

The data in the section "Spreading Institutional Base of Federally Funded Academic R&D" are drawn from NSF's Survey of Federal Science and Engineering Support to Universities, Colleges, and Nonprofit Institutions. This survey collects data on Federal R&D obligations to individual U.S. universities and colleges from the approximately 18 Federal agencies that account for virtually all such obligations. For various methodological reasons, data reported in this survey do not necessarily match those reported in the Survey of Research and Development Expenditures at Universities and Colleges.

Data on facilities are taken from the Survey of Scientific and Engineering Research Facilities. Data on research equipment are taken from the Survey of Research and Development Expenditures at Universities and Colleges. Although terms are defined specifically in each survey, in general, facilities expenditures are classified as "capital" funds, are fixed items such as buildings, often cost millions of dollars, and are not included within R&D expenditures as reported here. Equipment and instruments (the terms are used interchangeably) are generally movable, purchased with current funds, and included within R&D expenditures. Because the categories are not mutually exclusive, some large instrument systems could be classified as either facilities or equipment. Expenditures on research equipment are limited to current funds and do not include expenditures for instructional equipment. Current funds, as opposed to capital funds, are those in the yearly operating budget for ongoing activities. Generally, academic institutions keep separate accounts for current and capital funds.

* For descriptions of the methodologies of the NSF surveys, see NSF 1995a and 1995b and the Division of Science Resources Statistics website: <http://www.nsf.gov/sbe/srs/stats.htm>. Information about the NCES survey is available at the NCES website: <http://www.ed.gov/NCES>.

cent of the national total. Between 1953 and 1972, the academic sector's basic research performance grew steadily, increasing from about one-quarter to slightly more than one-half of the national total. It has since fluctuated at between 43 and 51 percent of the national total.

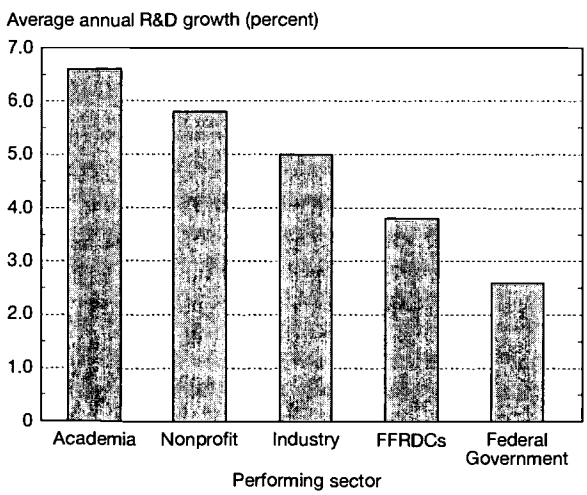
Growth

Over the course of the past half century (1953 to 2000), the average annual R&D growth rate (in constant 1996 dollars) of the academic sector has been higher than that of any other R&D-performing sector at 6.6 percent compared with about 5.8 percent for other nonprofit entities, 5.0 percent for industry, 3.8 for federally funded research and development centers (FFRDCs), and 2.6 percent for the Federal Government. (See figure 5-3 and appendix table 4-4 for time series data by R&D performing sector.) However, during the second half of the 1990s, average annual R&D growth within industry (an estimated 6.9 percent) was higher than at academic institutions (an estimated 4.1 percent). As a proportion of gross domestic product (GDP), academic R&D rose from 0.07 to 0.30 percent between 1953 and 2000, more than a fourfold increase. (See appendix table 4-1 for GDP time series.)

Major Funding Sources

The academic sector relies on a variety of funding sources for support of its R&D activities. Although the Federal Government continues to provide the majority of funds, its share has declined steadily since reaching a peak of slightly more than 73 percent in 1966. In 2000, the Federal Government accounted for an estimated 58 percent of the funding for R&D performed in academic institutions, its lowest share since the late 1950s. (See figure 5-4.) The Federal sector primarily supports basic research; 74 percent of its 2000 funding went to basic research versus 26 percent to applied R&D. (See appendix table 5-1.) Non-Federal sources also are used predominantly for basic research; 62 percent of its 2000 funding went to basic research versus 38 percent to applied R&D).

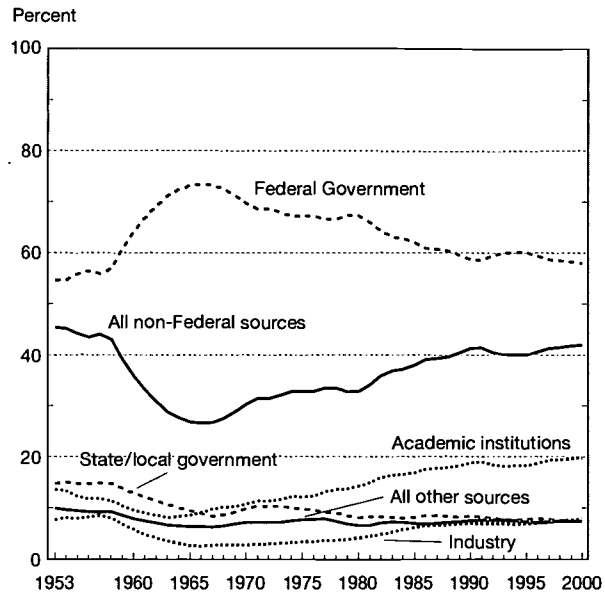
Figure 5-3.
Average annual R&D growth, by performing sector: 1953–2000



FFRDC = Federally Funded Research and Development Center

See appendix table 4-4. *Science & Engineering Indicators – 2002*

Figure 5-4.
Sources of academic R&D funding: 1953–2000



NOTE: Data for 1999 and 2000 are preliminary.

See appendix table 5-2. *Science & Engineering Indicators – 2002*

Federal support of academic R&D is discussed in detail later in this section; the following list summarizes the contributions of other sectors to academic R&D:[5]

- **Institutional funds.** In 2000, institutional funds from universities and colleges constituted the second largest source of funding for academic R&D, accounting for an estimated 20 percent, the highest level during the past half century. Institutional funds encompass three categories: separately budgeted funds from unrestricted sources that an academic institution spends on R&D, unreimbursed indirect costs associated with externally funded R&D projects, and mandatory and voluntary cost sharing on Federal and other grants. For more detailed discussions of both indirect costs and the composition of institutional funds, see the sidebars "The Composition of Institutional Academic R&D Funds" and "Recent Developments on the Indirect Cost Front."

The share of support represented by institutional funds has been increasing steadily since the early 1960s, except for a brief downturn in the early 1990s. Institutional R&D funds

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

Comparisons of International Academic R&D Spending

Countries differ in the proportion of their research and development that is performed at institutions of higher education. Among the G-7 countries (Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States) R&D performed in the academic sector, as a proportion of total R&D performance, varied between 12 percent in the United States and 25 percent in Italy. In Russia, only 5 percent of R&D was performed in academic institutions. (See text table 5-1.)

A number of factors may account for the differences in the role academia plays in the performance of R&D from country to country. The distribution of a country's R&D expenditures among basic research, applied research, and development affects the share performed by higher education. Because the academic sector primarily carries out research (generally basic) rather than development activities, countries in which development activities take greater prominence rely less on the academic sector for overall R&D performance. The importance of other sectors in R&D performance also affects the academic sector's share. Among the G-7 countries, the United States has the highest share of R&D performed by industry.* Institutional and cultural factors such as the role and extent of independent research institutions, national laboratories, and government-funded or -operated research centers, probably also affect the academic sector's share.

Finally, different accounting conventions among countries may account for some of the differences reported. The national totals for academic R&D for Europe, Canada, and Japan include the research components of general university funds (GUF) provided as block grants to the academic sector by all levels of government. Therefore, at least conceptually, the totals include academia's separately budgeted research and research undertaken as part of university departmental research activities. In the United States, the Federal Government generally does not provide research support through a GUF equivalent, preferring instead to support specific, separately budgeted R&D projects. On the other hand, a fair amount of state government funding probably does support departmental research at U.S. public universities. Universities generally do not maintain data on departmental research, which is considered an integral part of instruction programs. U.S. totals thus may be underestimated relative to the academic R&D efforts reported for other countries.

Text table 5-1.
Academic R&D as percentage of total R&D performance: 1998 or 1999

United States	12
Canada	24
France	18
Germany	17
Italy	25
Japan	15
Russia	5
United Kingdom	20

See appendix table 4-42.

Science & Engineering Indicators – 2002

*See "International R&D by Performer, Source, and Character of Work" in chapter 4 for more detailed information, including data on the sources of funding for academic R&D in different countries.

may be derived from (1) general-purpose state or local government appropriations (particularly for public institutions) or Federal appropriations; (2) general-purpose grants from industry, foundations, or other outside sources; (3) tuition and fees; (4) endowment income; and (5) unrestricted gifts. Other potential sources of institutional funds are income from patents or licenses and income from patient care revenues. See "Patents Awarded to U.S. Universities" later in this chapter for a discussion of patent and licensing income.

♦ **State and local government funds.** State and local governments provided an estimated 7 percent of academic R&D funding in 2000. They played a larger role during the early 1950s, when they provided about 15 percent of the funding. Since 1980, the state and local share of academic R&D funding has fluctuated between 7 and 8 percent. This share, however, only reflects funds directly targeted to academic R&D activities by the state and local governments. It does not include general-purpose state or local government appropriations that academic institutions designate and use for separately budgeted research or to cover unreimbursed indirect costs.[6] Consequently, the actual contribution of state and local governments to academic R&D is understated, particularly for public institutions.

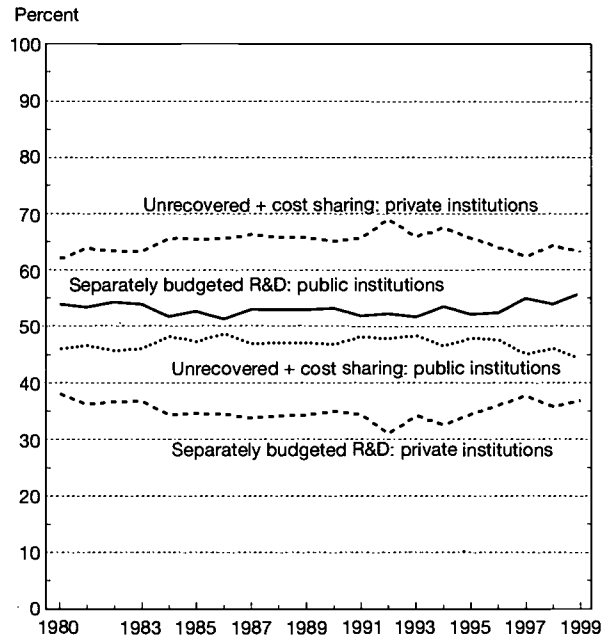
♦ **Industry funds.** In 2000, industry provided an estimated 8 percent of academic R&D funding. The funds provided for academic R&D by the industrial sector grew faster than funding from any other source during the past three decades, although industrial support still accounts for one of the smallest shares of funding. Industrial funding of academic R&D has never been a major component of industry-funded R&D. During the 1950s, industry's share was actually larger than it is currently, peaking at 8.5 percent in 1957. In 1994, industry's contribution to academic R&D represented 1.5 percent of its total support of R&D compared with 1.4 percent in 1990, 0.9 percent in 1980, 0.6 percent in 1970, and 1.1 percent in 1958. Since 1994, the share

[6] This follows a standard of reporting that assigns funds to the entity that determines how they are to be used rather than to the one that necessarily disburses the funds.

The Composition of Institutional Academic R&D Funds

During the past three decades, institutional funds for academic R&D grew faster than funds from any other sources except industry and faster than any other source during the past five years. (See appendix table 5-2.) In 2000, academic institutions are estimated to have committed a substantial amount of their own resources to R&D: roughly $6 billion, or 20 percent of total academic R&D. In 1999, the share of institutional support for academic R&D at public institutions (24 percent) was greater than at private institutions (9 percent). (See appendix table 5-3.) One possible reason for this large difference in relative support is that public universities and colleges' own funds may include considerable state and local funds not specifically designated for R&D but used for that purpose by the institutions. Throughout the 1980s and 1990s, institutional R&D funds were divided roughly equally between two components: separately budgeted institutional R&D funds and mandatory and voluntary cost sharing plus unreimbursed indirect costs associated with R&D projects financed by external organizations. Institutional funds at public and private universities and colleges differ not only in their importance to the institution but also in their composition. From 60 to 70 percent of private institutions' own funds were designated for unreimbursed indirect costs plus cost sharing compared with 44 to 50 percent of public institutions' own funds. (See figure 5-5.) For information about recent changes in indirect cost policy, see the sidebar, "Recent Developments on the Indirect Cost Front."

Figure 5-5.
Components of institutional R&D expenditures for public and private academic institutions: 1980–99



SOURCE: National Science Foundation, Division of Science Resources Statistics. Survey of Academic Research and Development Expenditures, special tabulations.

Science & Engineering Indicators – 2002

Recent Developments on the Indirect Cost Front

About three-quarters of the Federal investment in academic R&D supports the direct costs of conducting research, that is, those costs that can be directly attributed to a research project. The remainder of the investment reimburses indirect costs. These are general expenses that cannot be associated with specific research projects but pay for things that are used collectively by many research projects at an academic institution. Two major components of indirect costs exist: (1) the construction, maintenance, and operation of facilities used for research and (2) the support of administrative expenses such as financial management, institutional review boards, and environment, health, and safety management. The Office of Management and Budget (OMB) Circular A-21, the document governing indirect cost reimbursement policies, documentation, and accounting practices, refers to these costs as "facility and administrative" (F&A) costs (U.S. Office of Management and Budget (U.S. OMB) 2000). F&A rates are established through negotiations between the Federal Government and individual institutions and are then generally used to determine the F&A reimbursement.

In 1998, Congress, through the National Science Foundation Authorization Act (Public Law 105-207), directed the Office of Science and Technology Policy (OSTP) to address six issues related to the ways universities and colleges recover indirect costs incurred in performing research under Federal grants and contracts:

1. comparison of indirect cost rates across sectors,
2. distribution of rates by spending category,
3. the impact of changes in OMB Circular A-21,
4. the impact of Federal and state law on rates,
5. options to reduce or control the rate of growth of reimbursement rates, and
6. options for creating an indirect cost database.

In July 2000, OSTP produced a report addressing these issues (U.S. Office of Science and Technology Policy (U.S.

OSTP) 2000). In conducting its analyses, OSTP used input from a report that it commissioned from RAND (Goldman et al. 2000), data provided by the Council on Governmental Relations, discussions and data provided by a small group of public and private research universities, discussions with OMB and other Federal agencies, and other unpublished reports. In its analysis of the six major issues raised by Congress, OSTP concluded the following:

1. **Comparison of F&A rates across sectors.** Rates at universities and colleges appear to be slightly lower than those at other types of research institutions, such as Federal laboratories and industrial facilities.

2. **Distribution of F&A rates by spending category.** Negotiated F&A rates have remained stable at approximately 50 percent for at least a decade. The average rates for administration have declined somewhat, although rates for facilities have increased. The decline in the administrative rate can be attributed to the imposition of the administrative cap in 1991; however, the F&A rate often is not an accurate reflection of an institution's actual recovery. (See item 4 below.)

3. **Impact of changes in OMB Circular A-21.** During the 1990s, OMB implemented a number of changes in Circular A-21 to limit the payment of certain costs, to provide clarification for consistent treatment of other costs, and to simplify some administrative procedures. During 1993, the first full year of the 26 percent administrative cap, negotiated administrative rates fell by about 2 percent and have since remained constant. Depreciation/use allowance rates for buildings and equipment have increased gradually from 6 percent in 1988 to approximately 9 percent in 1999, although some of the increase has been offset by reductions in operations and maintenance rates.

4. **Impact of Federal and state laws on F&A rates.** Some Federal statutes and agency policies may limit the amount a university can recover. Moreover, state policies and internal institutional policies may also limit F&A recovery. In addition to the administrative requirements mandated by OMB circulars, universities must also satisfy other Federal, state, and local laws and regulations regarding the conduct of research. These laws and regulations govern practices in many areas, including hazardous waste, occupational safety, animal care, and the protection of human subjects and are associated with real administrative costs that most likely will affect F&A rates for universities that are below the 26 percent cap on administrative costs. Universities whose administrative expenses are already at or above the 26 percent cap may need to provide additional institutional resources for their research activities. See the previous sidebar, "The Composition of Institutional Academic R&D Funds," for further discussion of unreimbursed indirect costs.

5. **Options to reduce or control the rate of growth of Federal F&A reimbursement rates.** If changes were implemented to reduce F&A reimbursement, the resulting shift of costs to universities would be detrimental to the research enterprise by either reducing spending for research and education or being passed on to students through increased tuition rates. In addition, any enactment of the mechanisms to decrease indirect cost recovery that are discussed in the report could result in reduced investments in building and renovating scientific facilities, thus jeopardizing future research capability and the S&E workforce. For the specific options discussed to reduce F&A costs, see U.S. OSTP 2000, appendix B.

6. **Options for creating an F&A database.** Some existing databases capture some F&A data. However, no systematic method by which the Federal Government collects data on F&A rates and costs exists. Therefore, it would be advantageous to create and maintain a database for Federal research F&A data that could track Federal indirect cost rates and reimbursement. Such a database would permit analysis of the impact that changes in policies would have on indirect costs and on the Federal Government, researchers, and research institutions. Creating such a database would require an organization within the government to take responsibility for collecting and analyzing these data. A revision to Circular A-21 in August 2000, required institutions to use a standard format for F&A rate proposals submitted on or after July 1, 2001. Adoption of this standard format might prove useful in facilitating the future development of an F&A database.

In early 2001, OMB issued a memorandum clarifying its treatment of two indirect cost issues—voluntary uncommitted cost sharing and tuition remission costs. For a detailed discussion of the changes, see Gotbaum 2001. Most faculty-organized research effort is either charged directly to the sponsor or is considered mandatory or voluntary cost sharing and captured in the accounting system. Voluntary uncommitted cost sharing, university faculty effort over and above that which is committed and budgeted for in a sponsored agreement, is not generally captured in the accounting system. Some Federal Government officials have interpreted Circular A-21 to require that a proportionate share of F&A costs be assigned to the voluntary uncommitted cost sharing effort either by including an estimated amount in the organized research base (thereby lowering the F&A reimbursement rate) or by adjusting the allocation of facility costs related to this

effort (thereby lowering the facility costs eligible for reimbursement). The burden associated with detailed reporting of voluntary uncommitted cost sharing may be a disincentive for universities to contribute additional time to a research effort. In addition, the imprecise nature of the data concerning the amount of involuntary uncommitted cost sharing has made it difficult to compute and use as part of rate negotiations between the Federal Government and universities. Consequently, the memorandum stated that "voluntary uncommitted cost sharing should be treated differently from committed effort and should not be included in the organized research base for calculating the F&A rate or reflected in any allocation of F&A costs" (Gotbaum 2001).

Circular A-21 states that "the dual role of students engaged in research and the resulting benefits to sponsored agreements are fundamental to the research effort and shall be recognized in the application of these principles." It further states that "tuition remission costs for students are allowable on sponsored awards provided that there is a bona fide employer-employee relationship between the student and the institution." This last statement has been interpreted by some government officials to mean that, for tuition remission costs to be allowable, students must be treated as employees of the university for tax purposes, which would mean that the students' tuition remission benefits must be treated as taxable wages. This misunderstanding generated a considerable amount of concern from universities and Federal research agencies. The OMB memorandum clarified this by indicating that Federal policy on the support of graduate students participating in research is to provide a reasonable amount of support (tuition remission and other support) on the basis of the individual's participation in the project and is not contingent on there being an employer-employee relationship for tax purposes.

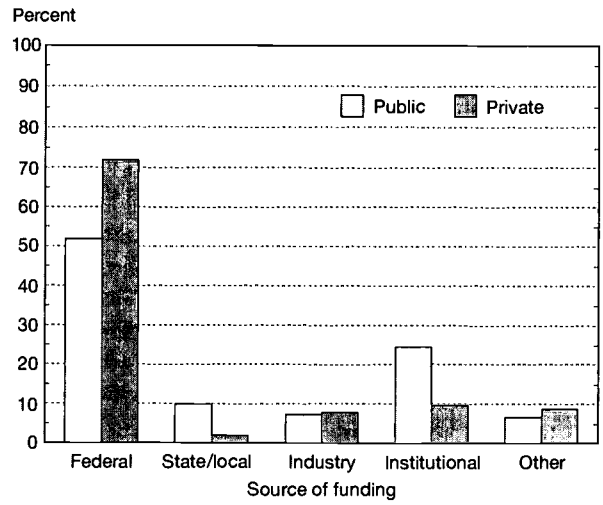
has steadily declined from 1.5 to 1.2 percent. (See appendix table 4-4 for time series data on industry-funded R&D.)

- **Other sources of funds.** In 2000, other sources of support accounted for 7 percent of academic R&D funding, a level that has stayed rather constant during the past three decades after declining from a peak of 10 percent in 1953. This category of funds includes grants for R&D from nonprofit organizations and voluntary health agencies and gifts from private individuals that are restricted by the donor to the conduct of research, as well as all other sources restricted to research purposes not included in the other categories.

Funding by Institution Type

Although public and private universities rely on the same funding sources for their academic R&D, the relative importance of those sources differs substantially for these two types of institutions. (See figure 5-6 and appendix table 5-3.) For all *public* academic institutions combined, slightly less than 10 percent of R&D funding in 1999, the most recent year for which data are available, came from state and local funds, about 24 percent from institutional funds, and about 52 percent from the Federal Government. *Private* academic institutions received a much smaller portion of their funds from state and local governments (about 2 percent) and institutional sources (10 percent), and a much larger share from the Federal Government (72 percent). The large difference in the role of institutional funds at public and private institutions is most likely due to a substantial amount of general-purpose state and local government funds that public institutions receive and decide to use for R&D (although data on such breakdowns are not collected). Both public and private institutions received approximately 7–8 percent of their respective R&D support from industry in 1999. Over the past two decades, the Federal share of support has declined, and the industry and institutional shares have increased for both public and private institutions.

Figure 5-6.
Sources of academic R&D funding for public and private institutions: 1999



See appendix table 5-3. *Science & Engineering Indicators – 2002*

Distribution of R&D Funds Across Academic Institutions

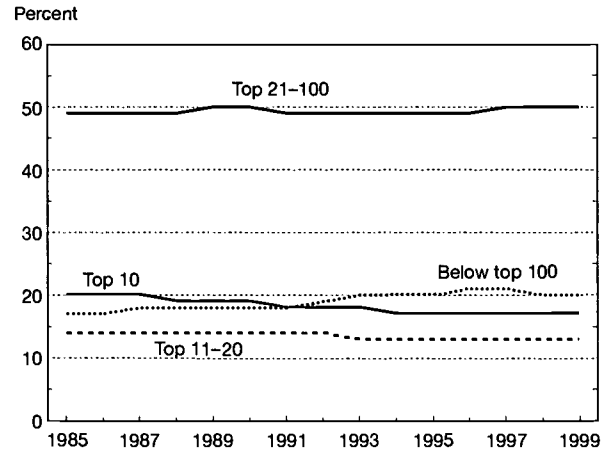
The nature of the distribution of R&D funds across academic institutions has been and continues to be a matter of interest to those concerned with the academic R&D enterprise. Most academic R&D is now, and has been historically, concentrated in relatively few of the 3,600 U.S. institutions

of higher education.[7] In fact, if all such institutions were ranked by their 1999 R&D expenditures, the top 200 institutions would account for about 96 percent of R&D expenditures. (See appendix table 5-4.) In 1999:

- the top 10 institutions spent 17 percent of total academic R&D funds ($4.6 billion),
- the top 20 institutions spent 30 percent ($8.3 billion),
- the top 50 spent 57 percent ($15.6 billion), and
- the top 100 spent 80 percent ($22.1 billion).

The historic concentration of academic R&D funds diminished somewhat between the mid-1980s and mid-1990s but has remained relatively steady since then. (See figure 5-7.) In 1985, the top 10 institutions received about 20 percent of the nation's total academic R&D expenditures and the top 11–20 institutions received 14 percent compared with 17 and 13 percent, respectively, in 1999. The composition of the universities in the top 20 has also fluctuated slightly from 1985 to 1999. There was almost no change in the share of the group of institutions ranked 21–100 during this period. The decline in the top 20 institutions' share was matched by the increase in the share of those institutions in the group below the top 100. This group's share increased from 17 to 20 percent of total academic R&D funds, signifying a broadening of the base. See "Spreading Institutional Base of Federally Funded Academic R&D" later in this chapter, under the section "Federal Support of Academic R&D," for a discussion of the increased number of academic institutions receiving Federal support for their R&D activities during the past three decades.

Figure 5-7.
Share of academic R&D of universities and colleges by rank of R&D expenditures: 1985–99



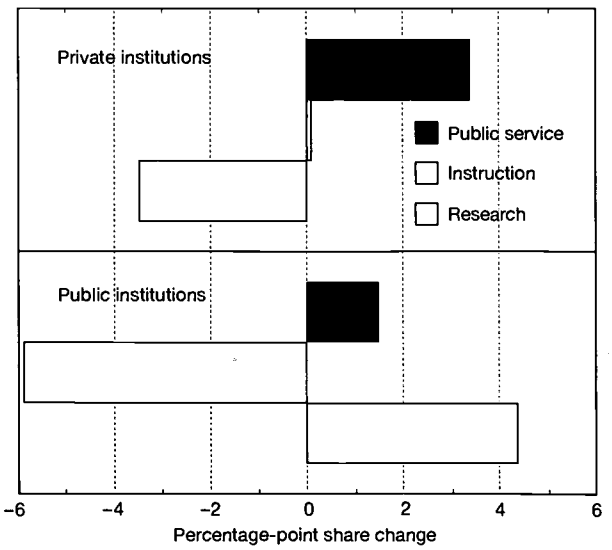
See appendix table 5-4. *Science & Engineering Indicators – 2002*

Emphasis on Research at Universities and Colleges

Between 1977 and 1996, the nation's universities and colleges increased their relative emphasis on research, as measured by research expenditures as a share of combined expenditures on instruction, research, and public service,[8] which are the three primary functions of academic institutions. This indicator rose from 19 to 21 percent during this period. This aggregate change, however, masks quite different trends at public and private institutions and among institutions with different Carnegie classifications. At public universities and colleges, the research expenditure share rose from 17 to 21 percent during this period, whereas at private institutions this share declined from 24 to 21 percent. (See figure 5-8 and appendix table 5-5.) The increased relative emphasis on research activity at public institutions was offset by a decline in emphasis on instruction. At private institutions, the declining relative emphasis on research was not offset by increased emphasis on instruction but by an increased emphasis on public service.

Although the increased emphasis on research in public institutions occurred in each of the four groups of institutions in Carnegie classes Research I and II and Doctorate-granting I and II, and the declining emphasis in research at private

Figure 5-8.
Changes in share of combined expenditures accounted for by research, instruction, and public service at public and private institutions: 1977–96



See appendix table 5-5. *Science & Engineering Indicators – 2002*

[7] The Carnegie Foundation for the Advancement of Teaching classified about 3,600 degree-granting institutions as higher education institutions in 1994. See chapter 2 sidebar, "Carnegie Classification of Academic Institutions," for a brief description of the Carnegie categories. These higher education institutions include four-year colleges and universities, two-year community and junior colleges, and specialized schools such as medical and law schools. Not included in this classification scheme are more than 7,000 other postsecondary institutions (secretarial schools, auto repair schools, etc.).

[8] *Public service* includes funds expended for activities that are established primarily to provide noninstructional services beneficial to individuals and groups external to the institution. These activities include community service programs and cooperative extension services.

institutions occurred in all four of these Carnegie classes, the extent of change was more substantial in some groups than in others. (See figure 5-9 and appendix table 5-6.) The increase in research emphasis in the public Doctorate-granting I group (6 to 13 percent) and the public Doctorate-granting II group (16 to 25 percent) were much larger than for the other two public groups. The decline for the private Research I class (42 to 36 percent) and the private Doctorate-granting II group (18 to 14 percent) were larger than for the other two groups.

Expenditures by Field and Funding Source

The distribution of academic R&D funds across S&E disciplines often is the unplanned result of numerous, sometimes unrelated, decisions and therefore needs to be monitored and documented to ensure that it remains appropriately balanced. The overwhelming share of academic R&D expenditures in 1999 went to the life sciences, which accounted for 57 percent of total academic R&D expenditures, 56 percent of Federal academic R&D expenditures, and 58 percent of non-Federal academic R&D expenditures. (See appendix table 5-7.) Within the life sciences, the medical sciences accounted for 29 percent of total academic R&D expenditures and the biological sciences for 18 percent.[9] The next largest block of total academic R&D expenditures was for engineering—15 percent in 1999. The distribution of Federal and non-Federal funding of academic R&D in 1999 varied by field. (See appendix table 5-7.) For example, the Federal Government supported more than three-quarters of academic R&D expenditures in both physics and atmospheric sciences but one-third or less of academic R&D in economics, political science, and the agricultural sciences.

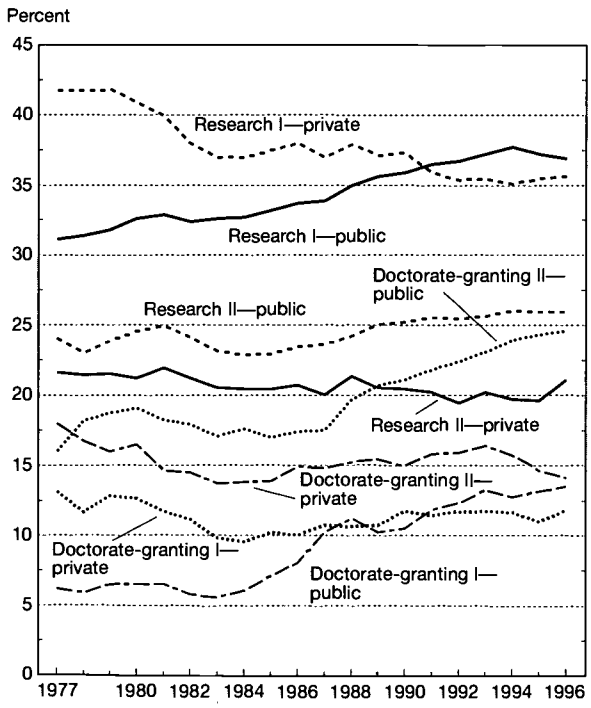
The declining Federal share in support of academic R&D is not limited to particular S&E disciplines. The federally financed fraction of support for *each* of the broad S&E fields was lower in 1999 than in 1973.[10] (See appendix table 5-8.) The most dramatic decline occurred in the social sciences, down from 57 percent in 1973 to 37 percent in 1999. The overall decline in Federal share also holds for all the reported fine S&E fields. However, most of the declines occurred in the 1980s, and most fields did not experience declining Federal shares during the 1990s.

Although academic R&D expenditures in constant 1996 dollars for every field increased between 1973 and 1999 (see figure 5-10 and appendix table 5-9), the R&D emphasis of

[9]The medical sciences include fields such as pharmacy, veterinary medicine, anesthesiology, and pediatrics. The biological sciences include fields such as microbiology, genetics, biometrics, and ecology. These distinctions may be blurred at times, because boundaries between fields often are not well defined.

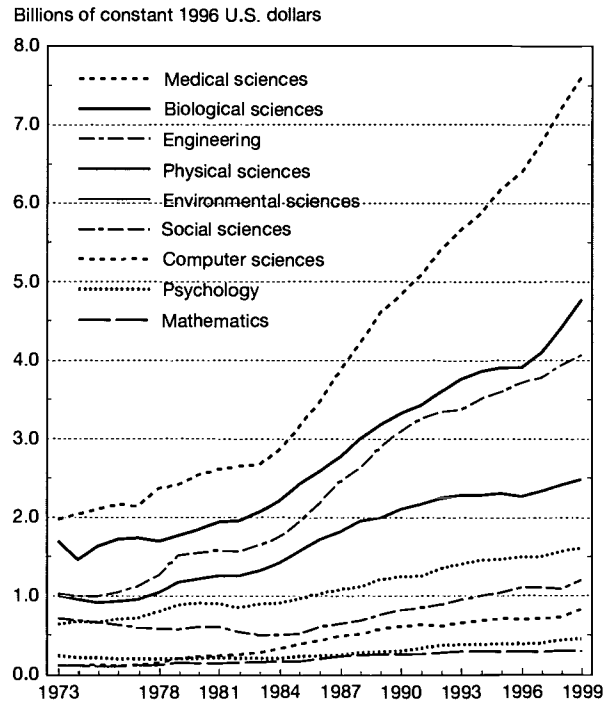
[10]In this chapter, the broad S&E fields refer to the physical sciences, mathematics, computer sciences, environmental sciences (earth, atmospheric, and ocean), life sciences, psychology, social sciences, other sciences (not elsewhere classified), and engineering. The more disaggregated fields of science and engineering are referred to as "fine fields" or "subfields."

Figure 5-9.
Research as percentage of the total of instruction, research, and public service expenditures, by Carnegie class and type of control: 1977–96



See appendix table 5-6. *Science & Engineering Indicators – 2002*

Figure 5-10.
Academic R&D expenditures, by field: 1973–99



NOTE: See appendix table 4-1 for GDP implicit price deflators used to convert current dollars to constant 1996 dollars.

See appendix table 5-9. *Science & Engineering Indicators – 2002*

the academic sector, as measured by its S&E field shares, changed during this period.[11] (See figure 5-11.) Absolute shares of academic R&D have:

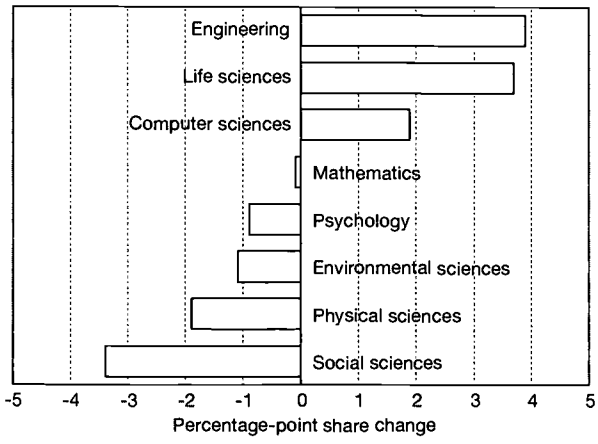
- increased for engineering, the life sciences, and the computer sciences;
- remained roughly constant for mathematics; and
- declined for psychology, environmental (earth, atmospheric, and ocean) sciences, physical sciences, and social sciences.

Although the proportion of the total academic R&D funds going to the life sciences increased by only 4 percentage points between 1973 and 1999, rising from 53 to 57 percent of academic R&D, the medical sciences' share increased by almost 7 percentage points, from 22 to 29 percent of academic R&D, during this period. (See appendix table 5-9.) The share of funds for each of the other two major components of the life sciences, agricultural sciences and biological sciences, decreased during the period. Engineering's share increased by almost 4 percentage points, from about 11.5 to 15.5 percent of academic R&D, while computer sciences' share increased by 2 percentage points, from 1 to 3 percent.

The social sciences' proportion of total academic R&D funds declined by more than 3 percentage points (from 8 to less than 5 percent) between 1973 and 1999. Within the social sciences, R&D shares for each of the three main fields, economics, political science, and sociology, declined over the period. Psychology's share declined by 1 percentage point (from 3 to 2 percent of academic R&D). The environmental sciences' share also declined by 1 percentage point (from 7 to 6 percent). Within the environmental sciences, the three major fields; atmospheric, earth, and ocean sciences, each experienced a decline in share. The physical sciences' share also declined during this period, from 11 to 9 percent. Within the physical sciences, however, astronomy's share increased, while the shares of both physics and chemistry declined.

[11]For a more detailed discussion of these changes, see *How Has the Field Mix of Academic R&D Changed?* (NSF 1998) and *Trends in Federal Support of Research and Graduate Education* (National Academies Board on Science, Technology and Economic Policy, forthcoming).

Figure 5-11.
Changes in share of academic R&D in selected S&E fields: 1973–99



See appendix table 5-9. *Science & Engineering Indicators – 2002*

Federal Support of Academic R&D

The Federal Government continues to provide the majority of the funding for academic R&D. Its overall contribution is the combined result of a complex set of Executive and Legislative branch decisions to fund a number of key R&D-supporting agencies with differing missions.

Some of the Federal R&D funds obligated to universities and colleges are the result of appropriations that Congress directs Federal agencies to award to projects that involve specific institutions. These funds are known as congressional earmarks. (See sidebar, "Congressional Earmarking to Universities and Colleges" for a discussion of this subject.) Examining and documenting the funding patterns of the key funding agencies is key to understanding both their roles and that of the government overall.

Top Agency Supporters

Three agencies are responsible for most of the Federal obligations for academic R&D are concentrated in three agencies: the National Institutes of Health (NIH), NSF, and the Department of Defense (DOD). (See appendix table 5-10.) Together, these agencies are estimated to have provided approximately 84 percent of total Federal financing of academic R&D in 2001: 60 percent by NIH, 15 percent by NSF, and 9 percent by DOD. An additional 11 percent of the 2001 obligations for academic R&D are estimated to be provided by the National Aeronautics and Space Administration (NASA) at 4 percent; the Department of Energy (DOE) at 4 percent; and the Department of Agriculture (USDA) at 3 percent. Federal obligations for academic research are concentrated similarly as those for R&D. (See appendix table 5-11.) Some differences exist, however, because some agencies (e.g., DOD) place greater emphasis on development, whereas others (e.g., NSF) place greater emphasis on research.

Between 1990 and 2001, NIH's funding of academic R&D increased most rapidly, with an estimated average annual growth rate of 4.9 percent per year in constant 1996 dollars. NSF and NASA experienced the next highest rates of growth: 4.2 and 3.1 percent, respectively.

Agency Support by Field

Federal agencies emphasize different S&E fields in their funding of academic research. Several agencies concentrate their funding in one field; the Department of Health and Human Services (HHS) and USDA focus on life sciences, whereas DOE concentrates on physical sciences. Other agen-

Congressional Earmarking to Universities and Colleges

Academic earmarking, the congressional practice of providing Federal funds to educational institutions for research facilities or projects without merit-based peer review, exceeded the billion-dollar mark for the first time ever in fiscal year (FY) 2000 and reached almost $1.7 billion in FY 2001.*

The lack of an accepted definition of academic earmarking, combined with the difficulty of detecting many earmarked projects because they are either obscured or described vaguely in the legislation providing the funding, often makes it difficult to obtain exact figures for either the amount of funds or the number of projects specifically earmarked for universities and colleges. Even with these difficulties, however, a number of efforts have been undertaken during the past two decades to measure the extent of this activity.†

A report from the Committee on Science, Space, and Technology (U.S. House of Representatives 1993) that estimates trends in congressional earmarking indicated that the dollar amount of such earmarks increased from the tens to the hundreds of millions between 1980 and the early 1990s, reaching $708 million in 1992. (See text table 5-2.) In the report, the late Congressman George E. Brown, Jr., (D-CA) stated, "I believe that the rational, fair, and equitable allocation and oversight of funds in support of the nation's research and development enterprise is threatened by the continued increase in academic earmarks. To put it colloquially, a little may be okay, but too much is too much."

During the past decade, the *Chronicle of Higher Education* also tried to estimate trends in academic earmarking through its annual survey of Federal spending laws and the congressional reports that explain them. The *Chronicle's* latest analysis showed that after reaching a peak of $763 million in 1993, earmarked funds declined rather substantially over the next several years, reaching a low of $296 million in FY 1996. After 1996, however, earmarks began to increase once again, and this growth continued throughout the latter part of the 1990s. Congress directed Federal agencies to award at least $1.044 billion for such projects in FY 2000, a 31 percent rise over FY 1999's record total of $797 million (Brainard and Southwick 2000), and $1.668 billion in FY 2001, a 60 percent rise over FY 2000 (Brainard and Southwick 2001). A record number of new institutions received earmarks in FY 2000, and money was provided for institutions in every state except Delaware. Also, for the first time, Congress earmarked funds to a virtual university. Helping to drive the large increase in FY 2000 was a sharp rise in earmarks for construction projects, with more than $152 million being spent on brick-and-mortar projects on campuses, more than double the amount spent in FY 1999.

Text table 5-2.
Funds for Congressionally earmarked academic research projects: 1980–2001
(Millions of dollars)

Year	Earmarked funds	Year	Earmarked funds
1980	11	1991	470
1981	0	1992	708
1982	9	1993	763
1983	77	1994	651
1984	39	1995	600
1985	104	1996	296
1986	111	1997	440
1987	163	1998	528
1988	232	1999	797
1989	299	2000	1,044
1990	248	2001	1,668

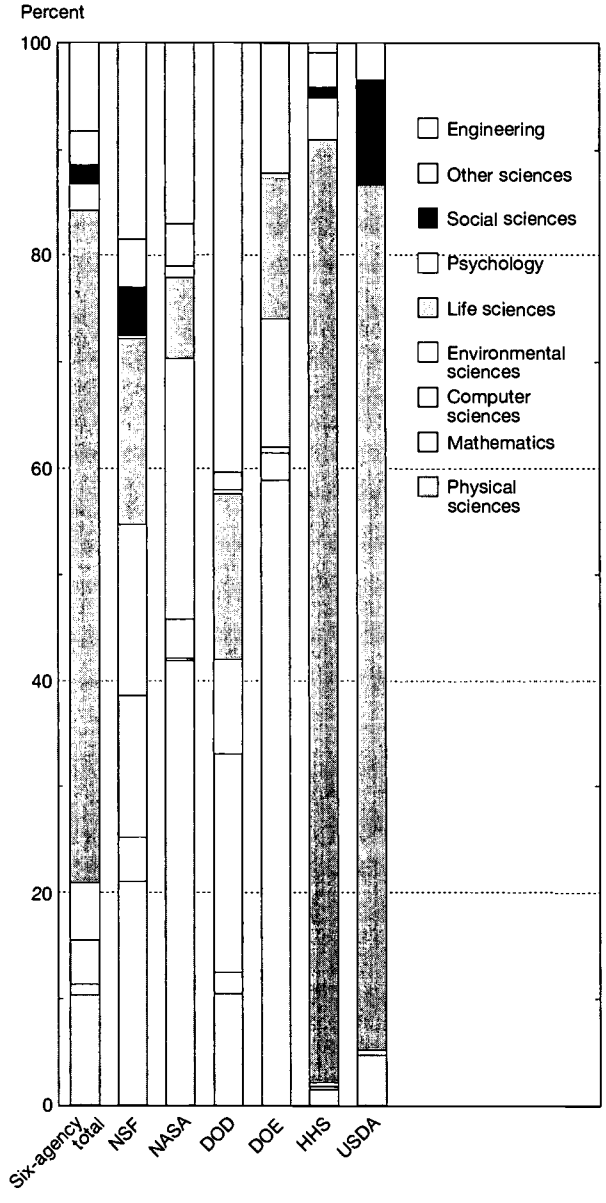
SOURCES: Data for 1980–92 are from the U.S. House of Representatives, Committee on Science, Space, and Technology, 1993; "Academic Earmarks: An Interim Report by the Chairman of the Committee on Science, Space, and Technology" (Washington, DC); data from 1993–2000 are from J. Brainard and R. Southwick, "Congress Gives Colleges a Billion-Dollar Bonanza in Earmarked Projects" (*The Chronicle of Higher Education*, Volume 46, July 28, 2000, p. A29); and data from 2001 are from J. Brainard and R. Southwick, "A Record Year at the Federal Trough: Colleges Feast on $1.67 Billion in Earmarks" (*The Chronicle of Higher Education*, Volume 47, August 10, 2001, p. A20).

Science & Engineering Indicators – 2002

* Not all of these funds go to projects that involve research. In FY 2001, an estimated 84 percent of the earmarked funds were for research projects, research equipment, or construction or renovation of research laboratories.

† In its FY 2001 budget submission to Congress (OMB 2001), OMB included a new category of Federal funding for research: research performed at congressional direction. This consists of intramural and extramural research in which funded activities are awarded to a single performer or collection of performers. There is limited or no competitive selection, or there is competitive selection but the research is outside the agency's primary mission, and undertaking the research is based on direction from the Congress in law, in report language, or by other direction. The total reported for this activity is $2.2 billion. The data are not disaggregated by type of performer.

Figure 5-12.
Distribution of Federal agency academic research obligations, by field: FY 1999

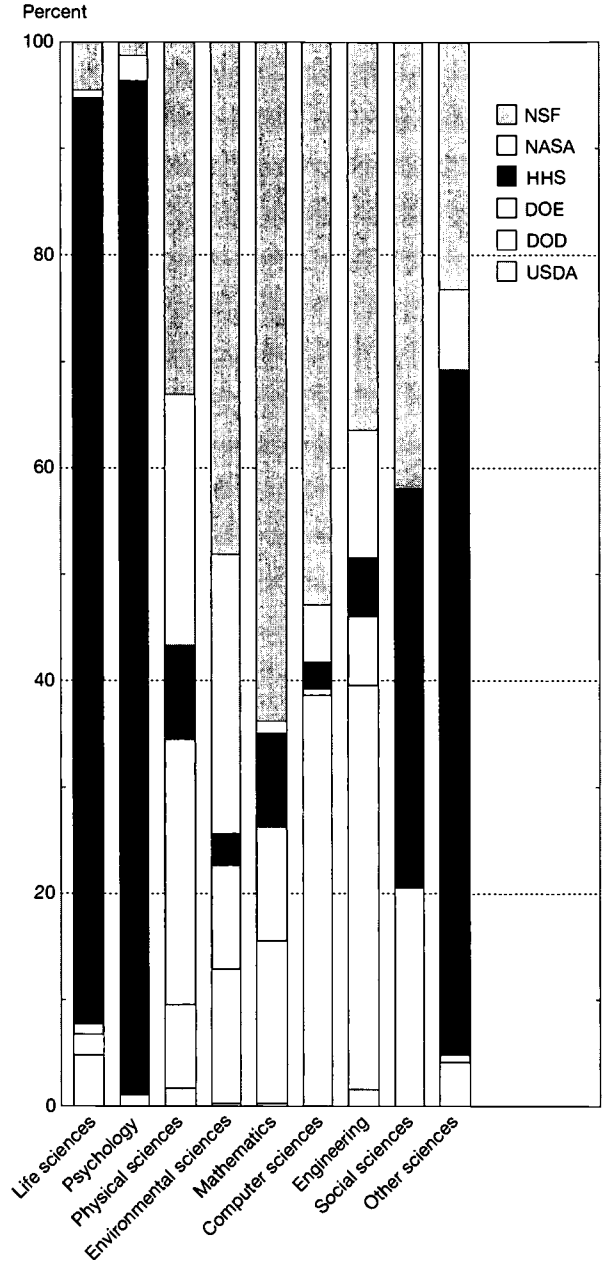


NSF = National Science Foundation; NASA = National Aeronautics and Space Administration; DOD = Department of Defense; DOE = Department of Energy; HHS = Department of Health and Human Services; USDA = Department of Agriculture

NOTE: Agencies reported represent approximately 97 percent of Federal academic research obligations.

See appendix table 5-12. *Science & Engineering Indicators – 2002*

Figure 5-13.
Major agency field shares of Federal academic research obligations: FY 1999



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

NOTE: Agencies reported represent approximately 97 percent of Federal academic research obligations.

See appendix table 5-13. *Science & Engineering Indicators – 2002*

cies, NSF, NASA, and DOD, have more diversified funding patterns. (See figure 5-12 and appendix table 5-12.) Even though an agency may place a large share of its funds in one field, it may not be a leading contributor to that field, particularly if it does not spend much on academic research. (See figure 5-13.) In FY 1999, NSF was the lead funding agency in physical sciences (33 percent of total funding), mathematics (64 percent), computer sciences (53 percent), environmental sciences (48 percent), and social sciences (42 percent). DOD was the lead funding agency in engineering (38 percent). HHS was the lead funding agency in life sciences (87 percent) and psychology (95 percent). Within the fine S&E

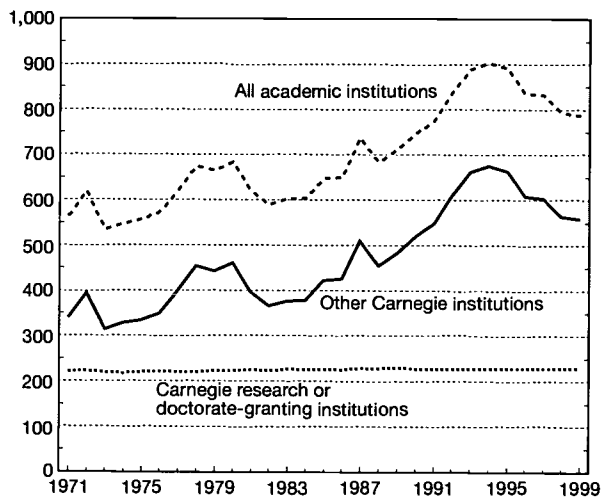
fields, other agencies took the leading role: DOE in physics (44 percent), USDA in agricultural sciences (100 percent), and NASA in astronomy (78 percent) and both aeronautical (55 percent) and astronautical (97 percent) engineering. (See appendix table 5-13.)

Spreading Institutional Base of Federally Funded Academic R&D

Since 1994, the number of academic institutions receiving Federal support for their R&D activities has declined. This decline followed a 20-year period in which there was a general upward trend in the number of institutions receiving such support.[12] (See figure 5-14.) The change in number has occurred almost exclusively among institutions of higher education not classified as Carnegie research or doctorate-granting institutions but in those classified as comprehensive; liberal arts; two-year community, junior, and technical; or professional and other specialized schools. The number of such institutions receiving Federal support nearly doubled between 1971 and 1994, rising from 341 to 676, but then dropped to only 559 in 1999. (See appendix table 5-14.) The institutions that were not classified as Carnegie research or doctorate-granting institutions also received a larger share of the reported Federal obligations for R&D to universities and colleges in the 1990s than they have at any time in the past. Their share even continued to increase during the latter part of the 1990s, reaching almost 14 percent in 1999. The largest percentage this group had received before the 1990s was just under 11 percent in 1977. This increase in share is consistent with the increase in the share of academic R&D going to institutions below the top 100 reported earlier in this chapter in "Distribution of R&D Funds Across Academic Institutions."

[12]Although there was a general increase in the number of institutions receiving Federal R&D support between 1974 and 1994, a rather large decline occurred in the early 1980s that was most likely due to the fall in Federal R&D funding for the social sciences during that period.

Figure 5-14.
Number of academic institutions receiving Federal R&D support by selected Carnegie classifications: 1971–99



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

See appendix table 5-14. *Science & Engineering Indicators – 2002*

Academic R&D Facilities and Equipment

The condition of the physical infrastructure for academic R&D, especially the state of research facilities and equipment, is a key factor in the continued success of the U.S. academic R&D enterprise. The National Science Board's (NSB's) concern that the quality and adequacy of the S&E infrastructure are critical to maintaining U.S. leadership in S&E research and education recently led it to establish a task force to examine this issue. (See sidebar, "The NSB Task Force on S&E Infrastructure.")

Facilities

Total Space. The amount of academic S&E research space[13] grew continuously over the past decade. Between 1988 and 1999, total academic S&E research space increased by almost 35 percent, from about 112 million to 151 million net assignable square feet (NASF).[14] (See appendix table 5-15.) Doctorate-granting institutions accounted for most of the growth in research space over this period.

Little change was noted in the distribution of academic research space across S&E fields between 1988 and 1999. (See appendix table 5-15.) About 90 percent of current academic research space continues to be concentrated in six S&E fields:

- biological sciences (21 percent in 1988 and 1999),
- medical sciences (17 percent in 1988 and 18 percent in 1999),
- agricultural sciences (16 percent in 1988 and 17 percent in 1999),
- engineering (14 percent in 1988 and 17 percent in 1999),
- physical sciences (14 percent in 1988 and 13 percent in 1999), and
- environmental sciences (5 percent in 1988 and 1999).

New Construction. Between 1986–87 and 1998–99, the total anticipated cost for completion of new construction projects for academic research facilities begun in each two-year period fluctuated between $2 and $3 billion. (See appendix table 5-16.) Projects planned for 2000 and 2001, however, are expected to cost $7.4 billion by the time they are completed, and those begun in 1998 and 1999 are expected to cost $2.8 billion (reported in 1999 survey). Earlier in the planning

[13] For more detailed data and analysis on academic S&E research facilities (e.g., by institution type and control), see NSF (2001d,e).

[14] "Research space" here refers to NASF within facilities (buildings) in which S&E research activities take place. NASF is defined as the sum of all areas (in square feet) on all floors of a building assigned to, or available to be assigned to, an occupant for a specific use, such as instruction or research. Multipurpose space within facilities (e.g., an office) is prorated to reflect the proportion of use devoted to research activities. NASF data for new construction and repair/renovation are reported for combined years (e.g., 1987–88 data are for FY 1987 and FY 1988). NASF data on total space are reported at the time of the survey and were not collected in 1986.

stage, however, projects expected to begin in 1998 and 1999 were expected to cost $3.9 billion (reported in the previous S&E Facilities survey). Construction projects initiated between 1986 and 1999 were expected to produce more than 72 million square feet of research space when completed, the equivalent of about 48 percent of estimated 1999 research space. A significant portion of newly created research space is likely to replace obsolete or inadequate space rather than actually increase existing space, indicated by the total research space increase of 39 million NASF between 1988–89 and 1999, a period in which new construction activity was expected to produce 62 million NASF. (See appendix table 5-15.)

The ratio of planned new construction during the 1986–99 period to 1999 research space differs across S&E fields. More than three-quarters of the research space in medical sciences at medical schools and in computer sciences appears to have been built in the 1986–99 period. In contrast, less than one-quarter of the research space for mathematics and psychology appears to have been newly constructed during this period. (See figure 5-15.)

Repair and Renovation. The total cost of repair/renovation projects has also fluctuated over time. Expenditures for major repair/renovation (i.e., projects costing more than $100,000) of academic research facilities begun in 1998–99 are expected to reach $1.7 billion. (See appendix table 5-16.) Projects initiated between 1986 and 1999 were expected to result in the repair/renovation of more than 87 million square feet of research space.[15] (See appendix table 5-15.) Repair/renovation expenditures as a proportion of total capital expenditures (construction and repair/renovation) have increased

[15] It is difficult to report repaired/renovated space in terms of a percentage of existing research space. As collected, the data do not differentiate between repair and renovation, nor do they provide an actual count of unique square footage that has been repaired or renovated. Thus, any proportional presentation might include double or triple counts, because the same space could be repaired (especially) or renovated several times.

The NSB Task Force on S&E Infrastructure

The National Science Board is responsible for monitoring the health of the national research and education enterprise. Within the past year, NSB determined that the status of the national infrastructure for fundamental science and engineering should be assessed to ensure its future quality and availability to the broad S&E community. The Board believed that the S&E infrastructure had grown and changed and that the needs of the S&E community had evolved since the last major assessments were conducted more than a decade ago. Several trends contributed to the need for a new assessment, including:

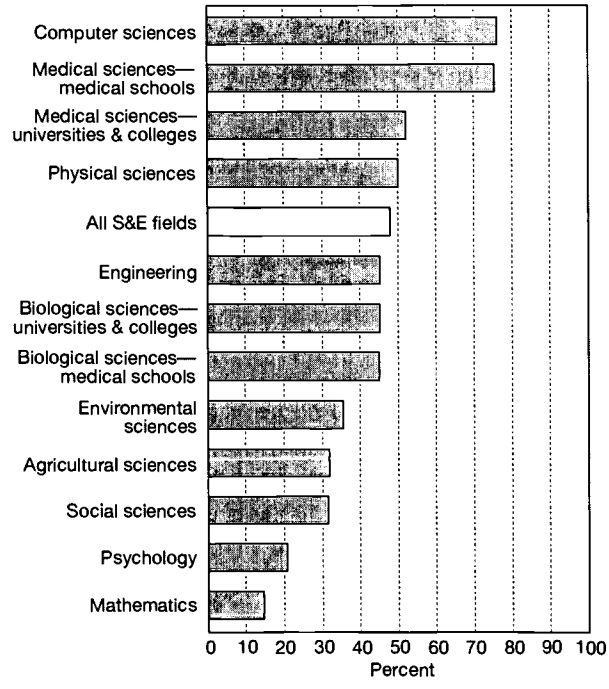
- the impact of new technologies on research facilities and equipment;
- changing infrastructure needs in the context of new discoveries, intellectual challenges, and opportunities;
- the impact of new tools and capabilities such as information technology and large databases;
- the rapidly escalating cost of research facilities;
- changes in the university environment affecting support for S&E infrastructure development and operation; and
- the need for new strategies for partnering and collaboration.

An NSB Task Force on S&E Infrastructure was established to undertake and guide the assessment. The task force was asked to assess the current status of the national S&E infrastructure, the changing needs of science and engineering, and the requirements for a capability of appropriate quality and size to ensure continuing U.S. leadership. Among the specific issues the task force was asked to consider were the following:

- appropriate strategies for sharing infrastructure costs for both development and operations among different sectors, communities, and nations;
- partnering and use arrangements conducive to ensuring the most effective use of limited resources and the advancement of discovery;
- the balance between maintaining the quality of existing facilities and the creation of new ones; and
- the process for establishing priorities for investment in infrastructure across fields, sectors, and Federal agencies.

Further information about the work of the task force can be found on the Board's website at <http://www.nsf.gov/nsb/>.

Figure 5-15.
New construction of research space planned during the 1986–99 period as a percentage of 1999 research space, by S&E field



See appendix table 5-15. *Science & Engineering Indicators – 2002*

steadily since 1990–91, rising from 22 percent of all capital project spending to 37 percent by 1998–99.

Sources of Funds. Academic institutions derive their funds for new construction and repair/renovation of research facilities from a number of sources: the Federal Government, state and local governments, institutional funds, private donations, tax-exempt bonds, other debt sources, and other sources. (See appendix tables 5-17 and 5-18.) In most years, state and local governments have provided a larger share of support than either private donations or tax-exempt bonds, followed by institutional funds. The Federal Government has never provided more than 14.1 percent of the funds for construction and repair/renovation. In 1998–99, the latest year for which data are available:

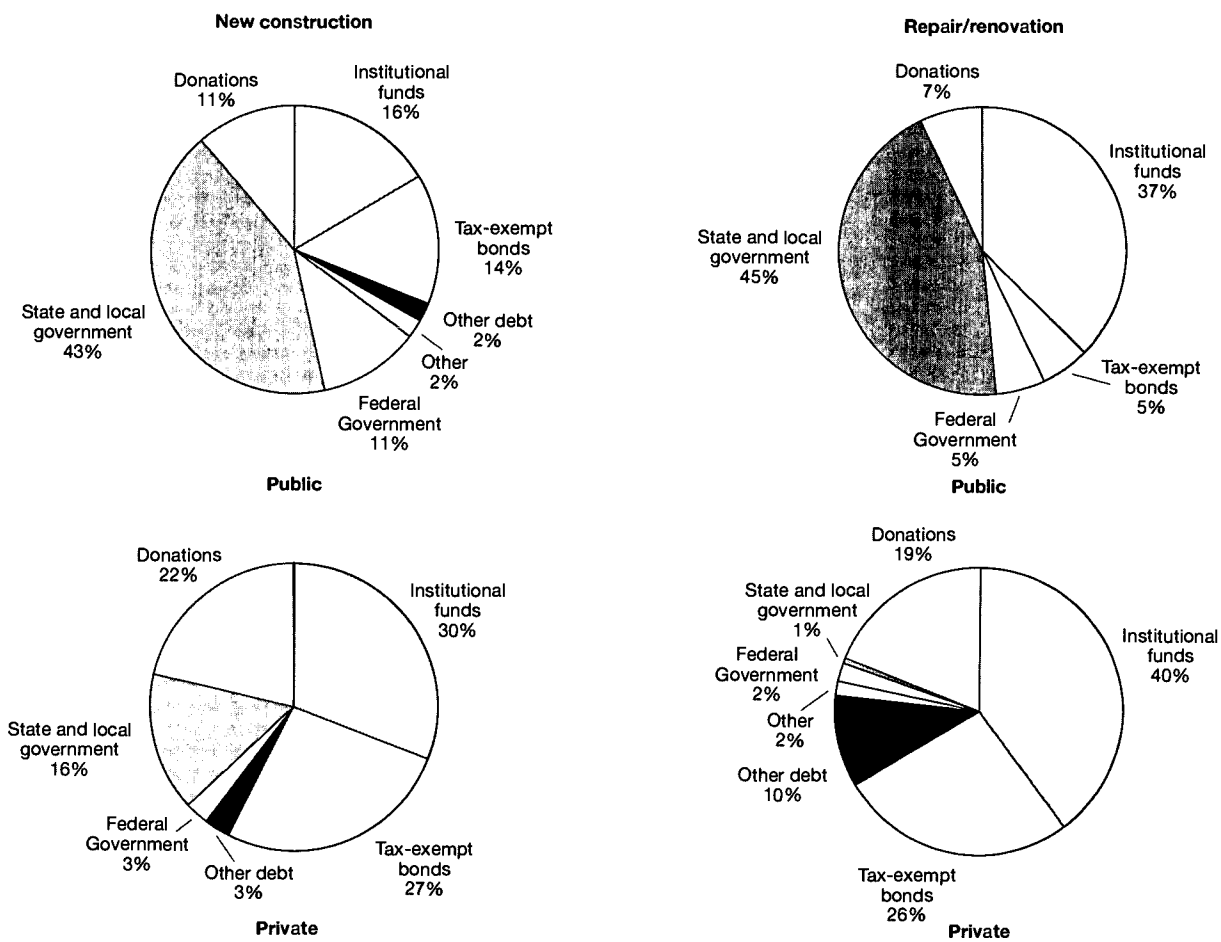
- the Federal Government directly accounted for only 8 percent of all construction funds and 4 percent of repair/renovation funds,[16]
- state and local governments accounted for 32 percent of all construction funds and 26 percent of repair/renovation funds,
- private donations accounted for 15 percent of all construction funds and 12 percent of repair/renovation funds,
- institutional funds accounted for 22 percent of all construction funds and 38 percent of repair/renovation funds, and
- tax-exempt bonds accounted for 19 percent of all construction funds and 14 percent of repair/renovation funds.

Public and private institutions drew on substantially different sources to fund the construction and repair/renovation of research space. (See figure 5-16) Public institutions relied primarily on:

- state and local governments (43 percent of funds for new construction and 45 percent of funds for repair/renovation),
- private donations (11 percent of funds for new construction and 7 percent of funds for repair/renovation),
- institutional funds (16 percent of funds for new construction and 37 percent of funds for repair/renovation), and

[16] Some additional Federal funding comes through overhead on grants and/or contracts from the Federal Government. These indirect cost payments are used to defray the overhead costs of conducting federally funded research and are reported as institutional funding on the NSF facilities survey. See the sidebar, "Recent Developments on the Indirect Cost Front," earlier in this chapter.

Figure 5-16.
Sources of funds for new construction and repair/renovation of research facilities at public and private universities and colleges: 1999



NOTE: Shares may not add to 100 percent because of rounding.

See appendix tables 5-17 and 5-18.

Science & Engineering Indicators – 2002

- tax-exempt bonds (15 percent of funds for new construction and 5 percent of funds for repair/renovation).

Private institutions relied primarily on:

- private donations (22 percent of funds for new construction and 19 percent of funds for repair/renovation),
- institutional funds (30 percent of funds for new construction and 40 percent of funds for repair/renovation), and
- tax-exempt bonds (27 percent of funds for new construction and 26 percent for repair/renovation).

Adequacy and Condition. Of the institutions reporting research space in 1999, more than 30 percent reported needing additional space in biological sciences in universities and colleges (as opposed to medical schools), physical sciences, psychology, and computer sciences. In all four of these fields, more than 25 percent of these institutions reported needing additional space equal to more than 25 percent of their current research space. (See text table 5-3.) Less than 20 percent of the institutions reported needing any additional space in medical sciences in both medical schools and universities and colleges, in biological sciences in medical schools, and in agricultural sciences.

Survey respondents also rated the condition of their research space in 1999. Slightly more than 40 percent of S&E research space was rated as "suitable for the most scientifically competitive research." (See text table 5-4.) However, 20 percent of the research space was designated as needing major repair/renovation and an additional 6 percent as needing replacement. The condition of this space differs across S&E fields. Fields with the largest proportion of research space needing major repair/renovation or replacement include agricultural sciences (33 percent), environmental sciences, biological sciences in universities and colleges, medical sciences in universities and colleges, and medical sciences in medical schools (each with between 26 and 28 percent).

Unmet Needs. Determining what universities and colleges need for S&E research space is a complex matter. To attempt to measure "real" as opposed to "speculative" needs, the survey asked respondents to report whether there was an approved institutional plan that included any deferred space needing new construction or repair/renovation.[17] Respondents were then asked to estimate, for each S&E field, the costs of such construction and repair/renovation projects and, separately, the costs for similar projects not included in an approved institutional plan.

In 1999, 44 percent of the institutions reported the existence of institutional plans that included deferred capital projects to construct or repair/renovate academic S&E research facilities. Twenty-five percent of institutions reported deferred projects not included in institutional plans. The total estimated cost for all deferred S&E construction and repair/renovation projects (whether included in an institutional plan or not) was $13.6 billion in 1999. Deferred construction projects accounted for 65 percent of this cost and deferred repair/renovation projects for the remaining 35 percent.

Deferred construction costs were close to or exceeded $1 billion in three fields: medical sciences in medical schools, biological sciences in universities and colleges, and engineering. Institutions reported deferred repair/renovation costs in excess of $500 million in the same three fields and in one additional field, as follows: medical sciences in medical

[17] Four criteria are used to define deferred space in a survey cycle: (1) the space must be necessary to meet the critical needs of current faculty or programs; (2) construction must not have been scheduled to begin during the two fiscal years covered by the survey; (3) construction must not have funding set aside for it; and (4) the space must not be for developing new programs or expanding the number of faculty positions.

Text table 5-3.
Adequacy of the amount of S&E research space, by field: 1999

Field	Percentage of institutions needing additional space		
	Less than 10 percent of current space	10–25 percent of current space	More than 25 percent of current space
Physical sciences	5.0	10.7	27.6
Mathematics	1.5	2.5	17.2
Computer sciences	0.6	3.6	28.4
Environmental sciences	3.9	5.2	18.2
Agricultural sciences	2.4	2.2	4.4
Biological sciences: universities and colleges	5.8	10.4	32.7
Biological sciences: medical schools	1.8	2.9	8.3
Medical sciences: universities and colleges	2.1	4.0	13.5
Medical sciences: medical schools	0.9	4.1	10.3
Psychology	2.4	6.9	25.8
Social sciences	3.6	4.5	19.8
Other sciences	1.5	0.3	1.6
Engineering	5.3	5.8	18.2

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Science and Engineering Research Facilities: 1999*, NSF 01-330 (Arlington, VA, 2001).

Science & Engineering Indicators – 2002

Text table 5-4.
Condition of academic S&E research facilities, by field: 1999
(Percentage of S&E research space)

Field	Suitable for use in the most scientifically competitive research	Suitable for most levels of research	Requires major repair/renovation to be used effectively	Requires replacement
All S&E	40.9	33.2	19.7	6.2
Physical sciences	40.5	35.7	19.2	4.6
Mathematics	52.4	32.9	11.7	3.1
Computer sciences	42.7	34.7	15.4	7.2
Environmental sciences	38.7	34.2	21.0	6.0
Agricultural sciences	32.6	34.4	23.0	10.1
Biological sciences: universities and colleges	41.2	30.4	22.2	6.2
Biological sciences: medical schools	47.9	28.5	17.5	6.1
Medical sciences: universities and colleges	31.1	42.6	20.0	6.3
Medical sciences: medical schools	43.7	28.3	21.4	6.6
Psychology	38.5	38.7	18.6	4.2
Social sciences	43.3	38.5	14.7	3.4
Engineering	43.1	35.1	17.0	4.8

NOTE: Components may not add to 100 percent because of rounding. Quality was assessed relative to current research program.

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Scientific and Engineering Research Facilities: 1999*, NSF 01-330 (Arlington, VA, 2001).

Science & Engineering Indicators – 2002

schools ($1.6 billion for construction and 0.5 billion for repair/renovation); biological sciences in universities and colleges ($1.5 billion for construction and $0.7 billion for repair/renovation); engineering ($1.0 billion for construction and $0.8 billion for repair/renovation); and physical sciences ($0.7 billion for construction and $1.0 billion for repair/renovation). (See appendix table 5-19.)

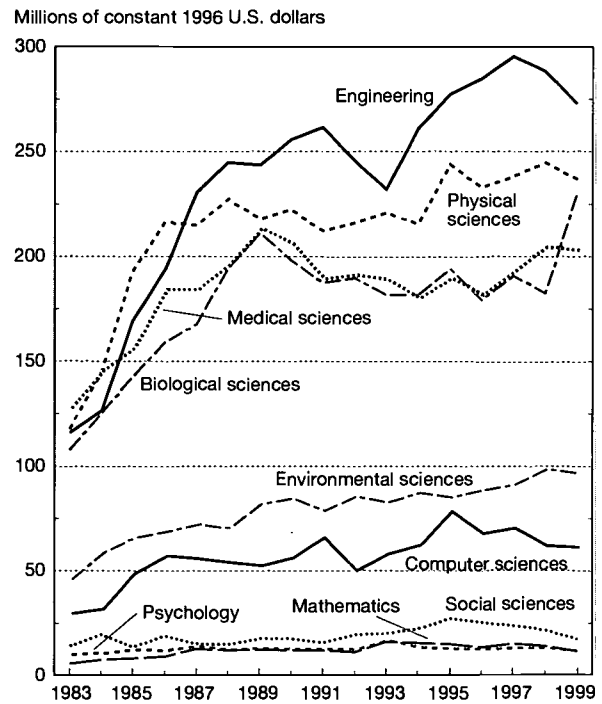
Equipment

Expenditures. In 1999, slightly more than $1.3 billion in current funds was spent for academic research equipment. About 80 percent of these expenditures were concentrated in three fields: life sciences (41 percent), engineering (22 percent), and physical sciences (19 percent). (See figure 5-17 and appendix table 5-20.)

Current fund expenditures for academic research equipment grew at an average annual rate of 4.2 percent (in constant 1996 dollars) between 1983 and 1999. Average annual growth, however, was much higher during the 1980s (8.7 percent) than it was during the 1990s (0.8 percent). The growth patterns in S&E fields varied during this period. For example, equipment expenditures for engineering (5.5 percent) grew more rapidly during the 1983–99 period than did those for the social sciences (1.4 percent) and psychology (1 percent).

Federal Funding. Federal funds for research equipment are generally received either as part of research grants, thus enabling the research to be performed, or as separate equipment grants, depending on the funding policies of the particular Federal agencies involved. The importance of Federal funding for research equipment varies by field. In 1999, the social sciences received slightly less than 40 per-

Figure 5-17.
Current fund expenditures for research equipment at academic institutions, by field: 1983–99



NOTE: See appendix table 4-1 for GDP implicit price deflators used to convert current dollars to constant 1996 dollars.

See appendix table 5-20. *Science & Engineering Indicators – 2002*

cent of their research equipment funds from the Federal Government; in contrast, Federal support accounted for more than two-thirds of equipment funding in the physical sciences, computer sciences, and environmental sciences. (See appendix table 5-21.)

The share of research equipment expenditures funded by the Federal Government declined from 62 to 58 percent between 1983 and 1999, although not steadily. This overall pattern masks different trends in individual S&E fields. For example, the share funded by the Federal Government actually rose during this period for both the social and the environmental sciences.

R&D Equipment Intensity. R&D equipment intensity is the percentage of total annual R&D expenditures from current funds devoted to research equipment. This proportion was lower in 1999 (5 percent) than it was in 1983 (6 percent), although it peaked in 1986 (7 percent). (See appendix table 5-22.) R&D equipment intensity varies across S&E fields. It tends to be higher in physical sciences (about 10 percent in 1999) and lower in social sciences (1 percent) and psychology (2 percent). For the two latter fields, these differences may reflect the use of less equipment, less expensive equipment, or both.

Doctoral Scientists and Engineers in Academia

U.S. universities and colleges are central to the nation's scientific and technological prowess. They generate new knowledge and ideas that form the basis of innovation that is vital to the advancement of science. In the process, they produce the highly trained talent needed to exploit and refresh this new knowledge. In addition, academia increasingly plays an active part in the generation and exploitation of new products, technologies, and processes.

The confluence of these key functions: the pursuit of new knowledge, the training of the people in whom it is embodied, and its exploitation toward generating innovation, makes academia a national resource whose vitality rests in the scientists and engineers who work there. Especially important are those with doctoral degrees who do the research, teach and train the students, and stimulate or help to produce innovation. Who are they, how are they distributed, what do they do, how are they supported, and what do they produce?[18]

Employment and research activity at the 125 largest research-performing universities in the United States are a special focus of analysis.[19] These institutions have a disproportionate influence on the nation's academic science, engineering, and R&D enterprise. They enroll 22 percent of full-time undergraduates and award one-third of all bachelors' degrees, but 40 percent of those in S&E; their baccalaureates, in turn, are the source of 54 percent of the nation's S&E doctoral degree-holders and more than 60 percent of those in academia with R&D as their primary work function. Their influence on academic R&D is even larger: they conduct more than 80 percent of it (as measured by expenditures), and they produce the bulk of academic article outputs and academic patents. For these reasons, they merit special attention.

Growth in academic employment over the past half century reflected both the need for teachers, driven by increasing enrollments, and an expanding research function, largely supported by Federal funds. Trends in indicators relating to research funding have been presented above, this section presents indicators about academic personnel. Because of the intertwined nature of academic teaching and research, much of the discussion deals with the overall academic employment of doctoral-level scientists and engineers, specifically the relative balance between faculty and nonfaculty positions, demographic composition, faculty age structure, hiring of new Ph.D.s, trends in work activities, and trends in Federal support. The section also includes a discussion of different estimates of the nation's academic R&D workforce and effort and considers whether a shift away from basic research toward more applied R&D functions has occurred.

Academic Employment of Doctoral Scientists and Engineers

Universities and colleges employ less than half of doctoral scientists and engineers.[20] Academic employment of S&E doctorate holders reached a record high of 240,200 in 1999, approximately twice their number in 1973. Long-term growth of these positions was markedly slower than that in business, government, and other segments of the economy. The academic doubling compares with increases of 230 percent for private companies, 170 percent for government, and 190 percent for all other segments. As a result, the academic employment share dropped from 55 to 45 percent during the 1973–99 period.

Within academia, growth was slowest for the major research universities. Text table 5-5 shows average annual growth rates for S&E Ph.D.-holders in various segments of the U.S. economy; appendix table 5-23 breaks down academic employment by type of institution.

Foreign-Born Academic Scientists and Engineers

An increasing number (nearly 30 percent) of Ph.D.-level scientists and engineers at U.S. universities and colleges are foreign-born. Like other sectors of the economy, academia has long relied extensively on foreign talent among its faculty, students, and other professional employees; this reliance increased during the 1990s. By a conservative estimate, for-

[18]The academic doctoral S&E workforce includes full and associate professors (referred to as "senior faculty"); assistant professors and instructors (referred to as "junior faculty"); and lecturers, adjunct faculty, research and teaching associates, administrators, and postdoctorates. S&E fields are defined by field of Ph.D. degree. All numbers are estimates rounded to the nearest 100. The reader is cautioned that small estimates may be unreliable.

[19]This set of institutions comprises the Carnegie Research I and II universities, based on the following 1994 classification: institutions with a full range of baccalaureate programs, commitment to graduate education through the doctorate, annual award of at least 50 doctoral degrees, and receipt of Federal support of at least $15.5 million (1989–91 average); see Carnegie Foundation for the Advancement of Teaching (1994). The classification has since been modified, but the older schema is more appropriate to the discussion presented here.

[20] Unless specifically noted, data on doctoral scientists and engineers refer to persons with doctorates from U.S. institutions, surveyed biannually by NSF in the *Survey of Doctorate Recipients*.

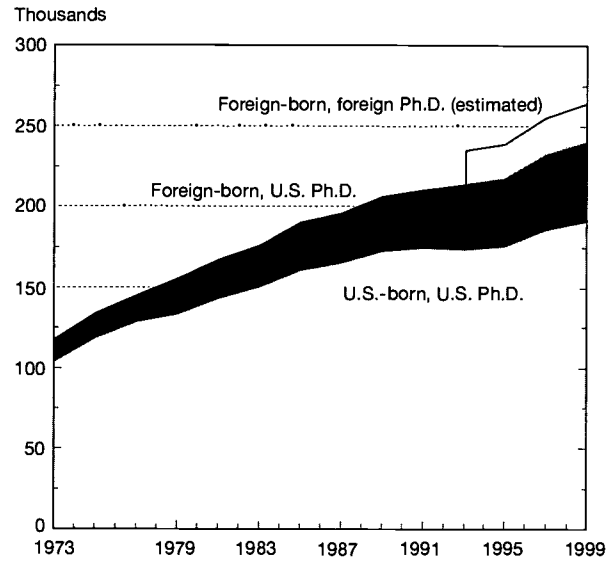
Text table 5-5.
Average growth rates for employment of doctoral scientists and engineers in the U.S. economy
(Percent)

Sector	1973–81	1981–91	1991–99
All sectors	5.7	3.4	2.3
Academia, total	4.4	2.8	1.7
Research universities	4.3	2.6	0.6
All others	4.7	3.0	2.7
Business	8.2	2.2	4.4
Government	5.0	2.3	4.9
All others	6.7	8.6	–3.4

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), Survey of Doctorate Recipients.

Science & Engineering Indicators – 2002

Figure 5-18.
Academic employment of U.S.-born and foreign-born doctoral scientists and engineers: 1973–99



NOTE: Data on foreign-born foreign-earned Ph.D.s unavailable for 1973–91.

See appendix table 5-24 and text table 5-6.

Science & Engineering Indicators – 2002

eign-born Ph.D.-holders accounted for about 28 percent of the total number of academically employed doctoral scientists and engineers at the end of the decade. Figure 5-18 delineates the academic employment estimate of 240,200 U.S.-earned Ph.D.s into those awarded to U.S. citizens and those awarded to foreign-born individuals.

The figure also shows an estimate of 24,300 individuals with S&E doctorates from foreign universities for each of the survey years.[21] The number is derived from the relationship of foreign-earned degrees to all U.S.-earned Ph.D.s in 1993, which was based on a sample drawn from the full doctoral population in the United States at the time of the 1990 census. (See text table 5-6.) The estimate of 24,300 represents a lower-bound value. It fails to take into account the rising pace of immigration into the United States during the 1990s, the creation of special visa programs to provide increased access to U.S. employment, an increase in the propensity of foreign Ph.D.-holders to remain in the United States, and some contrary evidence of a possible rise in return flows of foreign nationals in the second half of the decade. No reliable quantitative data are available on which to base a more solid estimate of the effects of these developments on academic employment.

[21]The actual 1999 survey estimate of 17,400 is clearly an underestimate. It is based only on a sample of those who were in the country in 1990 and responded to a 1999 survey of doctorate degree-holders.

Text table 5-6.
Estimates of foreign-born Ph.D. scientists and engineers at U.S. universities and colleges

Source of doctorate and place of birth	1973	1983	1993	1995	1997	1999
Total Ph.D. scientists and engineers						
Estimate 1	NA	NA	235,347	237,716	250,680	257,598
Estimate 2	NA	NA	235,347	239,513	255,987	264,427
Ph.D.s earned in U.S. (total)	117,957	176,082	213,758	217,543	232,505	240,169
Born in U.S.	104,426	150,397	173,288	175,764	185,957	191,158
Foreign-born	13,531	25,685	40,470	41,779	46,548	49,011
Ph.D.s earned abroad (total)						
Estimate 1	NA	NA	21,589	20,174	18,175	17,428
Estimate 2	NA	NA	21,589	21,971	23,482	24,257
Percent foreign-born						
Estimate 1	NA	NA	26.4	26.1	25.8	25.8
Estimate 2	NA	NA	26.4	26.6	27.4	27.7

NA = not available

NOTE: Estimate 1 is derived from Scientists and Engineers Statistical Data System (SESTAT). Estimate 2 is derived by applying the 1993 ratio of non-U.S.- to U.S.-earned degrees from SESTAT to all years. Data for 1973, 1983, and 1993 U.S.-born includes all persons with unknown place of birth.

See appendix table 5-24.

Science & Engineering Indicators – 2002

Nevertheless, figure 5-18 suggests that participation by foreign-born doctorate-holders in U.S. academic S&E increased continuously during at least the past two decades. For those with U.S.-earned doctoral degrees, employment rose from 11.7 percent in 1973 to 20.4 percent in 1999; for postdoctorates, it is double that percentage. (See appendix table 5-24.) Adding the lower-bound estimate for those with foreign-earned degrees boosts these percentages from 26.4 percent in 1993 to 27.7 percent in 1999.

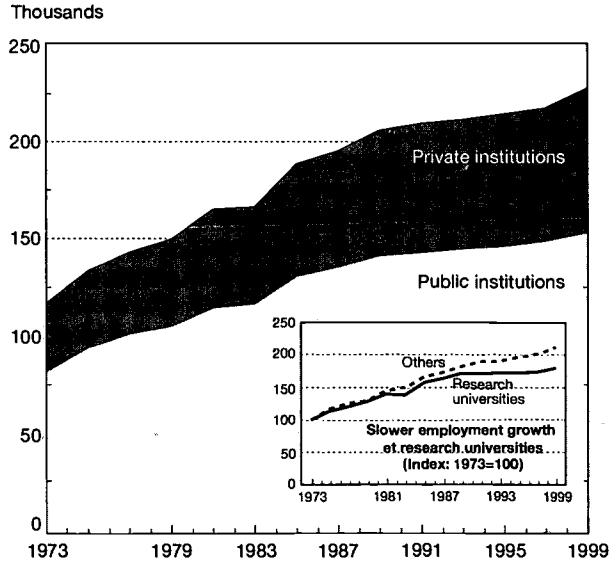
Slower Hiring at Research Universities and Public Institutions

Employment growth over the past decade was slower at the research universities than at other universities and colleges, after enjoying robust earlier increases.[22] (See appendix table 5-25.) From 1993 to 1999, doctoral S&E employment at research universities expanded by 3.8 percent. In contrast, employment at other institutions grew uninterruptedly for at least three decades, increasing by 10.8 percent during the 1990s, primarily during the second half of the decade. Figure 5-19 shows some of these employment trends.

During the 1990s, employment increased less rapidly at public universities and colleges than at their private counterparts (2.1 versus 8.0 percent for research universities; 9.3 versus 13.8 percent for others). Moreover, the much stronger growth in public universities and colleges outside the ranks of the research universities suggests that state governments are more interested in expanding the institutional segment that focuses on education and training than in raising the employment of the flagship institutions that conduct most of the research. (See appendix table 5-25.)

[22]Unless specifically stated, all subsequent analyses are based on U.S. doctorates only, since there is insufficient information on the faculty status of foreign-degreed Ph.D.-holders and on which academic institutions employ them.

Figure 5-19.
Doctoral scientists and engineers employed in public and private universities and colleges: 1973–99



See appendix table 5-25.

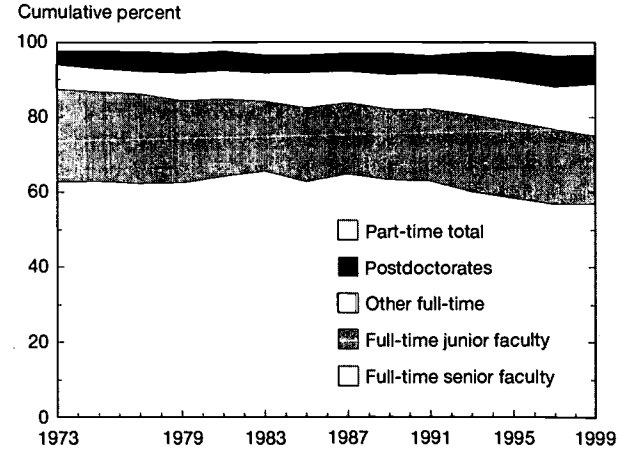
Science & Engineering Indicators – 2002

Declining Faculty Appointments, More Postdoctorate and Other Positions

The full-time tenured faculty position is being undermined as the academic norm by trends that accelerated in the 1990s. As faculty appointments decreased, appointments to postdoctorate and other types of positions increased. Overall, academic employment of doctoral scientists and engineers was quite robust, growing from 118,000 in 1973 to 240,200 in 1999. (See appendix table 5-26.) However, traditional faculty positions grew less rapidly, especially during the 1990s, when the number of senior faculty—full and associate professors—rose only modestly, and the number of junior faculty remained static. During that decade, full-time nonfaculty positions grew by half, as did postdoctorate appointments.

Figure 5-20 shows the resulting distribution in the structure of academic employment. The share of full-time senior faculty fell from 65 percent of total employment in the mid-1980s to only 57 percent in 1999, with particularly steep drops during the 1990s. The share of junior faculty also declined, bringing the overall faculty share to 75 percent of total employment, a steep loss from 88 percent in the early 1970s. The decline in the 1990s was linear, from 82 to 75 percent in fewer than 10 years. These employment trends in the past decade occurred as real academic R&D spending rose by half, retirement of faculty who had been hired during the expansionist 1960s increased, academic hiring of young Ph.D.-hold-

Figure 5-20.
Distribution of Ph.D. scientists and engineers, by type of academic appointment: 1973–99



NOTE: Junior faculty includes assistant professors and instructors; senior faculty includes full and associate professors.

See appendix table 5-25. *Science & Engineering Indicators – 2002*

ers showed a modest rebound, and universities placed a growing emphasis on the practical application of academic research results, discussed later in this chapter.[23]

Nonfaculty ranks, that is, full- and part-time adjunct faculty, lecturers, research and teaching associates, administrators, and postdoctorates, increased from 36,900 in 1989 to 59,800 in 1999. This 62 percent increase stood in sharp contrast to the 6 percent rise in the number of full-time faculty. Both the full-time nonfaculty and postdoctorate components both grew very rapidly between 1989 and 1999 (72 and 61 percent, respectively), while part-time employment rose 32 percent.[24] In fact, part-time employees accounted for between 2 and 4 percent of the total throughout the period. (See appendix table 5-26.)

Academic Employment Patterns for Recent Ph.D.-Holders

The trends just discussed reflect the pool of the entire academic workforce of S&E Ph.D.-holders. A sharper indication of current trends can be gleaned by looking at the academic employment patterns of those with recently awarded Ph.D.s, here defined as persons who earned their doctorates at U.S. universities within three years of the survey year.

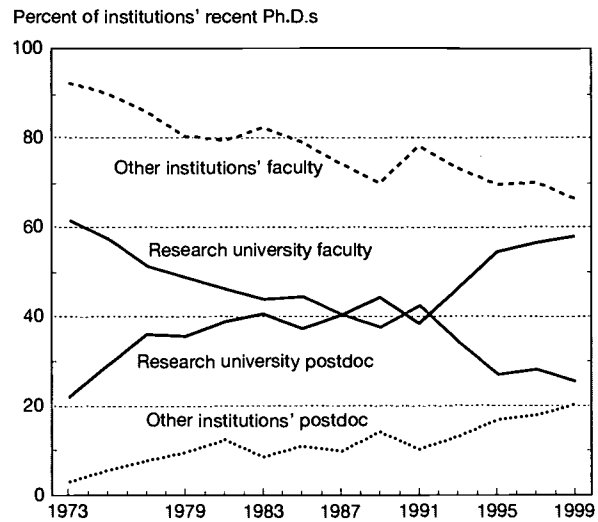
Recent Ph.D.-holders who enter academic employment today are more likely to receive postdoctorate appointments than faculty positions, which declined sharply over the past decade and have even undergone a reversal when viewed over the longer term. Those in research universities are more than twice as likely to be in postdoctorate appointments as to have faculty rank. (See appendix table 5-27 and figure 5-21.) Overall, since 1973, the percentage of recent Ph.D.-holders hired into full-time faculty positions has been cut nearly in half, from 74 to 37 percent. The decline at research universities has been sharper, from 60 to 24 percent. Conversely, the overall proportion of Ph.D.-holders who reported being in postdoctorate positions has risen from 13 to 43 percent (and from 21 to 58 percent at research universities). Those in public research institutions are somewhat more likely than those in private institutions to hold full-time faculty positions and somewhat less likely to have postdoctorate rank.

Similar Trends for Young Ph.D.s With a Track Record

For those in academia four to seven years after earning their doctorates, the picture looks quite similar: only two-thirds had attained faculty rank at that point compared with nearly 90 percent in the early 1970s, and the trend continues to point downward. (See appendix table 5-27.) Only about half were in tenure-track positions, with 10 percent already tenured, well below the experience of previous decades. Moreover, the overall proportion of those in a tenure track position, whether already tenured or not, has declined for the past two decades, and this trend shows no sign of abating.

Taken together, these data suggest a continuing shift, accelerating during the 1990s, toward forms of employment outside traditional tenure track positions. (See figure 5-22.) This shift toward nonfaculty employment touched most major fields. In fact, gains in the total number of full-time fac-

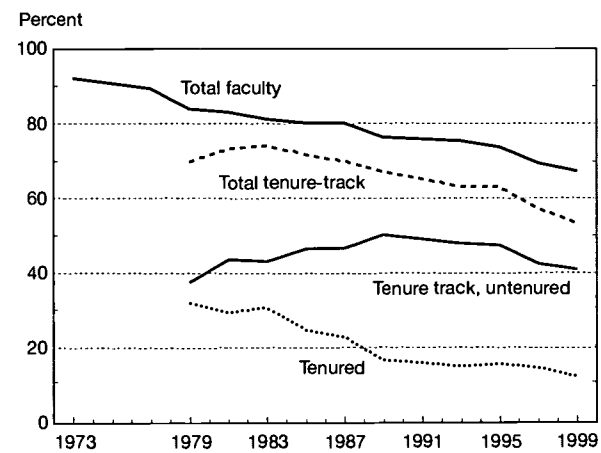
Figure 5-21.
Recent S&E Ph.D.s hired into faculty and postdoc positions at research universities and other academic institutions: 1973–99



NOTES: Recent Ph.D.s have earned doctorates within three years of the survey year. Those hired into other positions not shown.

See appendix table 5-27. *Science & Engineering Indicators – 2002*

Figure 5-22.
Faculty and tenure track-status of academic S&E Ph.D.s whose doctorate was earned 5–7 years earlier: 1973–99



SOURCE: National Science Foundation, Division of Science Resources Statistics. Survey of Doctorate Recipients.

Science & Engineering Indicators – 2002

[23] It is impossible with the data at hand to establish causal connections among these developments.

[24] For more information on this subject, see "Postdoctorate Appointments" in chapter 3.

ulty positions were restricted to the life and computer sciences, with the other fields holding steady or registering only marginal increases. However, for every field except environmental (i.e., earth, atmospheric, and ocean) sciences, the proportion of total doctoral employment held by full-time faculty decreased. (See appendix table 5-26.)

Concerns About Retirement Behavior of Doctoral Scientists and Engineers

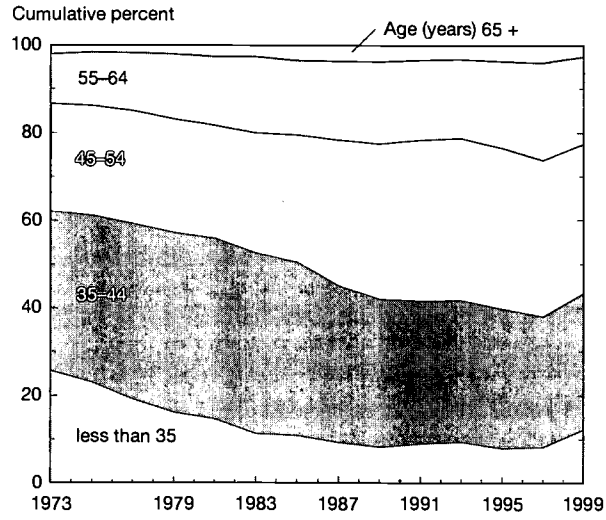
The trend toward fewer faculty appointments and more full-time nonfaculty and postdoctorate components is especially noteworthy because academia is in a period of increasing retirements. In the 1960s, the number of institutions, students, and faculty in the United States expanded rapidly, bringing many young Ph.D.-holders into academic faculty positions. This growth boom slowed sharply in the 1970s, and faculty hiring has since continued at a more modest pace. The result is that increasing numbers of faculty (and others in nonfaculty positions) are today reaching or nearing retirement age.[25]

A law defining age discrimination, the Age Discrimination in Employment Act, became fully applicable to universities and colleges in 1994.[26] It prohibits the forced retirement of faculty at any age, raising concerns about the potential ramifications of an aging professorate for scholarly productivity and the universities' organizational vitality, institutional flexibility, and financial health. These concerns were the focus of a National Research Council (NRC) (1991) study. The study concluded that "overall, only a small number of the nation's tenured faculty will continue working in their current positions past age 70" (NRC 1991, p. 29), but added: "At some research universities a high proportion of faculty would choose to remain employed past age 70 if allowed to do so" (NRC 1991, p. 38).

Sufficient data have now accumulated to allow examination of these concerns. Figure 5-23 shows the age distribution of academic doctoral scientists and engineers, and figure 5-24 displays the percentage of academic doctoral scientists and engineers 60 years of age or older. They show that the proportion of 60- to 64-year-olds was rising well before the act became mandatory, then leveled off. A similar progression can be seen for those age 65 or older, who made up 3 percent of the research universities' full-time faculty and 2 percent of other institutions' full-time faculty in 1999. The employment share of those older than age 70 rose during the last quarter century; it stood at 0.5 percent in 1999. (See appendix tables 5-28 and 5-29.)

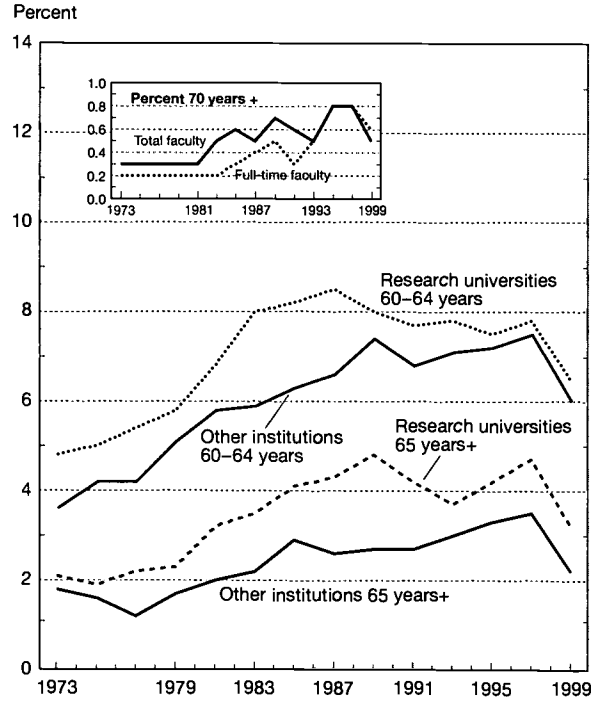
These data suggest that concerns that universities would continue to employ many unproductive professors have been

Figure 5-23.
Age distribution of full-time academic doctoral S&E faculty: 1973–99



See appendix table 5-29. *Science & Engineering Indicators – 2002*

Figure 5-24.
Full-time faculty age 60 and older at research universities and other higher education institutions: 1973–99



See appendix table 5-29. *Science & Engineering Indicators – 2002*

[25]See also the discussion of retirements from the S&E workforce in chapter 3, "Science and Engineering Workforce."

[26]A 1986 amendment to the Age Discrimination in Employment Act of 1967 prohibited mandatory retirement on the basis of age for almost all workers. Higher education institutions were granted an exemption through 1993, allowing termination of employees with unlimited tenure who had reached age 70.

Text table 5-7.
Percentage of academic S&E doctorate holders leaving full-time employment in 1993–95 period, by number of articles published in previous five years

Age in 1995	Number of articles			
	Total	0	1–5	6 or more
51–55	3.2	5.7	3.5	1.0
56–60	9.2	12.2	8.6	6.7
61–65	24.6	32.6	23.5	16.1
66–70	35.7	—	43.1	28.0
71–73	40.6	—	—	28.1

— = number of cases too small to estimate

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Survey of Doctorate Recipients.

Science & Engineering Indicators – 2002

misplaced. Further evidence is provided by examining the article output of those retiring at different ages, as shown in text table 5-7. The table compares the 1993–95 transition rates from full-time academic employment of S&E Ph.D.-holders with the number of articles they reported publishing over the previous five years. Within each age group, those with six or more articles were less likely to leave full-time employment than those with fewer or no articles.

Women and Minority Group Members As Faculty Role Models

The relatively large annual supply of new S&E doctorate-holders suggests that finding a sufficient number of replacement faculty may not be difficult. However, accumulating research points to the importance of role models and mentoring to student success in mathematics, science, and engineering, especially for women and minorities. These two groups make up a pool of potential scientists and engineers that has not been fully tapped and that, in the case of minorities, represents a growing share of U.S. youth, estimated to reach 45 percent of the college-age population by 2025. (See appendix table 2-2.) Thus, the presence of women and minority faculty on college campuses may well be one important factor in the recruitment of women and minorities to these fields. What have been the major hiring trends for them, and what is their current status?

Women

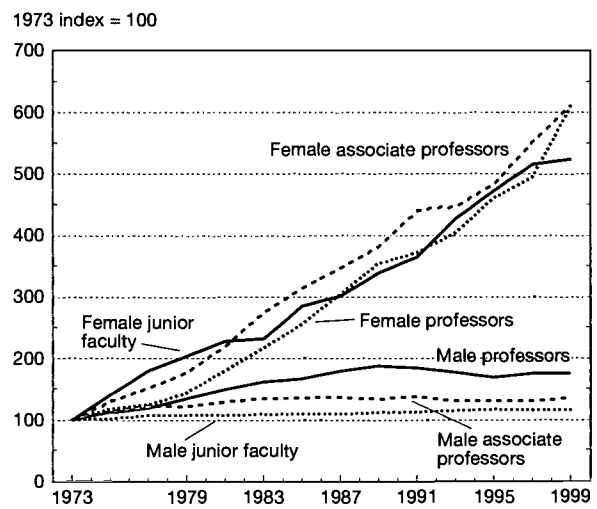
The academic employment of women with S&E doctorates has risen steeply over the past quarter century, reflecting the steady increase in the proportion of women among holders of newly awarded S&E doctorates. The number of women in academia increased sixfold between 1973 (when this type of employment information was first collected) and 1999, from 10,700 to an estimated 64,400, bringing their share from 9 to 27 percent. (See appendix table 5-30.) By the end of the decade, women constituted just under one-quarter of full-time faculty, up from 6 percent. Compared with men, women faculty remain relatively more heavily concentrated in life sciences and psychology, with correspondingly lower shares in engineering, physical sciences, and mathematics.

Women's growing share of academic employment reflects the confluence of three factors: their rising proportion among new doctorates, somewhat greater predilection for choosing an academic career, and being hired into these positions at somewhat higher rates than men. This historical dynamic is reflected in declining numbers of women as one moves up in faculty rank: in 1999, women constituted 12 percent of full professors, 25 percent of associate professors, and 37 percent of the junior faculty, the latter roughly in line with their recent share of Ph.D.s earned. (See the section "Doctoral Degrees by Sex" in chapter 2.) In contrast, the number of men increases as one moves from junior to senior faculty ranks. (See figure 5-25.) This contrasting pattern indicates the recent arrival of significant numbers of women doctorate-holders in full-time academic faculty positions. It suggests that the number of women among the faculty will continue to increase, assuming that women stay in academic positions at a rate equal to or greater than men.

Underrepresented Minorities

The U.S. Census Bureau's demographic projections have long indicated an increasing prominence of minority groups among future college and working-age populations. With the exception of Asians/Pacific Islanders, these groups have tended to be less likely than the majority population to earn S&E degrees or work in S&E occupations. Private and gov-

Figure 5-25.
Growth in full-time doctoral S&E faculty, by rank and sex: 1973–99



NOTE: Junior faculty includes assistant professors and instructors.

SOURCE: National Science Foundation, Division of Science Resources Statistics. Survey of Doctorate Recipients.

Science & Engineering Indicators – 2002

ernmental groups have sought to broaden the participation of blacks, Hispanics, and American Indians/Alaskan Natives in these financially attractive fields, with many programs targeting their advanced training through the doctorate.

In response, the rate of increase in conferrals of Ph.D.s to members of minority groups has been steep,[27] as have increases in academic employment; but taken together, blacks, Hispanics, and American Indians/Alaskan Natives remain a small minority. (See figure 5-26 and appendix table 5-31.) Because the increases in hiring come from a very small base, these groups still constitute less than 7 percent of total employment but represent nearly 10 percent of recent Ph.D.-holders hired into academia. Their share of full-time faculty positions is very similar to their employment share. Compared with whites, blacks tend to be relatively concentrated in the social sciences and psychology and relatively less so in the physical, environmental (earth, atmospheric, and ocean), and life sciences. The field distribution of Hispanic degree-holders is similar to that of the majority.

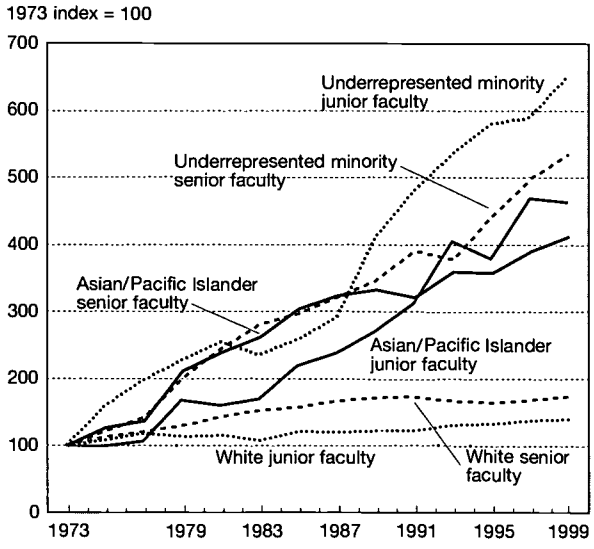
Asians/Pacific Islanders

Asians/Pacific Islanders as a group have been quite successful in entering the academic doctoral workforce in S&E, sending their employment share from 4 to 11 percent since 1973. Compared with whites, they are more heavily represented in engineering; represented to lesser degrees in life and physical sciences, mathematics, and computer science; and represented at very low levels in psychology and social sciences. In 1999, Asians/Pacific Islanders constituted nearly one-quarter of academic doctoral computer scientists and 18 percent of engineers. (See appendix table 5-31.)

In the last half of the 1990s, the percentage of Asian Ph.D.s among recent doctorate-holders sharply reversed a steep two-decade climb. The decline reflects a sharp drop in the percentage of all S&E doctoral degrees earned by Asians in the closing years of the 1990s. Between 1995 and 1999, S&E doctoral degrees awarded in the United States fell by 2 percent, but those awarded to Asians dropped by 45 percent. Consequently, the share decline of Asians among recent doctorate-holders is also evident in industry and other employment sectors.

[27]This, in turn, reflects their rising participation in higher education and graduate school training. See "Master's Degrees by Sex, Race/Ethnicity, and Citizenship" and "Doctoral Degrees by Race/Ethnicity" in chapter 2.

Figure 5-26.
Growth in full-time doctoral S&E faculty, by rank and race/ethnicity: 1973–99



NOTES: Underrepresented minority faculty includes blacks, Hispanics, and American Indians/Alaskan Natives. Junior faculty includes assistant professors and instructors; senior faculty includes full and associate professors.

See appendix table 5-31. *Science & Engineering Indicators – 2002*

Size of the Academic Research Workforce

The intertwined nature of research, teaching, and public service in academia makes it difficult to define the size of the academic research workforce precisely. Therefore, two estimates of the number of academic researchers are presented: a headcount of those who report that research is their primary work activity, and a headcount of those who report that research is either their primary or secondary work activity.

Postdocs and those in nonfaculty positions are included in both estimates. To provide a more complete measure of the number of researchers, a lower-bound estimate of the number of graduate students who support the academic research enterprise is included, based on those with research assistantship (RA) support.

Research as Primary Work Activity

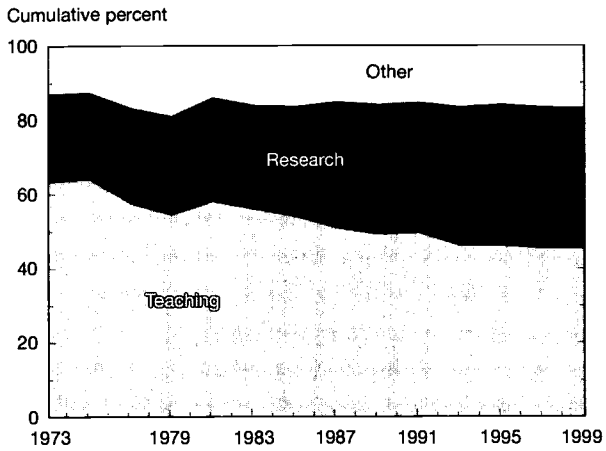
By this measure, the growth of doctoral-level academic researchers has been substantial, from 27,800 in 1973 to 91,400 in 1999. (See appendix table 5-32.) During this period, the number of those with teaching as their primary activity increased much less rapidly, from 73,300 to 108,600. Figure 5-27 displays the resulting shifting proportions in the academic workforce. It shows that after many years of increase, the proportion of those reporting research as their primary activity leveled off in the 1990s, as did the steep drop in those reporting teaching as their primary activity.

The different fields have distinct patterns of relative emphasis on research, but the shapes of their overall trends are largely the same. Life sciences, however, stand out for their much higher proportion of those identifying research as their primary activity and, correspondingly, their much lower proportion of those reporting teaching as their primary activity. (See figure 5-28.)

Research as Either Primary or Secondary Work Activity

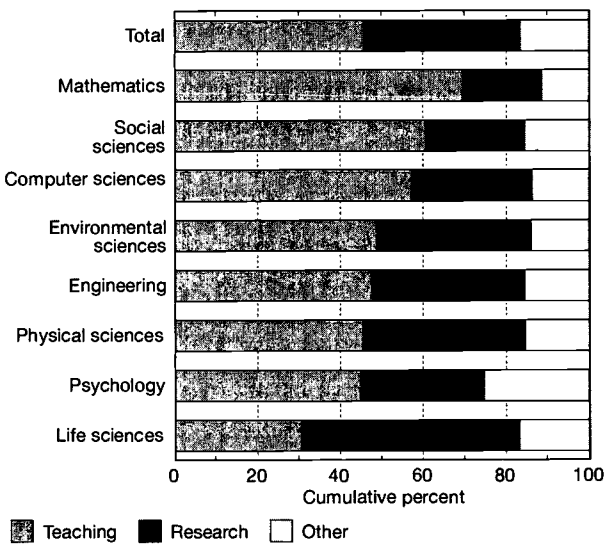
This measure, a straightforward headcount of doctoral respondents for whom research is either the primary or secondary work activity, also shows greater growth in the research than in the

Figure 5-27.
Primary work activity of academic doctoral S&E faculty: 1973–99



See appendix table 5-32. *Science & Engineering Indicators – 2002*

Figure 5-28.
Primary work activity of academic doctoral S&E workforce: 1999



See appendix table 5-32. *Science & Engineering Indicators – 2002*

teaching component. The number of doctoral researchers so defined increased from 82,300 in 1973 to 168,100 in 1999, that of teachers from 94,900 to 158,700.[28] (See appendix table 5-33.)

Life sciences accounted for much of this trend, with researchers growing from 26,000 to 60,800 and teachers from about the same base of 25,300 to 43,600. The other fields generally included fewer researchers than teachers in the early 1970s, but this trend has been reversed for physical, earth, atmospheric, and ocean sciences and engineering.

The close coupling of advanced training with hands-on research experience is a key strength of American graduate education. To the headcount of doctoral researchers for whom research is a primary or secondary work activity must thus be added an estimate of the number of graduate students who are active in research. The more than 300,000 full-time S&E graduate students can be expected to contribute significantly to the conduct of academic research.

Graduate RAs were the primary means of support for slightly more than one-quarter of these students. Text table 5-8, which shows the distribution of all full-time graduate students and graduate research assistants by field over the past quarter century, indicates that the number of research assistants has grown faster than overall graduate enrollment. In both enrollment and distribution of RAs, a shift away from physical sciences and into life sciences has occurred. Nevertheless, engineering, natural sciences, and mathematics and computer sciences have relatively higher proportions of research assistants measured against their enrollment.[29] For life sciences, enrollment and research assistant proportions are in balance, reflecting the relatively heavier reliance of these fields on postdoctoral researchers.

In estimating the headcount of doctoral researchers for whom research is the primary or secondary activity, only graduate research assistants (full-time graduate students whose primary mechanism of support is an RA) are included. Thus, the estimate excludes graduate students who rely on fellowships, traineeships, or teaching assistantships for their support, as well as the nearly 40 percent who are primarily self-supporting; and foreign-degreed doctoral researchers. With these caveats, the number of academic researchers in 1999 for whom research is the primary or secondary activity is estimated to have been close to 260,000. (See figure 5-29 and appendix table 5-34.) It is worth noting that in computer science and engineering the number of graduate research assistants exceeded the number of doctoral researchers.

Deployment of the Academic Research Workforce

This section describes trends in researcher headcount and in the number of S&E academicians whose primary activity is research. They are discussed as measures of the relative research intensity of academic institutions and the distribution of the academic research workforce across types of institutions, positions, and fields. The analysis is based on doctoral scientists and engineers with degrees from U.S. institutions, because insufficient detail is available for those with foreign degrees.

Distribution Across Types of Academic Institutions

The majority of the research workforce is concentrated in the research universities, followed by comprehensive and doctorate-granting institutions and freestanding medical institutions. (See appendix table 5-35.) In 1999, the research

[28] This measure was constructed slightly differently in the 1980s and in the 1990s, starting in 1993, and is not strictly comparable across these periods. Therefore, the crossing over of the two trends in the 1990s could reflect only a methodological difference. However, the very robust trend in the life sciences, where researchers started outnumbering teachers at a much earlier time, suggests that this methodological artifact cannot fully explain the observed trend.

[29] This reflects increasing support for computer science R&D.

Text table 5-8.
Full-time S&E graduate students and graduate research assistants at U.S. universities and colleges, by field

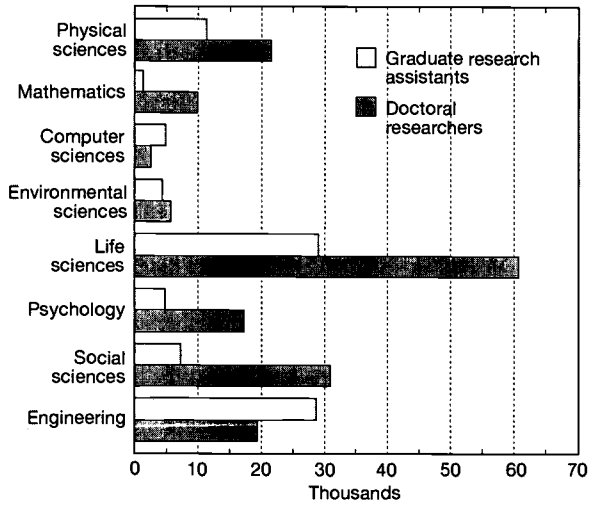
Year	Total S&E	Engineering	Physical sciences	Environmental sciences[a]	Mathematics and computer sciences	Life sciences	Psychology	Social sciences
Full-time graduate students (thousands)								
1973	161.6	31.2	21.1	7.8	13.3	40.7	15.2	32.4
1983	252.1	53.9	25.2	12.0	21.6	69.3	26.6	43.5
1993	329.7	73.8	30.6	11.4	31.9	91.7	34.8	55.6
1999	334.4	67.8	26.6	10.5	34.5	107.0	34.7	53.3
Full-time graduate research assistants (thousands)								
1973	35.9	10.4	6.3	2.6	1.4	9.5	1.9	4.0
1983	54.9	15.5	9.1	3.5	2.2	16.5	3.0	5.0
1993	90.2	27.9	12.3	4.7	5.2	28.0	4.6	7.4
1999	91.3	28.7	11.3	4.3	6.2	29.0	4.8	7.2
Distribution of full-time graduate students (percent)								
1973	100	19	13	5	8	25	9	20
1983	100	21	10	5	9	27	11	17
1993	100	22	9	3	10	28	11	17
1999	100	20	8	3	10	32	10	16
Distribution of full-time graduate research assistants (percent)								
1973	100	29	18	7	4	26	5	11
1983	100	28	17	6	4	30	5	9
1993	100	31	14	5	6	31	5	8
1999	100	31	12	5	7	32	5	8

[a]Environmental sciences include earth, atmospheric, and ocean sciences.

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Survey of Graduate Students and Postdoctorates.

Science & Engineering Indicators – 2002

Figure 5-29.
Estimated number of doctoral academic researchers and graduate research assistants, by field: 1999



NOTE: Academic researchers include those whose primary or secondary work activity is basic or applied research, development, or design.

See appendix table 5-34. *Science & Engineering Indicators – 2002*

universities employed 54 percent of doctoral scientists and engineers in academic positions, 61 percent of academic researchers (headcount), 76 percent of those whose primary activity is research, and 80 percent of graduate research assistants. The employment shares of the other institutions are generally the same or higher than their share of the researcher measures.

Over the years, the research universities' share of academic researchers has declined, reflecting their decreasing shares of total and Federal academic research expenditures. The research universities' losses were offset by gains in several other types of institutions. Text table 5-9 provides a long-term overview of the changes in these institutional distributions. (See appendix table 5-35.)

Distribution Across Academic Positions

A pool of academic researchers outside the regular faculty ranks has grown over the years, as shown by the distribution of the doctoral research workforce across different types of academic positions: faculty, postdoctoral fellows, and all other types of appointments. (See text table 5-10 and appendix table 5-36.) The faculty share of the academic research workforce (77 percent in 1999, approximately the same as their employment share) represents a decline from 89 percent in 1973. The shift toward nonfaculty research effort was

Text table 5-9.
Distribution of academic doctoral employment and researchers, by institution type
(Percentage)

Type of institution	Employment 1970s	Employment 1990s	Researchers 1970s	Researchers 1990s	Graduate Research Assistants 1970s	Graduate Research Assistants 1990s
Total	100.0	100.0	100.0	100.0	100.0	100.0
Research universities	57.3	54.6	66.7	61.4	87.8	81.2
Doctorate-granting institutions	12.3	12.2	11.6	12.1	9.1	11.2
Comprehensive institutions	18.6	19.4	12.7	15.0	1.7	4.5
All others	11.8	13.8	9.0	11.5	1.2	3.1

NOTES: Researchers are headcounts of those with research as primary or secondary work activity. "All others" includes freestanding medical schools, schools of engineering, and four-year colleges.

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Survey of Doctorate Recipients.

Science & Engineering Indicators – 2002

Text table 5-10.
Change in the composition of academic employment and academic researchers

Year	Total employment	Researcher headcount	Research is primary activity
Number (thousands)			
1973	118.0	82.3	27.8
1983	176.1	104.7	48.9
1993	213.8	150.1	80.2
1999	240.2	168.1	91.4
Full-time faculty (%)			
1973	87.6	87.5	71.3
1983	84.3	83.0	68.8
1993	80.7	81.1	70.9
1999	76.6	76.8	66.1
Postdoctorates (%)			
1973	3.5	4.9	13.8
1983	4.7	7.1	14.6
1993	6.2	8.9	15.8
1999	7.7	10.6	18.2
Other full- and part-time positions (%)			
1973	6.4	5.6	11.3
1983	9.2	8.6	14.4
1993	13.1	10.0	13.3
1999	15.6	12.5	15.7

NOTE: Researcher headcount is the sum of those for whom research is either the primary or secondary work activity.

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Survey of Doctorate Recipients.

See appendix table 5-36. *Science & Engineering Indicators – 2002*

especially pronounced in the 1990s. The data on share of employment and researcher headcount show increases for both postdoctorates and those in a variety of nonfaculty positions.

Distribution Across S&E Fields

The distributions of researchers and those whose primary activity is research were compared with the employment distribution. Researcher proportions in excess of a field's employment share were deemed to indicate greater research intensity. Text table 5-11 suggests that, by these measures, life sciences expend relatively more research effort than the other fields, and mathematics and social sciences expend relatively less. Life sciences have a smaller-than-expected share of graduate research assistants, reflecting their relatively heavy use of postdoctorates in research. (See appendix table 5-37.)

Research Intensity of Academic Institutions

Has the relative importance given to R&D in U.S. universities and colleges changed? In terms of inputs, this question has already been addressed by examining the number of dollars spent on R&D. See "Emphasis on Research at Universities and Colleges" earlier in this chapter. In this section, the question is addressed in terms of the number of academic research personnel using relative-to-total doctoral employment in S&E. The two measures, headcount and the number of those reporting research as their primary work activity, tell somewhat different stories. The reader is cautioned that the resulting ratios are suggestive rather than definitive.

The number of researchers (headcount) relative to total employment declined from its high in the 1970s to a low in the mid-1980s, then rose again to about the previous levels, indicating declining research intensity during the 1970s and early 1980s, when R&D funds grew relatively slowly. (See text table 5-12 and appendix tables 5-35 to 5-37.) The data also show that for computer sciences and earth, atmospheric, and ocean sciences, levels of research involvement were somewhat lower in the late 1990s than earlier in the decade. A long-term upward trend, from about 25 percent of total employment to nearly 40 percent, is evident in the percentage of those whose primary activity is research. This may indicate a strengthening of the research function in academia. (See figure 5-30.)

Text table 5-11.
Distribution of academic employment and researchers, by field: 1999
(Percent of academic total)

Field	Total employment	Researcher headcount	Research is primary activity	Graduate research assistants
Total	100.0	100.0	100.0	100.0
Physical sciences	12.9	12.8	13.3	12.3
Mathematics	6.3	5.9	3.2	1.4
Computer sciences	1.5	1.6	1.2	5.4
Earth, atmospheric, and space sciences	3.2	3.4	3.2	4.7
Life sciences	34.1	36.2	47.2	31.7
Psychology	12.1	10.2	9.5	5.3
Social sciences	19.2	18.4	12.1	7.9
Engineering	10.6	11.6	10.3	31.4

NOTES: Percentages may not add to 100 because of rounding. Researcher headcount is the sum of those for whom research is either the primary or secondary work activity.

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Survey of Doctorate Recipients.

Science & Engineering Indicators – 2002

Text table 5-12.
Research intensity of American universities
(Ratio of researcher headcounts to employment)

Field	1973	1983	1993	1999
S&E total	0.70	0.59	0.70	0.70
Physical sciences	0.74	0.64	0.70	0.70
Mathematics	0.70	0.56	0.62	0.65
Computer sciences	NA	0.74	0.79	0.71
Earth, atmospheric, and ocean sciences	0.72	0.68	0.78	0.73
Life sciences	0.75	0.70	0.76	0.74
Psychology	0.60	0.50	0.60	0.59
Social sciences	0.61	0.46	0.66	0.67
Engineering	0.73	0.62	0.76	0.76

NA = not available

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Survey of Doctorate Recipients.

See appendix tables 5-35 to 5-37.

Science & Engineering Indicators – 2002

Government Support of Academic Doctoral Researchers

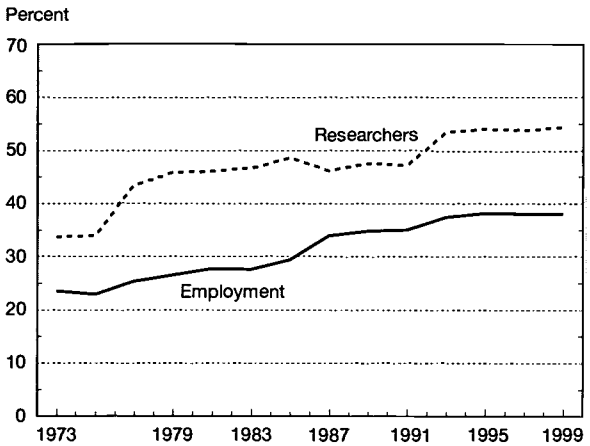
Academic researchers rely on the Federal Government for a significant share of their overall research support because about 60 percent of all academic R&D is federally funded. The institutional and field distributions of these funds are well documented, but little is known about their distribution across researchers. This section presents data from reports by doctoral scientists and engineers about the presence or absence of Federal support and an indication from those so supported as to which agencies have provided them with funds. However, nothing is known about the magnitude of these funds to individual researchers. (See sidebar, "Interpreting the Federal Support Data.")

Appendix table 5-38 shows the percentage of academic doctoral scientists and engineers who have received Federal support for their work, broken out by field. The analysis examines the overall pool of doctoral S&E researchers as well as young Ph.D.-holders, for whom support may be especially critical in establishing a productive research career.

Academic Scientists and Engineers With Federal Research Funds

In 1999, the Federal Government supported an estimated 46 percent of all doctoral academic scientists and engineers, 74 percent of those for whom research was the primary responsibility, and 37 percent of those for whom research was a secondary responsibility. (See appendix table 5-38.) With the exception of engineering, no major shifts appear to have occurred in the overall percentage of those so supported during the 1993–97 period. However, as text table 5-13 shows, the 1999 percentages, for S&E as a whole and physical sciences, mathematics, life sciences, psychology, and social sciences, were below those of the late 1980s, when Federal academic research funds were growing rapidly.

Figure 5-30.
S&E Ph.D.s employed in academe with research as primary activity as a percentage of all academic S&E Ph.D.s and of academic S&E Ph.D. researchers: 1973–99



NOTE: Academic researchers include those whose primary or secondary work activity is basic or applied research, development, or design.

See appendix tables 5-32 and 5-34.

Science & Engineering Indicators – 2002

The percentage of researchers who receive Federal support differs greatly across the S&E fields. In 1999, Federal support of S&E researchers ranged from 63 percent in earth, atmospheric, and ocean sciences to 29 percent in mathematics and 23 percent in social sciences. The earlier series (1973–91) shows an overall decline in the proportion of federally supported researchers through the early 1980s that coincided with stagnant real Federal R&D funds to academia, followed by a rise in the proportion supported during the second half of the 1980s, when funding again rose robustly. (See appendix table 5-38.)

Full-time faculty received Federal funding less frequently than other full-time doctoral employees, who, in turn, were less frequently supported than postdoctorates. In 1999, 43 percent of full-time faculty, 50 percent of other full-time employees, and 80 percent of postdoctorates received Federal support.

Interpreting Federal Support Data

Interpretation of the data on Federal support of academic researchers faces 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; in 1985, it was to one month. However, as clearly illustrated by these data series, the volume of academic research activity is not uniform over the entire academic year. A one-week (or one-month) reference period seriously understates the number supported over an entire year. Thus, the 1993–97 numbers (and those for 1985) cannot be compared directly with results for the earlier years or those from the 1999 survey, which again used an entire reference year.

The discussion here compares 1999 data with the earlier series and examines trend information for the mid-1990s using the 1993–97 data points. All calculations express the proportion of those 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 the trends in the proportion of all academic researchers supported by Federal funds occurred against a background of rising overall numbers of academic researchers.

Again, these proportions were lower than those during the latter part of the 1980s. (See appendix table 5-38.) It is unclear whether these estimates indicate relatively less generous support or greater availability of funds from other sources, some of which may not flow through university accounts.

Federal Support of Young Academic Ph.D.-Holders

Early receipt of Federal support is viewed as critical to launching a promising academic research career. The Federal

Text table 5-13.
Percentage of academic doctoral scientists and engineers with Federal support

Field	1979	1989	1999
S&E total	39.9	49.4	46.1
Physical sciences	44.1	58.2	55.7
Mathematics	21.7	33.5	29.1
Computer sciences	34.8	52.4	55.6
Earth, atmospheric, and ocean sciences	45.4	63.8	63.3
Life sciences	55.3	65.1	57.9
Psychology	32.6	35.5	32.9
Social sciences	20.4	27.7	22.9
Engineering	49.1	56.3	56.9

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Survey of Doctorate Recipients.

Science & Engineering Indicators – 2002

Government supports young academic doctoral scientists and engineers at higher rates than it does the overall academic S&E workforce but supports those in full-time faculty positions, as opposed to postdocs and those in other full-time positions, at lower rates. (See appendix tables 5-38 and 5-39.) Overall, 53 percent of those with recently earned doctorates (within three years of the survey) received Federal research funds, but only 29 percent of those in full-time faculty positions did (sharply lower than the rate of nearly 40 percent in the late 1980s). On the other hand, 80 percent of the postdocs had Federal funds. Mathematics and psychology stood out as having low percentages of postdocs with Federal support (59 and 64 percent, respectively) compared with 77 to 82 percent for the other fields.

In 1999, after young academics had gained some experience (i.e., four to seven years after award of the doctorate) their proportions of Federal support looked similar to those of the workforce as a whole. However, except for psychology, they experienced a much sharper decline in Federal support between 1989 and 1999. (See appendix tables 5-38 and 5-39 and text table 5-14.)

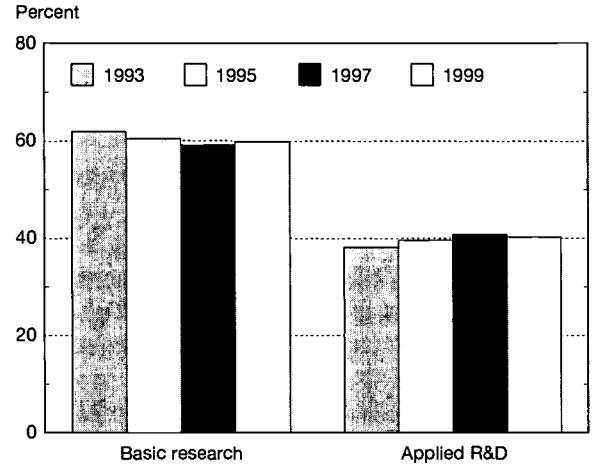
Has Academic R&D Shifted Toward More Applied Work?

Emphasis on exploiting the intellectual property that results from the conduct of academic research is growing. See "Outputs of Scientific and Engineering Research: Articles and Patents." Among the criticisms raised against this development is that it distorts the nature of academic research by focusing it away from unfettered basic research and toward the pursuit of more utilitarian, problem-oriented questions. One aspect of this issue is addressed in this section.

Did a shift toward applied research, design, and development occur during the 1990s, a period when academic patenting and licensing activities grew steeply? Doctoral academic scientists and engineers were asked about their primary or secondary work activities, including four R&D functions: basic research, applied research, design, and development. These data are used to address the question posed here.

As figure 5-31 shows, a very modest shift away from basic research from 61.9 percent in 1993 to 59.9 in 1999, which barely reaches statistical significance, is evident among those listing research as their primary work activity. However, when the headcount of all researchers is considered, no such effect is seen. These data suggest that among those whose primary work activity is research, some modest shift toward more applied work may have occurred. They also suggest that most academic researchers do not perceive a shift toward more applied kinds of research functions.

Figure 5-31.
Distribution of academic researchers' activities, by research function



NOTE: Academic researchers include those whose primary or secondary work activity is basic or applied research, development, or design.

SOURCE: National Science Foundation, Division of Science Resources Statistics. Survey of Doctorate Recipients.

Science & Engineering Indicators – 2002

Text table 5-14.
Percentage of academic doctoral scientists and engineers four to seven years after receiving their Ph.D. who have Federal support

Field	1979	1989	1999
S&E total	43.0	57.8	47.4
Physical sciences	52.0	72.4	57.0
Mathematics	32.3	39.0	32.2
Computer sciences	—	70.8	56.6
Earth, atmospheric, and ocean sciences	49.6	81.2	65.3
Life sciences	57.3	71.9	57.2
Psychology	39.3	36.1	35.6
Social sciences	20.8	33.2	22.8
Engineering	55.1	70.8	55.5

— = estimate suppressed because of small sample size

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Survey of Doctorate Recipients.

See appendix tables 5-38 and 5-39.

Science & Engineering Indicators – 2002

Outputs of Scientific and Engineering Research: Articles and Patents

The products of academic research include trained personnel and advances in knowledge. Trained personnel are discussed in chapter 4 of this volume and earlier in this chapter. This section presents two sets of indicators of advances in knowledge: articles published in a set of the world's most influential refereed journals (see sidebar, "Data Sources for Article Outputs") and patents awarded to U.S. universities and colleges.

Although academic researchers contribute the bulk of all scientific and technical articles published in the United States, the focus in this section is considerably broader. It includes U.S. articles in all sectors and total U.S. articles in the context of article outputs of the world's nations. The output volume of research, or article counts, is one basic indicator of the degree to which different performers contribute to the world's production of research-based S&E knowledge. The outputs of different U.S. sectors (universities and colleges, industry, government, and nonprofit institutions) indicate the relative prominence of these organizations in the United States overall and in particular S&E fields. The same indicator, aggregated by country, provides approximate information about the U.S. position in the global S&E enterprise and the emergence of centers of S&E activity to stimulate it, especially during the past decade.

Scientific collaboration in all fields increasingly crosses organizational and national boundaries. Articles by multiple authors in different venues or countries provide an indicator of the degree of collaboration across sectors and nations. Scientific collaboration has risen as governments have acted to stimulate it, especially over the past decade. Cross-sectoral collaboration is viewed as a vehicle for moving research results toward practical application. International collaboration, often compelled by reasons of the cost or scope of the issue, provides intellectual cross-fertilization and ready access to work done elsewhere.

The perceived influence of research results to advance the state of knowledge is reflected in citations. Both domestic and international citation patterns are examined in this section. References to scientific and technical articles on patents, which suggest the relatedness of research to presumed practical application, are also examined.

Finally, patents issued to U.S. universities are discussed. They provide another indicator of the perceived utility of the underlying research, with trends in their volume and nature

Data Sources for Article Outputs

The article counts, coauthorship data, and citations discussed in this section are based on S&E articles published in a stable set of about 5,000 of the world's most influential scientific and technical journals tracked since 1985 by the Institute of Scientific Information's (ISI's) Science Citation Index (SCI) and Social Science Citation Index (SSCI). Fields in these databases are determined by the classification of the journals in which articles appear. Journals, in turn, are classified based on the patterns of their citations. (See text table 5-15.)

Text table 5-15.
Classification of Institute for Scientific Information (ISI)-covered journals

Field	Percent of Journals
Clinical medicine	24
Biomedical research	11
Biology	10
Chemistry	7
Physics	5
Earth and space sciences	5
Engineering and technology	8
Mathematics	3
Psychology	6
Social sciences	11
Professional and health sciences[a]	10

[a]These fields have citation patterns strongly linked to social sciences and/or psychology. Appendix table 5-40 lists the constituent subfields (fine fields) of the journals covered here.

See appendix table 5-40. *Science & Engineering Indicators – 2002*

SCI and SSCI appear to give reasonably good coverage of a core set of internationally recognized scientific journals, albeit with some English-language bias. Journals of regional or local importance are not necessarily well covered, which may be salient for the categories of engineering and technology, psychology, social sciences, health, and professional fields, as well as for nations with a small or applied science base.

Articles are attributed to countries and sectors by the author's institutional affiliation at time of authorship. Thus, "coauthorship" or "multiauthorship" here refers to institutional coauthorship; a paper is considered coauthored only if its authors have different institutional affiliations. The same applies to cross-sectoral or international collaborations. For example, a paper written by an American temporarily residing in Britain with someone at his or her U.S. home institution is counted as internationally coauthored, thus overstating the extent of such collaborations. Likewise, an article written by a British citizen temporarily located at a U.S. university with a U.S. colleague would not be counted as internationally coauthored, thus understating the count. All data presented here derive from the Science Indicators database prepared for NSF by CHI Research, Inc. The database excludes all letters to the editor, news pieces, editorials, and other content whose central purpose is not the presentation or discussion of scientific data, theory, methods, apparatus, or experiments.

indicating the universities' interest in seeking commercialization of its results.

Publication Counts: U.S. and Worldwide Trends

The volume of articles published in the world's key science and technology (S&T) journals is an indicator of the national output of scientific and technical research in the United States and other countries. These core journals exercise a degree of quality control by requiring articles submitted for publication to undergo peer review, which in turn allows comparison of countries' relative efforts and helps reveal their priorities for scientific research. It also permits insight into both the patterns of collaboration across institutions and national borders and the degree and type of knowledge cited in scientific and technical articles.[30]

On a worldwide basis, scientific articles increased by 14 percent between 1986 and 1999, an average of 1 percent growth per year.[31] By region, the growth trend was disparate, with only the Pacific and Near East registering gains near the worldwide trend. Much of the growth was due to an increase of more than 30 percent in Western Europe, primarily in countries that are members of the Organization of Economic Cooperation and Development (OECD). These OECD countries account for more than 95 percent of Western Europe's output. It is likely that these gains reflect, at least in part, these nations' individual efforts as well as those of the European Union (EU) and other regional programs to strengthen the science base.[32] Many of the smaller and/or newer members of the EU, such as Austria, Belgium, Finland, Greece, Ireland, Portugal, and Spain, had very strong gains during this period. (See figure 5-32 and appendix table 5-41.)

Another region that witnessed very strong gains was Asia, where output nearly doubled during this period, primarily in the eastern half of Asia. This jump in output was driven by Japan, newly industrialized economies (NIEs) (South Korea, Taiwan, Singapore, and Hong Kong), and China. Despite its economic difficulties, Japan's output of articles grew by nearly 50 percent, coinciding with an increase in its R&D expenditures. The collective output of NIEs rose more than sevenfold during this period, coinciding with their rapid economic, technological, and scientific progress. China, a country with a far lower per capita income level compared with NIEs, registered a threefold gain in its publication output. China's economic development has characteristics similar to those of NIEs, as it has rapidly industrialized, adopted economic reform, and increased its expenditures for R&D. In the western half of Asia, output fell during this period by 5 percent due to a 7 percent decrease in India's output, a matter of concern to that nation (see Raghuram and Madhavi 1996).[33]

The largest increase in any region during this period occurred in Latin America, which more than doubled its output. However, this increase was from a low base and concentrated in three countries (Argentina, Brazil, and Mexico), which generated nearly 80 percent of the articles produced by this region in 1999. These countries share the following characteristics: a moderately high per capita income, a relatively large pool of scientists and engineers, and recent reform of their economies and scientific enterprise. In addition, Brazil and Mexico raised expenditures for R&D during the early and mid-1990s.[34]

The Near East, comprising North Africa and the Middle Eastern countries, increased its output by 20 percent during this period. Although Israel, a mature and wealthy industrialized country, dominates output in this region, its growth was stagnant. Excluding Israel, output rose by more than 50 percent during this period. Countries in North Africa, such as Algeria, Morocco, and Tunisia, and in the Middle East, such as Iran, Jordan, and Syria, more than doubled their output of journal articles, although this increase was from a very low base.

Regions whose share of world output decreased were Eastern Europe, Sub-Saharan Africa, and North America. (See

[30] To facilitate comparisons between countries, the numbers reported here are based on the 1985 ISI set of core journals. This set of influential world S&T journals has some English language bias but is widely used around the world. See, for example, Organization of American States (1997) and European Commission (1997). Also see the sidebar, "Data Sources for Article Outputs" in this chapter.

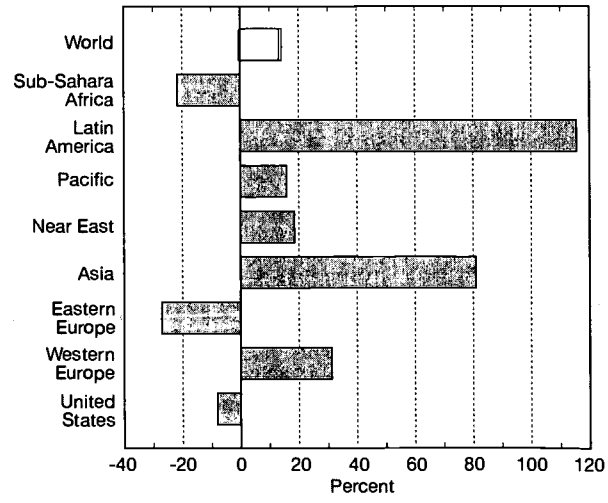
[31] This is a minimum estimate. An expanded 1991 journal set yields an average per annum growth rate of 1.4 percent for the 1990s. In addition, a fixed journal set is biased against growth by excluding the addition of new journals.

[32] These include five-year Framework Programmes of the EU, EU funding provided through Structural Funds, Community Initiatives Programmes, and efforts outside the EU framework such as EUREKA, a program to stimulate partnerships between industry, universities, and research institutes. See NSF (1996) for a brief discussion and European Commission (1997) for a fuller treatment.

[33] The authors note that this decline cannot be attributed to journal coverage in the SCI and that it is paralleled by a decline in citations to articles by authors from India. They speculate that an aging scientific workforce may be implicated, along with a "brain drain" of young scientists from India whose articles would be counted in the countries in which they reside, not in their country of origin.

[34] See the NSF report, "Latin America: R&D Spending Jumps in Brazil, Mexico, and Costa Rica at <http://www.nsf.gov/sbe/srs/nsf00316/start.htm>.

Figure 5-32.
Growth trends in scientific and technical publications by region: 1986–99

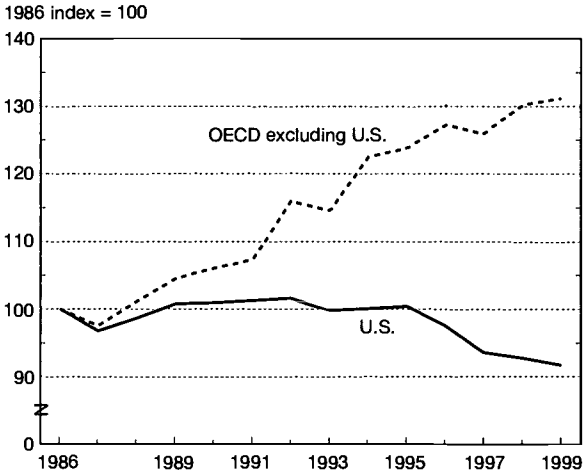


See appendix table 5-40. *Science & Engineering Indicators – 2002*

Trends in U.S. Scientific and Technical Articles

The number of scientific and technical articles by United States authors appears to have peaked in 1992, then fallen throughout the remainder of the 1990s, with output in 1999 down by 10 percent compared to 1992. This trend diverged from growth in most other OECD countries during this period and is a reversal from three prior decades of consistent growth. (See figure 5-33.)

Figure 5-33.
Output of scientific and technical papers for the U.S. and OECD: 1986–99



OECD = Organisation for Economic Co-operation and Development

NOTE: OECD count includes only high income (as defined by the World Bank) members.

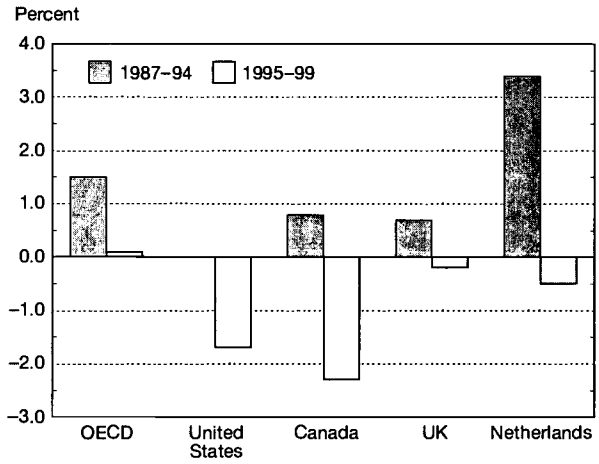
See appendix table 5-41. *Science & Engineering Indicators – 2002*

The 1985 journal set on which much of this chapter's analysis is based is biased against growth because it excludes articles published in journals issued since 1985. However, a larger set of journals from 1991 and 1995 shows similar trends for U.S. scientific and technical articles through the latter half of the 1990s. The reasons for this development remain unknown.

This phenomenon is not limited to the United States. Three industrialized countries with a significant output of publications (Canada, the United Kingdom, and the Netherlands) also experienced a fall in S&T articles during the latter half of the 1990s. (See figure 5-34.) In addition, in the latter half of the 1990s, the growth rate in the output of most other OECD countries slowed relative to the early 1990s.

As shown in text table 5-16, the downward trend in U.S. scientific and technical articles has been broad based, affecting almost all fields:

Figure 5-34.
Average growth in scientific and technical papers for selected countries



OECD = Organisation for Economic Co-operation and Development

NOTE: OECD count includes only high income (as defined by the World Bank) members.

See appendix table 5-41. *Science & Engineering Indicators – 2002*

Text table 5-16.
Change in U.S. output of scientific and technical articles, by fields: 1992–1999

Field	1992–1999 (percent change)	Percentage contribution to total decline
All fields/total	–10	100
Life sciences	–7	41
Clinical medicine	–5	15
Biomedical research	–6	10
Biology	–22	16
Chemistry	–9	7
Physics	–9	9
Earth and space sciences	13	–6
Engineering and technology	–26	19
Mathematics	–10	2
Social and behavorial sciences	–19	28

NOTE: Social and behavorial category consists of the social sciences, psychology, health, and professional fields. Computer science is included in engineering and technology.

SOURCES: Institute for Scientific Information, Science and Social Science Citation indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, Division of Science Resources Statistics (NSF/SRS).

Science & Engineering Indicators – 2002

- The largest decrease in published articles, 26 percent, occurred in the engineering and technical field, which accounted for 19 percent of the overall decline.
- Life sciences accounted for more than 40 percent of the overall decrease in articles. Biology experienced the steepest decrease (22 percent), accounting for 16 percent of the overall decline. Although the decrease in articles in clinical medicine and biomedical research was much smaller (5 and 6 percent, respectively), these two fields accounted for 25 percent of the overall decline due to their preponderant share (49 percent) of scientific and technical articles.
- Output in social sciences and related fields fell 19 percent, accounting for almost one-third of the overall decline.
- Articles in chemistry and physics each decreased by 9 percent during this period, accounting for 16 percent of the overall decline.

Almost all sectors were affected by this trend in S&T articles. Together, the private for-profit sector, which experienced a 24 percent decrease, and the Federal Government, which experienced a 17 percent decrease, accounted for 35 percent of the overall decline. (See text table 5-17.) The decrease in articles produced within academia was less pronounced (9 percent) but, because of the sector's high share of total output, it accounted for 64 percent of the overall decline.

In each of these sectors, several fields were most affected. In academia, almost half of the decrease was in the life sciences; one-third was in the social sciences; and about 15 percent was in the engineering and technical field. The life sciences were also the prime factor in the fall in publications in the Federal Government, accounting for two-thirds of the overall decrease. The engineering and technical field and social sciences contributed to most of the remainder of the lower article output in this sector. In the private sector, more than 80 percent of the decline was in three fields: physics (38 percent), engineering and technical (24 percent), and chemistry (19 percent).

Text table 5-17.
Trend in U.S. scientific and technical articles, by sector: 1992–99
(Percentage)

Sector	Decline	Contribution
Total	10	100
Academia	9	64
Federal Government	17	14
Private	13	20
For profit	24	21
Nonprofit	1	1
FFRDC	1	0
Other	13	3

FFRDC = Federally Funded Research and Development Center

SOURCES: Institute for Scientific Information, Science and Social Science Citation indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, Division of Science Resources Statistics (NSF/SRS).

Science & Engineering Indicators – 2002

A preliminary review of the reasons behind the trends in the number of U.S. articles examined the following:

- **Methodology.** Article counts for the United States and other countries are based on a fixed set of journals from the 1985 SCI/SSCI database. Unless noted, the journals are counted on a fractional basis, which credits the authors of multiple authored papers their fractional contribution. Although this approach facilitates consistent comparison over time and between countries, it biases against growth, for two reasons: A fixed set of journals excludes new journals that have been added to the SCI/SSCI database. Growth in international collaboration depresses the count of each nation's internationally coauthored papers (because each country's coauthor is credited with a portion of the paper). If counting is done on the basis of the entire SCI/SSCI database and with whole counts, the number of U.S. articles shows growth; however, their growth rate is slowing.
- **Coverage.** The coverage of the SCI/SSCI database may be incomplete or otherwise flawed, a problem shared by all bibliographic databases because of the impossibility of indexing all scientific literature. The SCI/SSCI database, however, has the most complete coverage of any bibliographic database, and it arguably covers the most significant and important peer-reviewed scientific journals. Because only a fraction of scientific literature is considered to be of high quality and important, based on the frequency of citations, the limited coverage of bibliographic databases does not appear to be a major problem for measuring quality scientific publications.
- **Electronic publishing.** The Internet is changing scholarly communication, but whether it is depressing traditional publishing is unclear. The number of peer-reviewed electronic publications has grown rapidly, from 29 in 1993 to 1,049 in 1997.* Although high-quality electronic journals are included in the SCI/SSCI database, it is possible that some publications are missed, especially if these journals are rapidly expanding. One way to ascertain whether electronic publishing is implicated in the U.S. article decline is to see whether established journals are citing electronic journals. An analysis of reference patterns in a sample of 986 papers published in 1990, 1995, and 1997 found few references to Internet URLs. The lack of references

* National Science Board. 2000. *Scientific and Engineering Indicators 2000.* NSB-00-1. Arlington, VA: National Science Foundation, pp. 9–30.

to Internet URLs might indicate that this practice was not very common in 1997.

- **Commercialization of academic science.** Academic science may have become increasingly commercialized over the past two decades. Universities, often in partnership with industry, have moved to commercialize their research through patenting, licensing, and establishing spin-off companies. In this environment, some academic researchers may be delaying or withholding their research because of proprietary concerns. In addition, patenting by academic researchers might absorb time that would otherwise be devoted to publishing. Some research suggests that researchers in the life sciences, which has been the key field in commercialization, delay or refrain from publishing. A 1997 survey of life science researchers found that 30 percent of respondents reported that they delayed or withheld publication of their research due to proprietary concerns.[†] In addition, in a survey of 1,000 technology managers and faculty of top research universities, 79 percent of technology managers and 53 percent of faculty reported that participating firms had asked that certain research findings be delayed or withheld from publication.[‡] Although the number of articles in this field fell at a slower rate than that of the overall decline, this field's predominance meant that it accounted for almost half of the apparent decrease. By sector, it was the major factor in the decline in articles from universities and the Federal Government. However, there appears to be no significant difference in the overall output of articles from universities that are major patenters and those that are not. The change in output of the former between the two three-year periods ending in 1995 and 1999 was –5.4 percent compared with –4.6 percent for the latter.

- **Changes in U.S. R&D funding.** U.S. research funding patterns could explain the decline in article output. It is very difficult or impossible, however, to precisely match funding and publication by field, because the fields are classified and defined differently. In addition, scientists in a given funding field may publish their results in a journal that is classified in a different bibliographic field. For fields in which an approximate match could be made, the findings were inconclusive. For example, the fall in articles in biology and physical sciences coincided with a fall in Federal spending (in real terms) in these two fields. However, increases in funding for physics coincided with a decline in articles. Matching funding and publication by sector is more straightforward, because institutions are classified the same way. However, there appears to be no correlation between these two variables. Basic and applied research expenditures have increased in universities and the Federal Government, but article output has declined in these sectors. However, funding increases in the nonprofit institutions and nonprofit FFRDCs have coincided with increased article output in these sectors. A more precise match between NIH publication output and intramural expenditures reveals that the trend of funding and publication growth diverged in the early 1990s, with publication growth flattening as funding continued to increase.

- **Demography.** The U.S. scientific workforce has aged significantly since the 1970s. In the early 1970s, nearly half of all academic scientists and engineers were younger than age 40. Twenty years later, that figure had fallen to 28 percent, and by 1997, it had dropped to 25 percent. If age affects research productivity negatively, then this factor could provide a plausible explanation.[§] However, the apparent decline in publications did not occur until after this demographic shift had been well under way during the previous two decades.

- **Growth in foreign publishing.** During the 1990s there has been robust growth in foreign-authored publications. Scientific publications indexed to SCI have grown rapidly in many developed and several developing countries, notably in Western Europe, Latin America, and East Asia reflecting the growth in their production of S&E Ph.Ds. In addition, IT developments may have helped to level the playing field for scientists who were isolated or lacked access to relevant journals in their research fields, particularly in developing countries. Because there is limited space for high-quality articles, it may be that foreign publications are displacing U.S. publications. An indication of that possibility is shown by articles published in *Science* magazine. The number of U.S. papers in *Science* decreased by 5 percent between 1994 and 1999, while the total number of papers increased by 9 percent.

These and other factors will be the subject of further assessment of the nature of the trends affecting U.S. articles in the world's premier scientific and technical journals.

[†] Blumenthal, D., E.G. Campbell, M.P. Anderson, N. Causino, and K. Seashore Louis, 1997. "Withholding Research Results in Academic Life Science."

[‡] Florida, R. 1999. "The Role of the University: Leveraging Talent, Not Technology."

[§] Two studies reached different conclusions on this issue. See Blackburn, R. and J. Lawrence. 1986. "Aging and the Quality of Faculty Job Performance." *Review of Educational Research* (Fall): 265–90, and Levin, S., and P. Stephan. 1991. "Research Productivity Over the Life Cycle: Evidence for Academic Scientists." *American Economic Review* (March): 114–32.

figure 5-32 and appendix table 5-41.) Eastern Europe's share of worldwide output fell from 9 to 6 percent during this period. Publication volume in countries of the former Soviet Union dropped by one-third. This decline mirrors the economic and political difficulties that affected their scientific enterprise, including significant cuts in their R&D spending. In contrast, the Eastern European countries (Bulgaria, the Czech Republic, Hungary, Poland, Romania, and Slovakia) experienced a much smaller decrease in articles, and in the mid-1990s, their output began trending upward. In Sub-Saharan Africa, output fell by 20 percent during this period, which reduced this region's share to less than 1 percent of world output. Countries that experienced significant declines included South Africa, which accounts for about half of the region's output, Nigeria, and Zimbabwe. However, several countries, including Cameroon, Cote d'Ivoire, Ethiopia, and Uganda, registered strong gains in their output, although these gains came from a very low base.

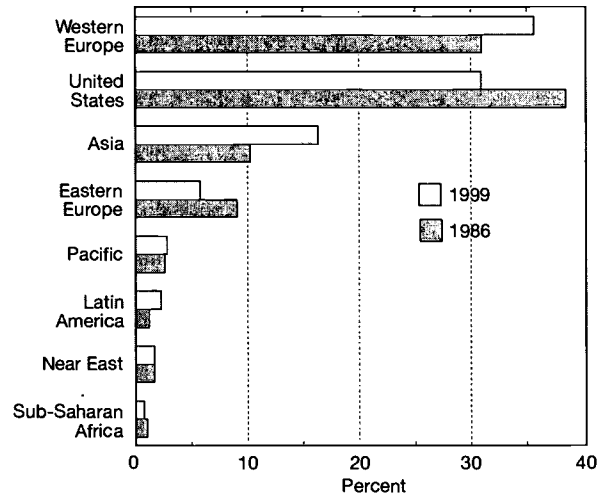
Notwithstanding the trend in the number of U.S. publications (see sidebar, "Trends in U.S. Scientific and Technical Articles"), the United States had the largest single share of worldwide publications in 1999, accounting for approximately one-third of the 530,000 articles in the 1985 SCI set of journals, more than triple the share of the next largest country, Japan. The United States and four other wealthy industrialized countries (Japan, Germany, the United Kingdom, and France) accounted for about 60 percent of worldwide publications in 1999. Japan, Germany, the United Kingdom, and France each had at least a 5 percent share of the worldwide output of articles, and on a per capita basis, their output was comparable with or exceeded that of the United States.

Nevertheless, the combined share of world output of the United States and these four countries declined from 64 to 60 percent during the 1986–99 period, due in large part to the apparent fall in U.S. articles, which reduced the U.S. share from 39 percent in 1986 to 31 percent in 1999. (See figure 5-35). The article share of Western Europe rose from 31 percent to 36 percent of world output during this period due to strong gains by most of these countries.

When the OECD and other high-income countries are added to the United States, Japan, Germany, the United Kingdom, and France, more than 80 percent of world output of the 1985 SCI journal set is accounted for. The predominance of these countries in scientific publications is consistent with their wealthy and technically advanced economies, extensive scientific and technical infrastructure, large pools of scientists and engineers, and comparatively high levels of expenditures for their science and engineering (S&E) enterprises.[35] However, increased S&T publishing in countries such as China, South Korea, Brazil, Mexico, and Argentina has increased the worldwide output of middle- and low-income countries. (See figure 5-36).

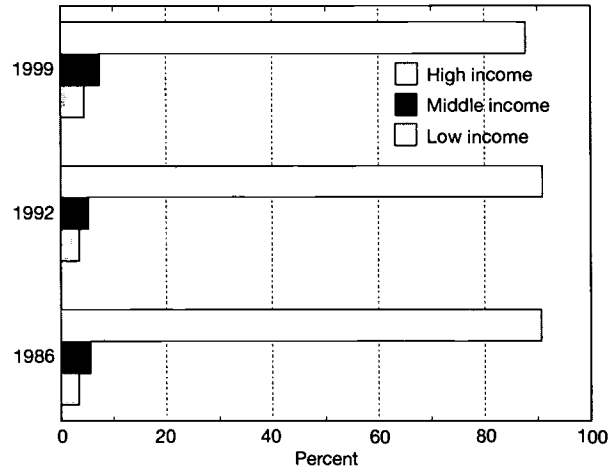
[35] Also see chapter 3, "Higher Education in Science and Engineering"; chapter 4, "U.S. and International Research and Development: Funds and Alliances"; and chapter 6, "Industry, Technology, and the Global Marketplace."

Figure 5-35.
Scientific publications: Regional share of world output



See appendix table 5-41. *Science & Engineering Indicators – 2002*

Figure 5-36.
Country share of world scientific publications, by income level



NOTE: Countries without World Bank income classification and new countries are excluded.

SOURCES: Articles: Institute for Scientific Information, Science and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, Science Indicators database. Country income: The World Bank, World Development Indicators 2000.

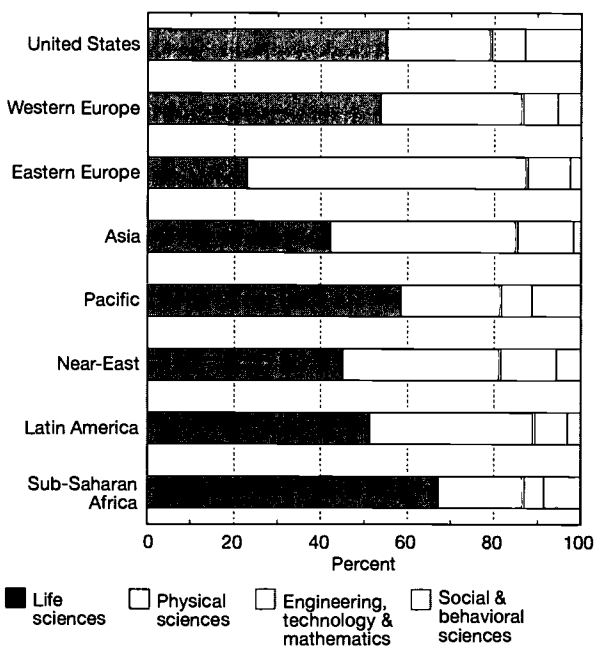
Science & Engineering Indicators – 2002

Examining the portfolio of scientific papers across regions and countries provides an indication of the priorities and emphasis of scientific research. The U.S. portfolio is broad and diverse, although dominated by life sciences. This pattern is similar to that of other OECD countries, but for major European nations the physical sciences shares are larger than in the

U.S. (See figure 5-37 and appendix table 5-43.) The life sciences (clinical medicine, biomedical research, and biology) accounted for more than half (55 percent) of all U.S. articles published in 1999. Their share has remained roughly constant over the past two decades, with marginal gains by clinical medicine and biomedical research offsetting a small loss by biology. Another one-quarter of the 1999 articles were produced in the physical and environmental sciences (chemistry, physics, and earth and space sciences) and mathematics. These fields registered a slight gain of three points compared with 1986. The remainder of the portfolio is accounted for by engineering and technology (6 percent) and social and behavioral sciences (13 percent), consisting of social sciences, psychology, health, and professional fields. The latter two fields have close ties (based on citations) to the former two fields.

The portfolio distribution in Western Europe and the Pacific is similar to that of the United States, except that physical sciences have greater prominence in Western Europe. (See figure 5-37.) Articles in physical sciences increased slightly in Western Europe between 1986 and 1999, while articles in life sciences decreased. In Asia, the physical sciences and engineering and technical fields were more prominent and life sciences and social sciences less so, especially in NIEs, China, and India. In these countries, life sciences accounted for one-quarter of the portfolio and physical sciences for more than half. The portfolios of the Asian NIEs underwent sizable shifts, with the share of physical, engineering and technical, and mathematical sciences growing dramatically from 40 percent of total output to more than 54 percent, largely due to an 11 percent share increase by physics. During the same period, the share of social and behavioral sciences declined from 12 to 3 percent. In contrast, Japan's portfolio is closer to that of Western Europe, with greater emphasis in life sciences (half of all articles) and less emphasis in the engineering and technical field.

Figure 5-37.
Portfolio distribution of scientific and technical publications, by region: 1999



NOTES: Life sciences consist of clinical medicine, biomedical research, and biology. Physical sciences consist of chemistry, physics, and earth and space sciences. Social and behavioral sciences consist of social science, psychology, health, and professional fields. Computer sciences is included in engineering and technology.

See appendix table 5-43. *Science & Engineering Indicators – 2002*

In Eastern Europe and the former Soviet Union, the portfolio mix is similar to that of Asia, with physical sciences accounting for more than half of the total article output. The portfolio has shifted notably during this period; the share of life sciences declined from 36 to 23 percent, while that of physical sciences rose from 56 to 65 percent. The Near East region's portfolio is similar to that of Asia and Eastern Europe, with greater prominence of articles in physical sciences, which have increased relative to life sciences over the past two decades. Sub-Saharan Africa has the highest regional share of output in life sciences in the world (67 percent) and the smallest share in engineering and technology. The portfolio mix in Latin America is similar to that of Western Europe, with life and physical sciences being prominent, although the mix has shifted to a greater share for physical sciences relative to the life and social sciences.

In the United States, universities were the primary institutional source of publications (74 percent) in 1999, followed by much smaller shares from the Federal Government (7 percent), private for-profit (8 percent), private nonprofit (7 percent), and federally funded research and development centers (FFRDCs) (3 percent). (See figure 5-38.) Examining the data by field of science shows that the academic sector produced a greater-than-average share of articles in the fields of biomedical research, mathematics, and the social and behavorial sciences. Industry articles were prominent in physics, engineering and technology, and chemistry. Articles published by the Federal Government were prominent in the fields of biology, clinical medicine, and earth and space sciences. The nonprofit's portfolio was dominated by clinical medicine.(See appendix table 5-44).

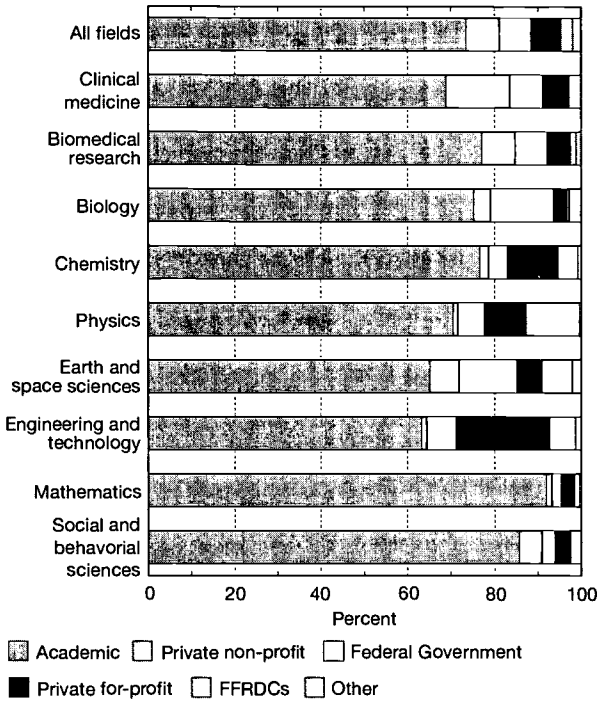
Scientific Collaboration

Scientific collaboration within and across national borders has increased significantly in the last two decades. Worldwide, more than half of all articles were coauthored[36] in 1999 compared with 37 percent in 1986. During the same period, the share of internationally coauthored articles rose from 7 to 17 percent of all publications; i.e., more than one-third of coauthored articles were internationally coauthored. Several factors have been driving the rise in collaboration:

- **IT.** Advances in IT have helped to reduce the geographical and cost barriers to domestic and international collaboration. E-mail greatly facilitates collaboration by allowing rapid exchange of information and eliminating the need for costly face-to-face meetings. The increasing use of high-capacity networks allows researchers to exchange

[36]A paper is considered co-authored when it has authors from different institutions. "Internationally coauthored" papers have at least one international institutional author. See "Data Sources for Article Outputs" on pg. 56-57.

Figure 5-38.
U.S. authorship, by sector: 1999



FFRDCs = Federally Funded Research and Development Centers

NOTES: Social and behavorial sciences consist of social sciences, psychology, health, and professional fields. Computer science is included in engineering and technology.

SOURCES: Institute for Scientific Information, Science and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; National Science Foundation, Division of Science Resources Statistics.

Science & Engineering Indicators – 2002

huge data files, and improvements in software permit researchers to share research findings or conduct research on-line without requiring a centralized laboratory. (See also the "IT and R&D" section in chapter 8).

- **Economic growth.** Technology is increasingly recognized as a key determinant of economic growth by most nations, and the lag between scientific research and practical applications appears to have narrowed. In an environment of liberalization of trade and investment, scientific collaboration allows countries to acquire scientific and technological proficiency to maintain their competitive advantage or compete in new markets. For established scientific nations, domestic and international collaboration affords benefits such as cost savings, the potential to make faster progress, the ability to apply different or multidisciplinary approaches to problems, and the ability to stay abreast of advances made in related fields and other countries. Domestic and international collaboration allows nations with smaller or less developed S&T systems, to leverage and boost their indigenous capacity and provides a means to acquire knowledge from more advanced nations.

- **Scale, cost, and complexity of scientific research.** As the scale, cost, and complexity of attacking many problems have increased, research teams have become common, changing the structure of the research. Cutting-edge science in many fields increasingly involves a broad range of knowledge, perspectives, and techniques that extend beyond a given discipline or institution. Moreover, the scale, cost, and complexity of some of today's scientific problems, such as mapping the human genome, studying global environmental trends, or constructing an observatory in space, invite or often compel domestic and international collaboration.

- **Politics.** The end of the cold war has allowed countries to establish and/or renew political, economic, and scientific ties that previously were not possible. The dissolution of the former Soviet Union also increased the number of collaborating countries. In addition, a web of intergovernmental agreements invites or requires multinational participation in some research activities.

- **Education.** The extent of the advanced training students receive outside their native countries also appears to be a factor.[37] Relationships established between foreign students and their teachers can form the basis of future collaboration after the students return to their native countries. IT facilitates this type of collaboration.

Collaboration Within the United States

Work produced by single authors is in decline in virtually all fields, and the proportion of U.S. scientific and technical articles by multiple authors has continued to rise. In 1999, 60 percent of all S&E articles had multiple authors, up from 48 percent in 1988. This reflected an approximate 30 percent decrease in the number of U.S. articles by single authors and a corresponding increase in the number of articles by multiple authors. This general pattern held for all but psychology and social and behavioral sciences; in that group output by authors from the same institution fell and from authors from multiple institutions was static. (See appendix table 5-45.) Multiple authorship was highest in clinical medicine, biomedical research, earth and space sciences, and physics (ranging from 63 to 69 percent), and lowest in the social sciences, psychology, and chemistry (ranging from 35 to 48 percent).

Collaboration across institutions in the United States is extensive. The Federal Government has long sought to stimulate this trend in several ways, for example, by promoting collaboration across sectors (e.g., industry-university or FFRDC-industry activities). Such cross-sector collaboration is seen as enriching the perspectives of researchers in both settings and as a means for more efficiently channeling research results toward practical applications.

In 1999, cross-institution or -sector collaboration (the share of multi-authored papers authored in different sectors as a percentage of all multi-authored papers was 77 percent or greater for all institutions except the academic sector. (Text

[37]See chapter 3, "Higher Education in Science and Engineering."

Text table 5-18.
U.S. sector cross-collaboration: 1999
(Percentage)

Sector	Share of sector's coauthored papers with other sectors	Share of sector's cross-sectoral collaborated papers					
		Academic	Federal Government	Private for-profit	Private nonprofit	FFRDC	Other government
Academic	37	NA	32	25	36	13	6
Federal Government	81	87	NA	14	14	6	3
Private for profit	77	82	17	NA	16	7	2
Private nonprofit	79	90	13	13	NA	3	3
FFRDC	80	85	14	14	7	NA	0
Other government	92	86	19	11	20	1	NA

FFRDC = Federally Funded Research and Development Center, NA = not applicable

NOTES: Shares based on whole counts of publications, where each institutional author is assigned a whole count. This counting methodology results in the sum of sector shares exceeding 100 percent because some coauthored papers involve collaboration across more than two sectors. FFRDC includes FFRDCs administered by university, industry, and nonprofits.

See appendix table 5-46.

Science & Engineering Indicators – 2002

table 5-18 and appendix table 5-46.) The academic sector was at the center of cross-sectoral collaboration in every sector and field, although the academic sector itself had a much lower cross-sectoral share (37 percent), because the majority of its collaboration occurred among institutions of higher education. Cross-sector coauthorship rates with academia (the percentage of a sector's cross-sector coauthored papers with an academic collaborator) were at least 82 percent for other sectors.

Distinct collaborative relationships exist by field of science, as measured by the share of cross-institutional papers:

- **Clinical medicine.** This field is characterized by a high degree of collaboration across institutions (as well as a high share of multiauthored papers). Important partnerships in this field include universities and the Federal Government with nonprofit organizations and FFRDCs and the Federal Government and nonprofit organizations.
- **Biomedical research.** The private sector is a key collaborator with other institutions, with nonprofits authoring papers with academia and the FFRDCs and industry partnering with the Federal Government and nonprofits.
- **Biology.** Although the proportion of multiauthored papers is lower than for other life sciences, cross-institutional papers are a significant share of these multiauthored papers. Similar to biomedical research, the private sector is a key collaborator, authoring papers with the Federal Government, academia, and nonprofits. In addition, academia and the FFRDCs are significant collaborators.
- **Chemistry.** Industry is a key collaborator, authoring papers with nonprofit organizations, academia, and the Federal Government.
- **Earth and space sciences.** This field has the highest share of multiauthored papers, including collaboration across sectors. The Federal Government and FFRDCs have prominent ties to the private sector in this field.
- **Engineering and technology.** This field is similar to biology, with a lower share of multiauthored papers but a higher-than-average share of cross-sector papers. Industry is a collaborator with academia, FFRDCs, and the Federal Government. In addition, FFRDCs have prominent ties with the academic sector.
- **Physics.** The Federal Government has prominent ties to FFRDCs and industry in this field.

International Collaboration

International collaboration increased greatly over the past two decades, as indicated by multiauthor articles with at least one international author. From 1986 to 1999, the total number of internationally coauthored articles increased by 14 percent, while multiauthored papers rose by 65 percent, raising the share of multiauthor articles from 37 percent to more than half of total publications. Internationally coauthored papers nearly tripled in volume, raising their share from 20 to 32 percent of multiauthored papers. In 1999, 17 percent of scientific articles had at least one international author.

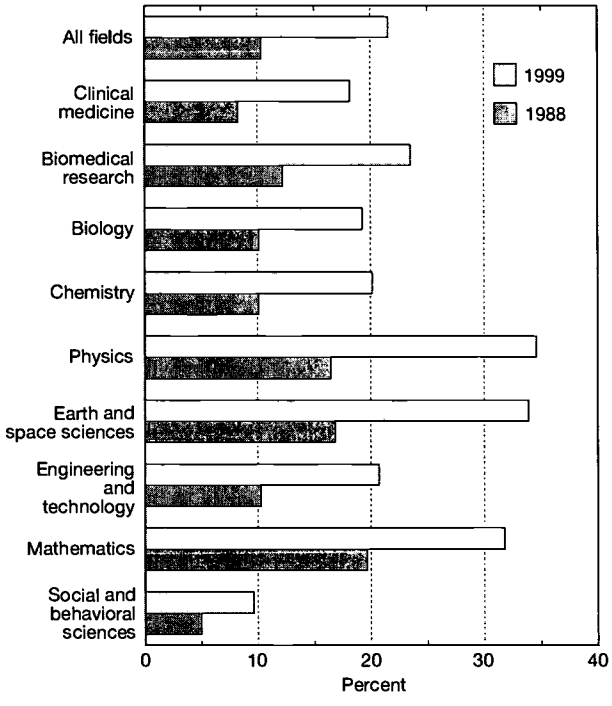
Patterns of international coauthorship provide one indication of the extent of collaborative ties among nations and regions. By this indicator, several trends in international collaboration are evident:

- The dominant centers in the production of S&T papers, the United States, Western Europe, Japan, and several other Asian countries, are centers of international scientific collaboration. A substantial part of these countries' international collaboration is with the other countries in this group.
- The remaining regions of the world with largely developing and emerging economies (Eastern Europe, the Near East, North and Sub-Saharan Africa, and Latin America) conduct most of their collaboration outside their regions with the United States, Western Europe, and Asia.

U.S. International Collaboration. Almost all the increase in coauthored U.S. articles reflected rising international collaboration. By 1999, 1 article in 5 had at least one non-U.S. author, compared with 1 article in 10 in 1988. (See figure 5-39.) Rates of international coauthorship were highest for physics, the earth and space sciences, and mathematics, ranging from 32 to 35 percent of all U.S. articles. International collaboration rates were much lower (10 percent) in social and behavioral sciences.

United States authors participate prominently in international collaborations. In 1999, 43 percent of all published papers with at least one international coauthor had one or more U.S. authors. U.S.-international coauthorships encompass not only the world's major scientific countries but also many developing and emerging economies. This included countries with low overall rates of international collaboration. In 1999, U.S. researchers published collaborative scientific papers with researchers from 160 countries—almost every country in the world that authored international scientific papers. (See appendix table 5-47).

Figure 5-39.
U.S. international collaboration, by field



NOTES: Social and behavioral sciences consist of social science, psychology, health, and professional sciences. Computer science is included in engineering and technology. Field volume is in terms of whole counts, where each collaborating institutional author is assigned an entire count.

SOURCES: Institute for Scientific Information, Science and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, Division of Science Resources Statistics.

Science & Engineering Indicators – 2002

With few exceptions, U.S. coauthorship with Western Europe is extensive. This share ranged from 23 to 35 percent, including the three Western European countries with the highest output of scientific publications: the United Kingdom (29 percent), Germany (30 percent), and France (25 percent). (See text table 5-19 and appendix table 5-48.) U.S. coauthorship

Text table 5-19.
International coauthorship with the United States: 1986 and 1999
(Percentage)

Country/economy	U.S. share of country's internationally coauthored articles 1999	1986
Taiwan	60	67
South Korea	57	67
Israel	53	68
Canada	51	53
Mexico	43	56
Japan	42	56
Brazil	40	38
India	37	37
Kenya	37	36
New Zealand	37	38
Australia	37	40
Uganda	36	36
Turkey	35	40
Chile	35	47
Egypt	34	40
Singapore	33	28
Italy	32	36
Switzerland	32	32
South Africa	32	37
Argentina	30	44
China	30	51
Germany	30	35
Netherlands	30	30
United Kingdom	29	35
Hong Kong	29	64
Norway	29	29
Finland	28	34
Denmark	28	28
Hungary	28	25
Sweden	27	36
Poland	25	21
Russia	25	na
Spain	25	29
France	25	29
Ireland	25	24
Belgium	23	28
Czech Republic	22	na
Nigeria	21	34
Ethiopia	18	13
Malaysia	10	24

na = not applicable

NOTES: U.S. internationally coauthored articles involve at least one U.S. author. Countries ranked by share in 1999.

SOURCES: Institute for Scientific Information, Science and Social Science Citation indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, Division of Science Resources Statistics (NSF/SRS).

Science & Engineering Indicators – 2002

rates with Asia were generally higher than with Western Europe, ranging from 30 to 60 percent (with a few exceptions) of each country's internationally coauthored papers. U.S. collaboration was especially high with NIEs (Taiwan at 60 percent, South Korea at 57 percent, and Singapore at 33 percent); China at 30 percent; and two countries that have low overall rates of international collaboration, Japan at 42 percent and India at 37 percent. U.S. coauthorship rates with Latin American countries were similar to those of Asia, ranging from 20 to 60 percent in most countries in this region. This includes the countries of Argentina and Brazil, which have a significant share of regional output but a lower overall rate of international coauthorship than other countries in this region.

U.S. coauthorship rates with Sub-Saharan Africa and the Near East varied widely, from less than 10 percent to greater than 60 percent. However, the United States tended to have a relatively high rate of collaboration with countries that have significant regional output, such as Israel (53 percent), Egypt (34 percent), Kenya (37 percent), and South Africa (32 percent) U.S. coauthorship rates with Eastern Europe were lower, generally ranging from 15 percent to 38 percent, such as Hungary (28 percent), Poland (25 percent), Russia (25 percent), and the Czech Republic (22 percent) in 1999.

The countries which had the highest rate of collaboration with the U.S., as measured by their share of U.S. international articles, were largely those with mature S&T systems. Of the top 10 countries, 6 are in Western Europe; Germany (14 percent), the United Kingdom (12 percent), France (9 percent), Italy (7 percent), Switzerland (4 percent), and the Netherlands (4 percent). (See text table 5-20.) Japan is also a significant collaborator, with a 10 percent share of U.S. international papers. Of these countries, Germany, the United Kingdom, Japan, and France have the highest worldwide share of output after the United States. Canada and Australia are significant collaborators, with shares of 11 and 5 percent, respectively. Russia, with a share of 4 percent, rounds out the top 10 countries.

Little change occurred in these countries' shares of articles coauthored with the United States as compared with the previous decade, except for Russia, which established strong institutional partnerships with the United States during that period. Another important change in U.S. ties is the growing partnership with the Asian NIEs. Although no single NIE is among the top 10 countries, the NIEs have collectively increased their share of U.S. international articles from 2 percent in 1986 to 6 percent in 1999. The patterns of U.S. collaboration with the rest of the world also appear to reflect the ties of foreign students who received advanced training in the United States. (See figure 5-40.)

Compared with the previous decade, U.S. international collaboration declined slightly, falling from 51 percent in 1986 to 43 percent in 1999, as the volume of internationally coauthored papers expanded at a rate faster than the strong growth rate of U.S. coauthored international papers in almost all countries. This pattern, a robust expansion of U.S. coauthored papers accompanied by declining U.S. shares, held for almost all countries. This pattern suggests that new centers of activity and collaboration are evolving.

International Collaboration in the Rest of the World. International collaboration in the rest of the world followed trends similar to those of the United States. In most countries, the number of articles with multiple authors, especially those with at least one international coauthor, grew faster than the number of articles with single authors. This was generally due to an expansion in the volume of internationally coauthored articles and an increase in the number of collaborating countries. The scope of international collaboration among other nations can be seen in appendix table 5-47, which shows the total number of countries with any collaborating nondomestic author on a given nation's papers.

Text table 5-20.
U.S. international papers: top collaborating countries
(Percentage)

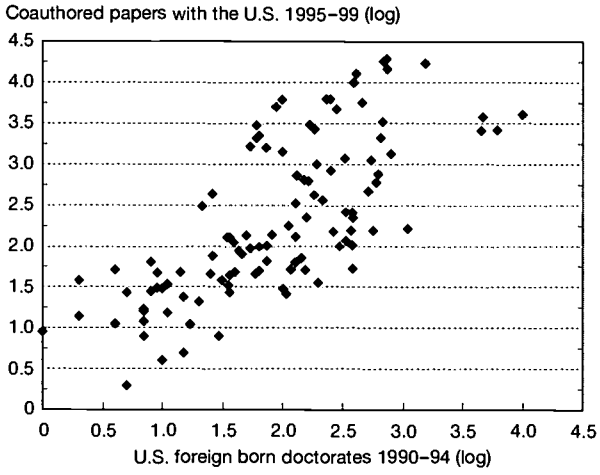
1986			1999		
Rank	Country	Share	Rank	Country	Share
1	Canada	13.6	1	Germany	13.8
2	United Kingdom	13.3	2	United Kingdom	12.4
3	Germany	11.7	3	Canada	11.2
4	France	8.3	4	Japan	9.9
5	Japan	8.1	5	France	8.7
6	Israel	6.3	6	Italy	6.9
7	Italy	5.5	7	Australia	4.5
8	Switzerland	4.1	8	Switzerland	4.3
9	Sweden	4.0	9	Netherlands	4.2
10	Australia	3.9	10	Russia	4.1

NOTES: U.S. internationally coauthored articles involve at least one author from indicated countries. Countries ranked by share in 1999.

SOURCES: Institute for Scientific Information, Science and Social Science Citation indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, Division of Science Resources Statistics (NSF/SRS).

Science & Engineering Indicators – 2002

Figure 5-40.
Relationship of foreign-born U.S. doctorates to their country's scientific collaboration with the U.S.

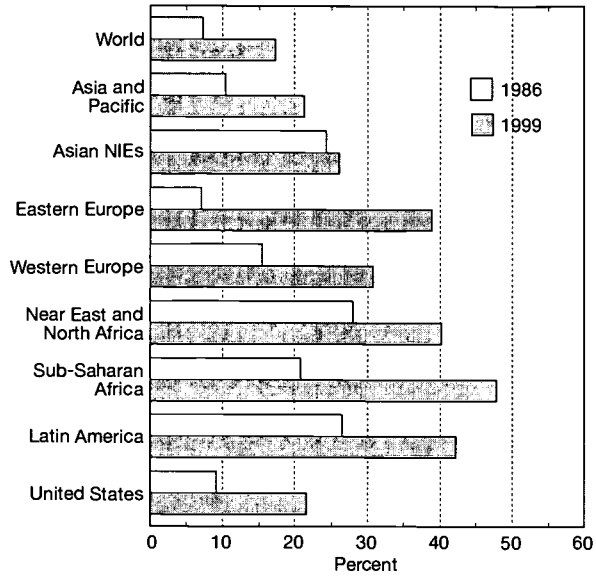


NOTE: This figure includes countries that have at least a .01 percent share of all internationally coauthored papers.

SOURCES: Institute for Scientific Information, Science and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, Division of Science Resources Statistics. Ph.D's: National Science Foundation, Survey of Earned Doctorates.

Science & Engineering Indicators – 2002

Figure 5-41.
International scientific collaboration by region



NOTES: Asian NIEs are the newly industrialized economies of Hong Kong, Singapore, South Korea, and Taiwan. Asia & Pacific excludes these countries.

SOURCES: Institute for Scientific Information, Science and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, Division of Science Resources Statistics.

Science & Engineering Indicators – 2002

The table reveals a dramatic expansion of cross-national collaboration over the 13 years due to the creation of new countries and an increase in the number of partnerships with existing countries. A total of 50 countries (including 6 new nations) had ties to at least 50 or more other nations in 1999 compared with 15 in 1986.

The strong growth of collaborative activity occurred in developing and industrialized countries in every region. (See figure 5-41.) In Western Europe, articles by multiple authors rose strongly, increasing their share from 41 percent in 1986 to 60 percent of all publications in 1999. This increase was driven by a rise in internationally coauthored articles, which nearly tripled during this period. By 1999, articles with at least one international coauthor accounted for 31 percent of all publications, up from 16 percent in 1986. Countries in this region, many of which had extensive ties during the previous decade, continued to expand their partnerships. There were 8 Western European countries with ties to 100 or more nations in 1999, an evident sign of this region's extensive scientific collaboration with other nations. Much of the high degree of international collaboration in Western Europe reflects the extensive amount of intraregional collaboration among these countries. Intraregional collaboration increased in virtually all Western European countries between 1986 and 1999, as measured by the share of the countries' international papers with coauthored papers from other European countries. For example, the share of France's international papers with German coauthors increased from 11 to 15 percent; its share with coauthors from the United Kingdom increased from 11 to 14 percent; and its share with Italian coauthors rose from 8 to 11 percent. (See appendix table 5-49.) Outside their region, the Western European countries had a high degree of collaboration with the United States, Eastern Europe, and Asia, especially Japan.

In Eastern Europe and central Asia, internationally coauthored articles grew during this period from less than 10 percent to almost 40 percent of these regions' articles. This jump in international collaboration reflects both a continuation of ties among countries that were part of the former Soviet Union and new partnerships with the rest of the world, especially scientifically advanced countries. For example, roughly one-quarter each of internationally coauthored papers in Russia and the Eastern European countries have at least one author from the United States or Germany. The Baltic states have developed strong collaborative ties with the Nordic states, reflecting the reestablishment of historical and regional connections.

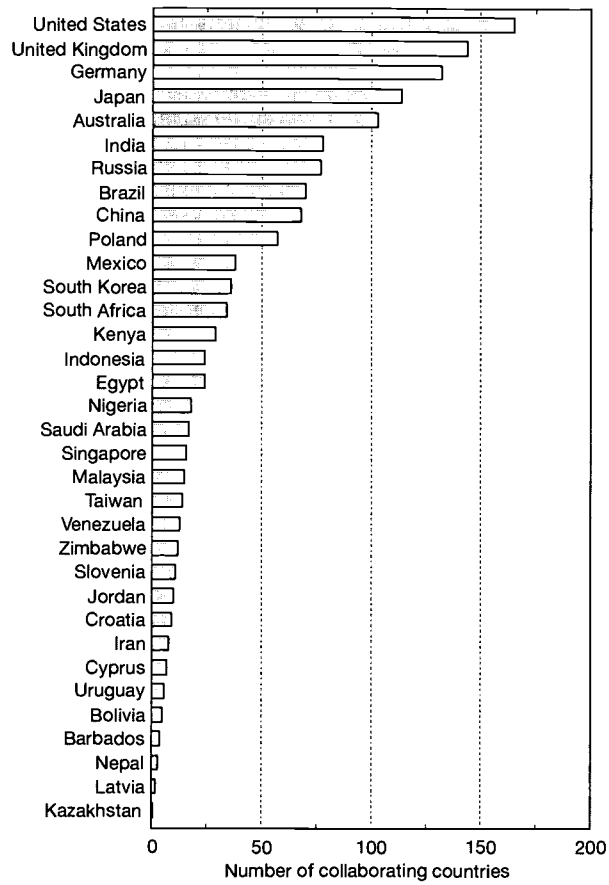
In Asia and the Pacific (excluding the Asian NIEs), multiple authorship more than tripled during this period, largely due to an increase in international articles in these regions from 10 to 21 percent. The share of internationally coauthored papers in NIEs was also significant, accounting for more than one-quarter of their publications. Several Asian countries (Hong Kong, Singapore, Indonesia, and Malaysia) expanded their international ties threefold during this period, and India

increased its ties to more than 100 countries in 1999. Greater intraregional collaboration was a significant factor in the increase in international collaboration, especially in China, NIEs, India, and other countries. (See appendix table 5-49.) For example, China's share of articles coauthored with Japan, Singapore, and South Korea rose from 12 to 16 percent, less than 0.5 to 3 percent, and 0.5 to 2 percent, respectively. Japan's rate of intraregional collaboration is much lower, but it also increased its partnerships with other countries in this region, notably with South Korea (from 2 to 5 percent) and China (from 4 to 7 percent). India is similar to Japan in its relatively low level of intraregional collaboration; however, its share of internationally coauthored articles with China, Japan, and the Taiwanese economy did rise. A high degree of collaboration outside the region occurs with the United States and Western Europe.

Gains in international collaboration led to a marked increase in coauthorship in Latin America and Sub-Saharan Africa. In 1999, the share of all papers in the region that were coauthored by at least one international author was nearly half in Sub-Saharan Africa and more than 40 percent in Latin America. These rates were substantially higher than in the previous decade. Intraregional collaboration among the Latin American countries also increased but remained modest in comparison with Western Europe or Asia. (See appendix table 5-49.) Argentina's share of papers coauthored with Mexico rose from 1 to 5 percent, and its share with Chile rose from 3 to 4 percent; however, its share with Brazil, its largest collaborator, fell by 3 percentage points, to 13 percent. Brazil's share with other countries in the region showed little change during this period, and its small shares with other countries attest to its pattern of collaborating largely outside the region. Mexico's collaboration increased with countries such as Argentina, Brazil, and Chile. Outside their own regions, these countries collaborate mainly with the United States and Western Europe, reflecting the importance of partnering with advanced countries with which they have educational, historical, and cultural ties.

Although international ties have expanded greatly, figure 5-42 shows that many countries tend to concentrate their collaborations in relatively few countries, most of which are developed countries with mature S&T establishments. The sharp drop-off in the number of countries collaborated with suggests that developing countries restrict much of their collaboration to major science-producing nations. The rise in intraregional collaboration in most developing regions suggests that their collaboration outside major science-producing nations is confined to developing countries in their own regions. It also suggests that countries with ties to large numbers of other countries, mainly those with a well-developed S&T infrastructure, conduct a large share of their collaboration with other major science producers, and their share with developing nations is a much lower portion of their total collaboration.

Figure 5-42.
Breadth of international scientific collaboration by country: 1999



NOTE: Number of countries that shared at least 1 percent of their internationally coauthored papers with indicated country.

See appendix table 5-47. *Science & Engineering Indicators – 2002*

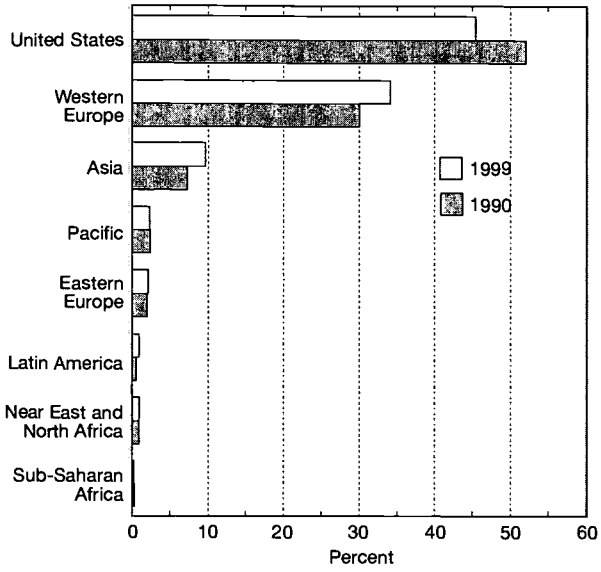
International Citations to Scientific and Technical Articles

The global dimensions of scientific activity, discussed above in terms of international research collaboration, also are reflected in the patterns of citations to the literature. Scientists and engineers around the world cite previous work done elsewhere to a considerable extent, thus acknowledging the usefulness of this output for their own work. Citations, aggregated here by region, country, and field, thus provide an indicator of the perceived influence of a nation's scientific outputs to other countries' scientific and technical work.[38] Citations to the work done in one's own country are generally prominent and show less of a time lag than citations to foreign outputs.

Citations within scientific papers to scientific research are dominated by the major science paper producers: the United States, Western Europe, and Asia. (See figure 5-43.) Scien-

[38]Citations are not a straightforward measure of quality because of self-citations by authors; authors citing colleagues, mentors, and friends; and a possible non-linear relationship of a country's number of publications and citations to that output.

Figure 5-43.
Scientific research cited by scientific and technical papers, by region



See appendix table 5-47. *Science & Engineering Indicators – 2002*

Text table 5-21.
Relative prominence of citations to U.S. scientific publications, by region

Citing country/region	Relative citation index 1990	1999
World	1.36	1.35
United States	1.84	1.94
Western Europe	0.98	1.02
Asia and Pacific	0.95	0.99
Asian NIEs	1.07	1.10
Eastern Europe	0.78	0.78
Near East	1.15	1.08
Latin America	1.04	0.97
Sub-Saharan Africa	0.82	0.85

NOTES: Asian NIEs are the newly industrialized economies of Hong Kong, Singapore, South Korea, and Taiwan. Relative citation indexes are frequency of citations to U.S. literature by each region adjusted for U.S. share of scientific papers. A value of 1.00 would indicate that the U.S. share of cited literature is equivalent to the U.S. share of published literature in the world.

SOURCE: CHI Research, Inc.

Science & Engineering Indicators – 2002

tific research from these regions accounts for nearly 90 percent of all cited research. U.S. literature is the most widely cited, although its share fell in the last decade from 52 percent in 1990 to 45 percent in 1999, a decline similar in magnitude to that of the fall in its world share of scientific literature. Meanwhile, the share of cited literature from Western Europe and Asia grew during this period at a magnitude comparable to that of the rise in their share of scientific papers. The increase in the shares of these two regions was driven by many of the same countries that increased their production of scientific papers. In Western Europe, countries such as Germany, France, Italy, Switzerland, the Nordic countries, Spain, and Portugal increased their world share of cited literature. (See appendix table 5-50.) In Asia, the rise in share was driven by countries such as Japan and China and by NIEs. Latin America, which had the fastest growth rate in scientific papers, was the only developing region whose world share of cited literature rose, increasing from 0.6 percent in 1990 to 1 percent in 1999.

Adjusted for its world share of scientific papers, U.S. literature is the most often cited in the world compared with other regions. Over the past two decades, on average, the U.S. share of cited scientific research has been 35 percent greater than the U.S. share of scientific literature. Although the world share of U.S. literature and citations to U.S. literature have declined, the perceived influence of U.S. science remains high on a relative basis. (See text table 5-21 and appendix table 5-51.) The prominence of cited U.S. literature reflects, to a considerable extent, the even higher propensity of U.S. scientists to cite their own literature. U.S. literature, however, is the most highly cited literature by most other regions of the world and is especially prominent in Western Europe, the Near East, and the Asian NIEs. Western European literature is also highly cited by the United States and other regions, especially by Eastern Europe. Although U.S. and Western European literature are generally the most highly cited by developing regions, Latin America and Sub-Saharan Africa each cite the other's literature at a fairly high rate.

Text table 5-22.
Relative prominence of cited scientific literature, by country

Rank	Country	1990	1999
1	Switzerland	1.46	1.37
2	United States	1.36	1.35
3	Netherlands	1.13	1.12
4	Sweden	1.14	1.07
5	Denmark	1.03	1.04
6	United Kingdom	1.06	1.04
7	Finland	0.89	1.02
8	Germany	0.99	1.01
9	Canada	0.93	0.99
10	Belgium	0.98	0.95
11	France	0.94	0.93
12	Austria	0.94	0.91
13	Italy	0.81	0.88
14	Australia	0.94	0.87
15	Israel	0.80	0.84

NOTES: Countries ranked by their relative citation index in 1999. Relative citation indexes are the citations by the world's scientific papers to the country's scientific literature, adjusted for the country's share of scientific papers. A value of 1.00 would signify that the country's share of cited literature is equivalent to its share of published literature in the world.

See appendix table 5-51. *Science & Engineering Indicators – 2002*

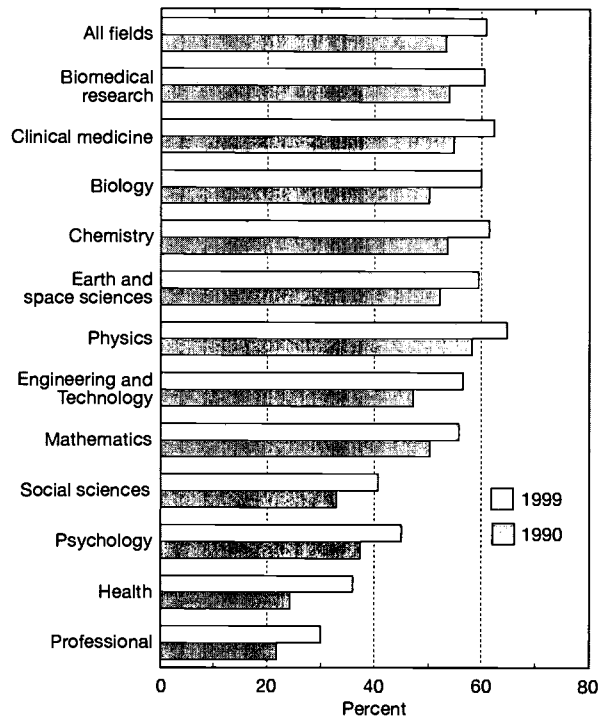
Adjusted for country share of world literature, the most frequently cited countries are major science producers and members of OECD (see text table 5-22 and appendix table 5-52):

- Switzerland is the most highly cited country in the world and is the largest producer of scientific papers on a per capita basis. (See appendix table 5-42.) It is the top-cited country in engineering and technology (with an especially high index of 1.8) and biology, and shares the top spot with the United States in biomedical research.
- The United States is a close second to Switzerland, with U.S. papers the most frequently cited in physics, clinical medicine, biomedical research (tying with Switzerland), chemistry, and earth and space sciences. It is also highly cited in the social and behavioral sciences. Citations to U.S. literature are relatively fewer in biology compared with other fields.
- The Nordic countries, the Netherlands, and Denmark also are very highly cited countries across many fields of science.
- The United Kingdom is highly cited in social and behavioral sciences, along with the United States.

In contrast to OECD countries, developing and emerging countries are cited 25–75 percent less relative to their worldwide share of literature. Despite the high growth rates in article output in NIEs and China, their relative citation indexes, which are at 0.6 or less, did not rise in the 1990s. (See appendix table 5-52.) The lack of increase in the citation of their literature may reflect, in part, that their international ties have been concentrated with the United States and within their own regions. Another difference is that developing countries cite publications produced in their own regions at a much higher rate than do developed countries. For example, the self citation indexes in Latin America (11.4) and Sub-Saharan Africa (32.0) are much higher than their interregional citation indexes. (See appendix table 5-51.) This suggests that these regions lack access to scientific research outside their own regions, although important differences exist between them. Latin America's self-citation index fell markedly during the last decade, whereas its world share of citations increased, suggesting that this region increased its access to international science and that the perceived influence of Latin American research also increased in the rest of the world. Sub-Saharan Africa, on the other hand, continued to have a very high self-citation rate, but its rate of citation in the rest of the world improved only slightly. Although developing and emerging countries are less prominently cited across all fields, certain countries do have particular prominence, adjusted for their share of literature, that rivals that of OECD countries. For example, Chile is the second most-cited country in earth and space sciences, the Hong Kong economy is highly cited in chemistry and biology, and Slovenia is highly cited in mathematics.

The international nature of scientific research, as evidenced by the degree of international collaboration discussed in the previous section, is underscored by the high and growing share of citations to work done abroad. Averaged across all countries and fields, 61 percent of all citations in 1999 were to foreign research compared with 53 percent in 1990. (See figure 5-44.) This overall rate masks a much lower citation rate by the United States compared with much higher rates in the rest of the world. (See appendix table 5-53.) Many of the citations to foreign science are to publications outside each region, primarily to the publications of regions with a well-developed science base: the United States, Western Europe, and to some extent, Asia and the Pacific. The exception to this is Western Europe, where about half of the citations are intraregional, consistent with the region's high degree of intraregional collaboration. The rate of citing foreign science varies by field, with high shares in physics, mathematics, and engineering and technical fields, and the lowest shares in the social and behavioral sciences.

Figure 5-44.
Citations to foreign articles in the world's major scientific and technical journals, by field: 1990 and 1999



NOTES: Citations are for a three-year period with a two-year lag; for example, 1999 citations consist of 1999 articles citing articles published in 1995–97. Computer science is included in engineering and technology.

SOURCES: Institute for Scientific Information, Science and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, Division of Science Resources Statistics.

Science & Engineering Indicators – 2002

Citations in U.S. Patents to Scientific and Technical Literature

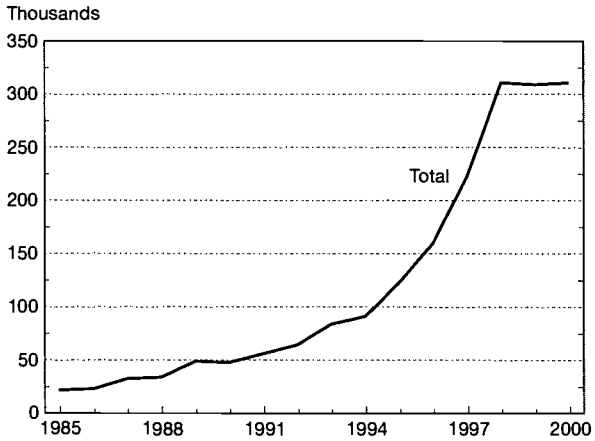
Patent applications cite "prior art"[39] that bounds the inventor's claims to the product or process to be patented. Citations to prior art have traditionally been to other patents; increasingly, these citations include scientific or technical articles. The percentage of U.S. patents that cited at least one such article increased from 11 percent in 1985 to 24 percent in 1997, before falling to 21 percent in 2000.[40] This development attests to both the growing closeness of some research areas, for example, life sciences, to practical applications and the increasing willingness of the U.S. Patent and Trademark Office (PTO) to award "upstream" patents, that is, research-driven products and processes that have less immediate commercial application, such as genetic sequencing. Thus, citations of scientific and technical articles provide an indicator of the growing link between research and innovative application, as judged by the patent applicant and recognized by PTO.[41]

[39]A U.S. Patent application is evaluated on whether it is useful, novel, and non-obvious. The novelty requirement leads to references to other patents, scientific journal articles, meetings, books, industrial standards, technical disclosure, etc. These references are termed "prior art."

[40]Personal communication with Kimberly Hamilton, CHI Research, Inc.

[41]Some caveats apply. The use of patenting varies by industry segment, and many citations on patent applications are to prior patents. Industrial patenting is only one way of seeking to ensure firms' ability to appropriate returns to innovation and thus reflects, in part, strategic and tactical decisions (e.g, laying the groundwork for cross-licensing arrangements). Most patents do not cover specific marketable products but might conceivably contribute in some fashion to one or more such products in the future. (See Geisler 2000.)

Figure 5-45.
Number of citations in U.S. patents to scientific and technical articles: 1985–2000

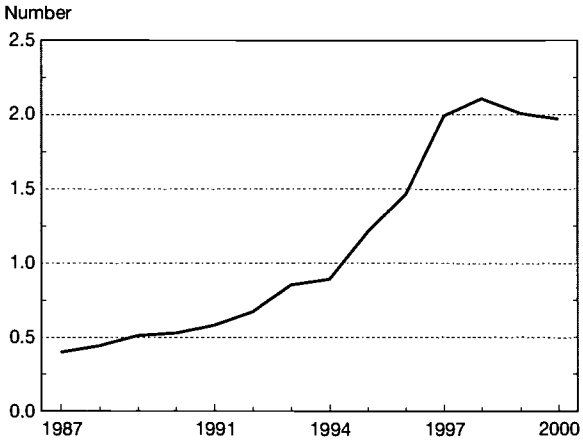


NOTES: Citations include all references to scientific articles. Citation counts are on the basis of a twelve-year period with a three-year lag; for example 2000 citations are references of U.S. patents issued in 2000 to articles that were published 1986–97. Changed U.S. Patent & Trademark Office procedures, greater ease of locating scientific articles, and greater incentive to cite them may have contributed to some of these increases.

SOURCES: U.S. Department of Commerce, Patent and Trademark Office; CHI Research, Inc., Science Indicators and Patent Citations databases; and National Science Foundation, Division of Science Resources Statistics.

Science & Engineering Indicators – 2002

Figure 5-46.
Average number of citations to scientific and technical articles per U.S. patent: 1987–2000



NOTES: Citations include all references to scientific articles. Citation counts are on the basis of a twelve-year period with a three-year lag; for example 2000 citations are references by U.S. patents issued in 2000 to articles that were published 1986–97. Changed U.S. Patent & Trademark Office procedures, greater ease of locating scientific articles, and greater incentive to cite them may have contributed to some of these increases.

SOURCES: U.S. Department of Commerce, Patent and Trademark Office; CHI Research, Inc., Science Indicators and Patent Citations databases; and National Science Foundation, Division of Science Resources Statistics.

Science & Engineering Indicators – 2002

The number of patent citations to articles appearing in any of the world's scientific and technical literature increased rapidly since the mid-1980s. They stood at about 22,000 in 1985, reached almost 123,000 in 1995, then more than doubled to reach more than 310,000 in 1998. (See figure 5-45.)[42] Even as the number of patents rose rapidly, the average number of citations per U.S. patent increased more than fivefold during this period. (See figure 5-46.) The rapid growth of citations ceased in 1999–2000, with total and average citations falling slightly in each of these two years.[43]

Citations to research articles were matched to a subset of approximately 5,000 of the world's most important scientific and technical journals to ascertain information about these citations: scientific field, country of publication and inventor, and performing sector (which is referenced to a smaller subset of U.S. literature) for all U.S. patents issued from 1987 through 2000. Although this eliminates references to other journals, this restricted set of citations helps provide insight on the factors driving this rapid growth of citations.

The rapid growth of article citations in patents throughout much of the past decade was centered in huge increases in the life science fields of biomedical research and clinical medicine. In 1987, each of these fields had about 3,000 citations; by

[42]The number of citations is based on scientific and technical articles published in a 12-year span that lagged 3 years behind issuance of the patent. For example, 2000 patent citations are to articles published in 1986–97, and so forth.

[43]The growth of citations likely has been influenced by changes in PTO procedures, regulations, and legal precedent. See sidebar, "The Growth of Referencing in Patents."

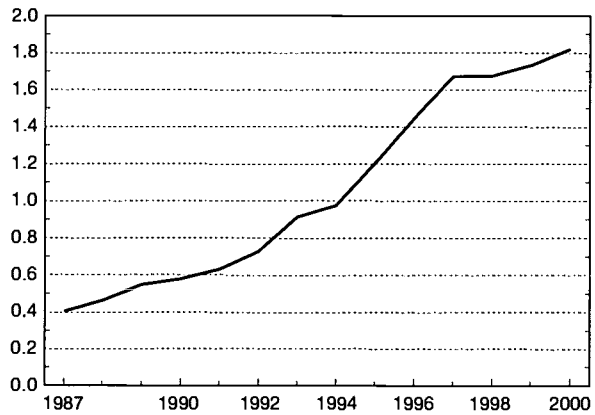
The Growth of Referencing in Patents

During the past decade, the rate at which patents reference scientific papers has increased rapidly. The causes of this growth are complex, but they appear to include 1995 changes in patent law. These changes, enacted to comply with the General Agreement on Tariffs and Trade (GATT), changed the term of protection from 17 years from the award date to 20 years from the filing date for applications received after June 8, 1995. Previously rejected patents refiled after this date would also be subject to the GATT rules. Applications submitted to the U.S. Patent and Trademark Office (PTO) more than doubled in May and June of 1995. These applications carried an unusually large number of references to scientific material. Patents applied for in June 1995 carried three times the number of science references as those from March 1995 and six times the number as those from July 1995. This sudden increase in referencing affected patents in all technologies, not just those in biotechnology and pharmaceuticals, in which referencing is most extensive.

The surge in applications during this period suggests that applicants and their attorneys rushed to file their patents under the old rules, perhaps out of caution and uncertainty about the GATT rules. One source of uncertainty in the application process at the time, affecting especially biotechnology, was ambiguity about what constituted adequate written description. Because a rejected application would have to be refiled under the GATT rules, referencing a great deal of scientific material may have been a strategy to minimize the chance of rejection because of lack of adequate written description.

Patents applied for in May and June 1995 were issued gradually over the next few years. As these patents were issued, the rate of referencing increasing rapidly. However, after the last of these applications were processed, the rate of referencing fell again to levels more nearly like those found earlier. In fact, if these patents are eliminated from consideration, a more gradual long-term trend of increased referencing is evident. (See figure 5-47.)

Figure 5-47.
Science references per U.S. patent excluding "spike" patents: 1987–2000



NOTES: Citations include all references to scientific articles. Citation counts are on the basis of a twelve-year period with a three-year lag; for example 2000 citations are references by U.S. patents issued in 2000 to articles that were published 1986–97. "Spike" patents are those with an application date of May–June 1995 and are excluded from this count.

SOURCES: U.S. Department of Commerce, Patent and Trademark Office, CHI Research, Inc., Science Indicators and patent databases, and National Science Foundation, Division of Science Resources Statistics.

Science & Engineering Indicators – 2002

2000, the number had risen to more than 60,000 in biomedical research and more than 40,000 in clinical medicine. Citations to these two fields accounted for about 70 percent of all citations in 2000. Although citations in other fields also increased, the huge increases in clinical medicine and biomedical research resulted in big shifts in field shares (see appendix table 5-54):

- The share of biomedical research citations rose from 24 percent in 1987 to 45 percent in 2000; clinical medicine rose from 23 to 29 percent, respectively.
- The combined share of physics, chemistry, and engineering and technology citations dropped from 49 to 22 percent between 1987 and 2000.

The bulk of patents citing scientific literature were issued to U.S. inventors, who accounted for 64 percent in 2000. The U.S. share has increased slightly over the past two decades. This share is disproportionately higher than the U.S. share of all patents. The share of Asian inventors, however, is disproportionately lower than their share of total U.S. patents. Other key inventor regions and countries of patents that cite scientific literature include Western Europe (17 percent), including France (3 percent), Germany (4 percent), and the United Kingdom (4 percent), Japan (12 percent), NIEs (2 percent), and Canada (3 percent). Since the late 1980s, the share of U.S. patents issued to Western European and Japanese inventors fell 3 to 4 points, while the share by the NIE's rose from almost zero to 2 percent in 2000. (See text table 5-23.)

Articles authored from the academic sector were the most widely cited in U.S. literature,[44] accounting for 60 percent in 2000, and were prominently represented in the life science fields, particularly biology. The rapid increase of citations to this sector increased its share from just below half in 1987, whereas shares fell in all other sectors. (See appendix table

[44] U.S. performer data is restricted to citations of U.S. literature in the ISI journal set.

Text table 5-23.
Inventor nationality of U.S. patents that cite scientific literature

Nationality of inventor	2000 U.S. patents citing scientific literature	2000 All U.S. patents	1994 U.S. patents citing scientific literature	1994 All U.S. patents	1988 U.S. patents citing scientific literature	1988 All U.S. patents
Number of U.S. patents	13,945	157,497	7,589	101,676	4,572	77,924
Percentage share of patents						
World	100.0	100.0	100.0	100.0	100.0	100.0
North America	66.9	56.2	62.3	57.1	62.2	53.9
Canada	2.5	2.2	1.6	2.0	1.6	1.9
United States	64.4	54.0	60.7	55.1	60.6	52.0
Western Europe	16.9	16.7	16.5	16.9	20.4	22.9
Germany	4.4	6.5	5.1	6.6	6.6	9.4
France	2.7	2.4	3.4	2.7	3.7	3.4
Italy	0.9	1.1	1.0	1.2	1.4	1.4
Netherlands	1.0	0.8	1.1	1.0	0.9	0.8
Switzerland	0.9	0.8	1.3	1.1	1.6	1.6
United Kingdom	3.8	2.3	2.6	2.2	4.2	3.3
Asia	14.1	25.3	19.7	24.5	15.8	21.6
Japan	11.8	19.9	18.9	22.0	15.5	20.7
Asian NIEs	2.0	5.3	0.7	2.5	0.1	0.8
Other	2.1	1.8	1.6	1.4	1.7	1.7

NOTES: Asian NIEs are newly industrialized economies of Hong Kong, Singapore, South Korea, and Taiwan. The number of U.S. patents and nationality of inventor is based on U.S. patents that reference scientific articles in approximately 5,000 journals classified by the Institute of Scientific Information.

SOURCES: U.S. Department of Commerce, Patent and Trademark Office; Institute for Scientific Information; CHI Research, Inc., Science indicators and patent database; and National Science Foundation, Division of Science Resources Statistics (NSF/SRS).

Science & Engineering Indicators – 2002

5-55.) The increase in citations to academic articles was particularly strong in physics (28 to 46 percent); the earth and space sciences (40 to 64 percent); and engineering and technology (25 to 49 percent), which are fields with stagnating or declining industry article output. Industry was the next most widely cited sector (20 percent share). Industry articles were prominently cited in the fields of physics and engineering and technology (42 percent for each field).

Life sciences, particularly biomedical research and clinical medicine, dominated nearly every sector, with from 67 percent to almost 100 percent of all citations. (See appendix table 5-55.) The composition of citations to industry articles in life sciences, in particular, illustrates the key role of these areas of inquiry. Sectors that had prominent citation shares in the physical sciences earlier in the decade (for-profit industry and FFRDCs) had significant declines in citations to these fields, while their share of life sciences citations grew significantly.

Examining the share of cited literature in the United States, Western Europe, and Asia adjusted for their respective shares of scientific literature reveals that inventors favor their own country or region. This is similar to the pattern of citations to scientific papers. U.S. literature, however, is highly cited by foreign inventors, a trend similar to the high frequency of citation of U.S. literature by non-U.S. scientists. U.S. literature is highly cited by Western European and Asian inventors, especially in the fields of chemistry, physics, clinical medicine, and biomedical research. (See text table 5-24.) In addition, Asian physics articles are highly cited by U.S. inventors and Asian engineering and technical articles are highly cited by Western European inventors.

Patents Awarded to U.S. Universities

The results of academic S&E research increasingly extend beyond articles in technical journals to patents protecting inventions deemed to be novel, useful, and nonobvious.[45] The Bayh-Dole University and Small Business Patent Act of 1980 provided a standard framework for university patenting, which a few institutions were already undertaking, and stimulated wider use of the practice. The act permitted government grantees and contractors to retain title to inventions resulting from federally supported R&D and encouraged the licensing of such inventions to industry.

Trends in academic patenting provide an indication of the importance of academic research to economic activity. The bulk of academic R&D is basic research, that is, it is not undertaken to yield or contribute to immediate practical applications. However, academic patenting data show that universities are giving increased attention to potential economic benefits inherent in even their most basic research and that PTO grants patents based on such basic work, especially in the life sciences.

The number of academic institutions receiving patents has increased rapidly since the 1980s after slow growth in the preceding decade but appears to have leveled off within the past several years to between 175 and 184. Both public and private institutions participated in this rise.[46] (See appendix table 5-56.)

[45] Research articles also are increasingly cited on patents, attesting to the close relationship of some basic academic research to potential commercial application. See the previous section, "Citations in U.S. Patents to Scientific and Technical Literature."

Text table 5-24.
U.S. patent citations of scientific literature relative to output of scientific literature: 2000

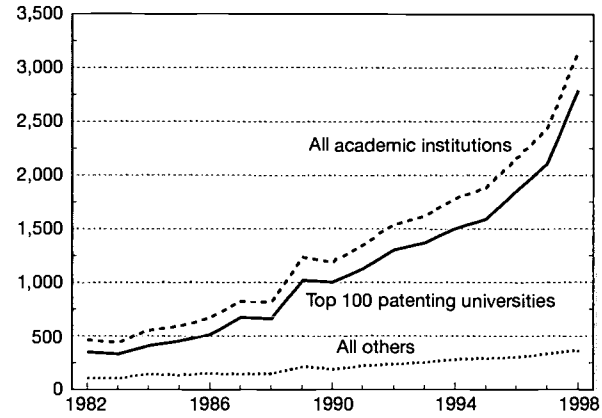
Citing inventor country/region	Cited literature: United States	Western Europe	Asia
All fields			
United States	1.86	0.67	0.60
Western Europe	1.33	1.20	0.57
Asia	1.22	0.60	2.53
Clinical medicine			
United States	1.61	0.67	0.63
Western Europe	1.19	1.11	0.56
Asia	1.20	0.47	3.15
Biomedical research			
United States	1.27	0.64	0.51
Western Europe	1.30	1.17	0.48
Asia	1.36	0.64	1.21
Biology			
United States	1.70	0.75	0.75
Western Europe	1.01	1.55	0.77
Asia	0.76	0.72	3.62
Chemistry			
United States	2.53	0.78	0.69
Western Europe	1.53	1.35	0.73
Asia	1.49	0.79	1.87
Physics			
United States	2.24	0.49	1.10
Western Europe	1.53	1.03	1.02
Asia	1.38	0.53	2.42
Engineering and technical			
United States	1.72	0.70	0.71
Western Europe	1.05	1.38	2.13
Asia	1.25	1.08	1.66

NOTES: County/region listed by its relative citation index, an indicator of the propensity of the inventor to cite literature adjusted for the inventor region/country's share of scientific literature. A value of 1.00 would signify that the country/region's share of cited literature by U.S. patents is equivalent to its share of published literature. Citations for 2000 are for a 12 year period with a three-year lag, i.e., 1986-1997 articles in the entire ISI journal set, which consists of approximately 5,000 journals. The share of the inventor country/region's publications in the world literature is on the basis of a more restricted fixed 1985 set of ISI journals. The difference in the coverage of the journal sets means that these indexes should be treated as approximate measures.

SOURCES: Institute for Scientific Information, Science and Social Science Citation Indexes; U.S. Department of Commerce, Patent and Trademark Office; CHI Research, Inc., Science Indicators and patent database; and National Science Foundation, Division of Scientific Resources Statistics (NSF/SRS).

Science & Engineering Indicators – 2002

Figure 5-48.
Granted academic patents: 1982–98



NOTE: Top 100 patenting universities are determined by the sum of patents awarded during the 1990s.

See appendix table 5-55.

Science & Engineering Indicators – 2002

The expansion of the number of institutions was dwarfed by the steep rise in the number of patent awards to academia, from about 250–350 annually in the 1970s[47] to 3,151 in 1998, accelerating rapidly since 1995. (See figure 5-48.) As a result, academic patents now approach 5.0 percent of all new U.S.-owned patents, up from less than 0.5 percent two decades ago.

During the 1990s, the 100 largest recipients of academic patents accounted for more than 90 percent of the total. This reversed a trend during much of the 1980s, when many smaller universities and colleges began to receive patents, thus pushing the large institutions' share as low as 82 percent. (See appendix table 5-56.)

The vigorous increases in the number of academic patents largely reflect developments in life sciences and biotechnology (see Huttner 1999). Patents in a mere three application areas or "utility classes," all with presumed biomedical relevance,[48] accounted for 41 percent of the academic total in 1998, up from a mere 15 percent through 1980. (See figure 5-49.)

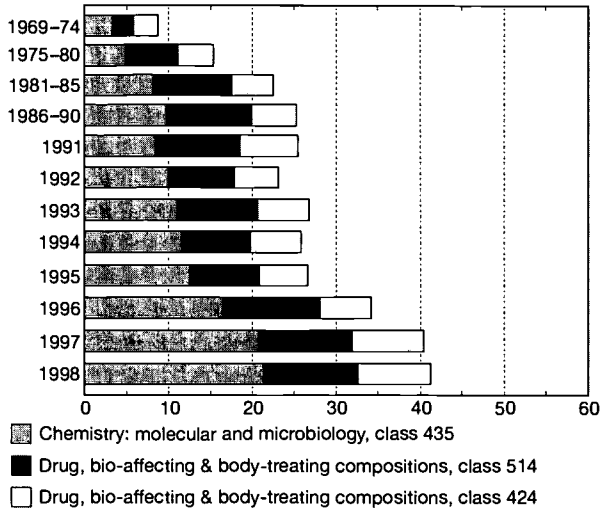
Academic institutions are increasingly successful in negotiating royalty and licensing arrangements based on their patents. Although total reported revenue from such licensing arrangements remain low in comparison to R&D spending, a

[46] It is difficult to be precise. Patent assignment depends on university practices, which vary and can change with time. Patent assignation may be to boards of regents, individual campuses, subcampus organizations, or entities with or without affiliation with the university. The data presented here have been aggregated consistently by PTO starting in 1982. The institution count is conservative, because several university systems are included in the count and medical schools are often counted with their home institutions.

[47] See National Science Board (1996), appendix table 5-42.

[48] Utility class numbers 424 and 514 capture different aspects of "Drug, bio-affecting and body treating compositions"; utility class number 435 is "Chemistry: molecular biology and microbiology." Patents are classified here according to their primary technology class.

Figure 5-49.
Percent of total academic patents in three largest academic utility classes: 1969–98



SOURCES: U.S. Patent and Trademark Office, TAF Report: U.S. Universities and Colleges; and NSF, Division of Science Resources Statistics, special tabulations.

Science & Engineering Indicators – 2002

strong upward trend points to the confluence of two developments: a growing eagerness of universities to exploit the economic potential of research activities conducted under their auspices, and the readiness of entrepreneurs and companies to recognize and invest in the market potential of this research.

A survey by the Association of University Technology Managers has tracked several indicators of academic patenting, licensing, and related practices. Text table 5-25 summarizes this information for the 1990s. The number of license disclosures, applications, new patents, startup firms, and revenue-generating licenses and options have all grown rapidly.

University income from patenting and licenses reached $641 million in 1999, still low relative to academic research expenditures but more than double the 1995 total. About half of total royalties were classified related to the life sciences; about one-third were not classified; and the remainder, labeled "physical sciences," appears to include engineering.

New licenses and options granted have risen by half since 1995. More than half were granted to startups or other small companies, but about 40 percent went to large firms. Of particular interest is the rise in new equity licenses and options executed relative to the number of startup companies formed, indicating that universities are increasingly taking a longer view of their investments.

Text table 5-25.
Academic patenting and licensing activities: 1991–99

Indicators of activity	1991	1992	1993	1994	1995	1996	1997	1998	1999
	Millions of dollars								
Gross royalties	130.0	172.4	242.3	265.9	299.1	365.2	482.8	613.6	675.5
Royalties paid to others	NA	NA	19.5	20.8	25.6	28.6	36.2	36.7	34.5
Unreimbursed legal fees expended	19.3	22.2	27.8	27.7	34.4	46.5	55.5	59.6	58.0
New research funding from licenses	NA	NA	NA	106.3	112.5	155.7	136.2	126.9	149.0
	Number								
Invention disclosures received	4,880	5,700	6,598	6,697	7,427	8,119	9,051	9,555	10,052
New patent applications filed	1,335	1,608	1,993	2,015	2,373	2,734	3,644	4,140	4,871
Total patents received	NA	NA	1,307	1,596	1,550	1,776	2,239	2,681	3,079
Startup companies formed	NA	NA	NA	175	169	184	258	279	275
Number of revenue generating licenses, options	2,210	2,809	3,413	3,560	4,272	4,958	5,659	6,006	6,663
New licenses and options executed	1,079	1,461	1,737	2,049	2,142	2,209	2,707	3,078	3,295
Equity licenses and options	NA	NA	NA	NA	99	113	203	210	181
	Percent of national academic total represented by responding institutions								
Sponsored research funds	65	68	75	76	78	81	82	83	82
Federal research funds	79	82	85	85	85	89	90	90	90
Patents awarded	NA	NA	81	90	83	82	92	86	92
	Number of reporting institutions								
Number of institutions	98	98	117	120	127	131	132	132	132

NA = not available

NOTE: New research funding refers to research funding to an institution that was directly related to a license or option agreement.

SOURCE: Association of University Technology Managers. AUTM Licensing Survey, various years (Norwalk, CT).

Science & Engineering Indicators – 2002

The Bayh-Dole Act may have contributed to the strong rise in academic patenting in the 1980s, although this activity was already increasing before then. However, the act did stimulate the creation of university technology transfer and patenting units and increased attention to commercially relevant technologies and closer ties between research and technological development. A landmark 1980 Supreme Court ruling (*Diamond* v. *Chakrabarty*) allowing patentability of genetically modified life forms may have been a major stimulus behind the recent rapid increases.

University patenting and collaboration with industry in the United States have contributed to the rapid transformation of new and often basic knowledge into industrial innovations, including new products, processes, and services. Other nations, seeing these benefits, are endeavoring to import these and related practices in an effort to strengthen their innovation systems. In the United States, however, the relative success of university-industry collaboration and academic patenting has raised a number of questions about unintended consequences for universities, academic researchers, and academic basic research.

Concerns have been expressed about potential distortions of the nature and direction of academic basic research and about contract clauses specifying delays or limitations in the publication of research results. The possibility exists that research results may be suppressed for commercial gain, deleterious not only to the conduct of research but potentially also to the perception of academia as an impartial seeker of knowledge. Unsettled questions also arise from faculty members' potentially conflicting economic and professional incentives in their relationships with industry or as officers or equity holders in spinoff firms.

The latter issue also arises for universities, which are moving in the direction of acquiring equity in spinoff firms they generate. They also face the question of balancing their support across different fields or concentrating on a few lucrative areas. Scholars are now asking whether academic patenting practices may in fact be undermining the intended goal of enhancing the transfer of new technologies (National Academies STEP 2001).

Conclusion

Strengths and challenges characterize the position of academic R&D in the United States at the beginning of the 21st century. Its graduate education, linked intimately to the conduct of research, is regarded as a model by other countries and attracts large numbers of foreign students, many of whom stay after graduation. Funding of academic R&D continues to expand rapidly, and universities perform nearly half the basic research nationwide. U.S. academic scientists and engineers are collaborating extensively with colleagues in other sectors and increasingly with international colleagues: in 1999, one U.S. journal article in five had at least one international coauthor. Academic patenting and licensing continue to increase, and academic and other scientific and technical articles are increasingly cited on patents, attesting to the usefulness of academic research in producing economic benefits. Academic licensing and option revenues are growing, as are spinoff companies, and universities are increasingly moving into equity positions to maximize their economic returns.

However, there are challenges to be faced and trends that bear watching. The Federal Government's role in funding academic R&D is declining, and fewer institutions receive these funds. Research-performing universities have increased their own funds, which now account for one-fifth of the total. Industry support has grown, but less than might be surmised given the close relationship between R&D and industrial innovation. Industry support barely reached 8 percent of the total in 1999, well below half of universities' own funds. Spending on research equipment as a share of total R&D expenditures declined to 5 percent during the 1990s, a trend worthy of attention.

Academic employment has undergone a long-term shift toward greater use of nonfaculty appointments, both as postdoctorates and in other positions. A researcher pool has grown independent of growth in the faculty ranks. These developments accelerated during the latter half of the 1990s, when both retirements and new hires were beginning to rise. This raises the question of the future development of these related trends during the next decade, when retirements will further accelerate. Another aspect of this issue is the level of foreign participation in the academic enterprise. Academia has been able to attract many talented foreign-born scientists and engineers, and the nation has benefited from their contributions. However, as the percentage of foreign-born degree-holders approaches half the total in some fields, attention shifts to degree-holders who are U.S. citizens. Among those, majority males have been earning a declining number of S&E doctorates, and they also have shown a disinclination to enter academic careers. On the other hand, the number of S&E doctorates earned by U.S. women and members of minority groups has been increasing, and these new Ph.D.-holders have been entering academia. This development will perhaps aid the growing numbers of students from minority backgrounds expected to enroll in college over the next quarter century by providing role models.

Questions arise about the changing nature of academic research and the uses of its results. The number of U.S. articles published in the world's leading journals is declining in absolute numbers, a trend that remains unexplained. This development follows increased funding for academic R&D and coincides with reports from academic researchers that fail to show any large shift in the nature of their research. Regarding protection of intellectual property, universities moving into equity positions raise conflict-of-interest concerns for institutions and researchers that remain unresolved. Public confidence in academia could decline should academia's research or patenting and licensing activities be perceived as violating the public interest.

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Chapter 6
Industry, Technology, and the Global Marketplace

Highlights

U.S. Technology in the Marketplace

- **The United States continues to be the leading producer of high-technology products, responsible for about one-third of the world's production.** Although the margin of U.S. leadership narrowed during the 1980s when Japan rapidly enhanced its stature in high-technology fields, by 1998 U.S. high-technology industries had regained some of the world market share lost during the previous decade.
- **The market competitiveness of individual U.S. high-technology industries varies, although each maintained strong, market positions over the 19-year period examined.** Three of the four science-based industries that form the high-technology group (computers and office machinery, pharmaceuticals, and communications equipment) gained world market share in the 1990s. The aerospace industry was the only U.S. high-technology industry to lose market share from 1990 to 1998.
- **Technology products account for a larger share of U.S. exports than imports, thereby making a positive contribution to the U.S. overall balance of trade.** A trend of declining trade surpluses in technology products reversed after several years during the mid-1990s. Between 1990 and 1995, trade in aerospace technologies consistently produced large—albeit declining—trade surpluses for the United States. Since then, U.S. exports of aerospace technologies, electronics, biotechnologies, and software have outpaced imports, leading to increasing trade surpluses in 1996 and 1997 before narrowing slightly in 1998 and 1999.
- **The United States is also a net exporter of technological know-how sold as intellectual property.** Royalties and fees received from foreign firms have been, on average, three times greater than those paid out to foreigners by U.S. firms for access to their technology. U.S. receipts from licensing of technological know-how to foreigners plateaued at about $3.5 billion between 1996 and 1998. Japan is the largest consumer of U.S. technology sold as intellectual property; South Korea is a distant second. Together, Japan and South Korea accounted for more than 44 percent of total receipts in 1999.

New High-Technology Exporters

- **When a model of leading indicators is applied, Ireland and Israel appear to be headed toward prominence as technology developers and exporters to global markets.** Ireland led the group of 15 small or less-advanced countries examined in three of four leading indicators and received the second highest score in the fourth, technological infrastructure. On that indicator, Israel ranked first because of its large number of trained scientists and engineers, highly regarded research enterprise, and contribution to scientific knowledge. Hungary and India also posted strong scores on at least three of the four indicators.

International Trends in Industrial Research and Development

- **Internationally comparable data show the importance of service-sector research and development (R&D) in several industrialized countries.** In 1997, service-sector industries, such as those involved in communications or computer software development, accounted for 20 percent of all R&D performed by industry in the United States and in the United Kingdom, 15 percent in Italy, and 10 percent in France. Although it has increased in recent years, service-sector R&D still accounted for only about 5 percent of all R&D performed by industry in Germany and in Japan.
- **In most industrialized countries, the aerospace, motor vehicle, electronic equipment, and pharmaceutical industries conduct the largest amounts of R&D.** In the United States, industries making computer hardware, electronics, and motor vehicles led the nation in R&D. Japan's electronic equipment industry was the leading performer of R&D throughout the period reviewed, followed by its motor vehicle industry. Manufacturers of electronics equipment, motor vehicles, and industrial chemicals have consistently been among the top five performers of R&D in the European Union.

Patented Inventions

- **In 1999, more than 153,000 patents were issued in the United States, 4 percent more than were granted a year earlier.** This record number of new inventions, resulting in new patents, caps off nearly a decade of year-to-year growth during the 1990s. The proportion of all new patents granted to U.S. inventors has generally risen since the late 1980s, reaching 55 percent in 1999.
- **Foreign patenting in the United States continues to be highly concentrated by country of origin.** In 1999, Japan and Germany accounted for slightly more than 58 percent of foreign-origin U.S. patents, and the top four countries, Japan, Germany, France, and the United Kingdom, accounted for 70 percent. Both South Korea and Taiwan dramatically increased their U.S. patent activity in the late 1980s, and in 1999, each was awarded more U.S. patents than Canada, historically one of the top five nations patenting in the United States.
- **Recent U.S. patents by foreign inventors emphasize several commercially important technologies.** Japanese patents focus on consumer electronics, photography, photocopying, and, more recently, computer technology. German inventors are developing new products and processes associated with heavy industry, such as motor vehicles, printing, advanced materials, and manufacturing technologies. Inventors from Taiwan and South Korea are earning an increasing number of U.S. patents in communications and computer technology.

Venture Capital and High-Technology Enterprise

- **The amount of money managed by venture capital firms grew dramatically during the 1980s as venture capital emerged as an important source of financing for small, innovative firms.** In the early 1990s, the venture capital industry slowed as investor interest waned and the amount of venture capital disbursed declined. But this slowdown was short lived: investor interest picked up in 1992, and disbursements began to rise again in 1993. Both investor interest and venture capital disbursements continued to grow through 2000.
- **Internet companies attracted more venture capital than any other technology area.** In 2000, venture capital firms disbursed nearly $90.6 billion, of which more than 45 percent went to Internet firms. Telecommunications companies were second with nearly 17 percent, and companies developing computer software or delivering software services were third with just more than 14 percent.
- **Little venture capital is used as seed money.** During the past 10 years, money given to entrepreneurs to prove a concept or to support early product development never accounted for more than 6 percent of total venture capital disbursements and most often represented only 2 to 4 percent of the annual totals. In 2000, seed money accounted for just 1.4 percent of all venture capital disbursements, whereas money for company expansion was about 61 percent.

Introduction

Chapter Background

Science & Engineering Indicators 2000 showed that advances in information technology (IT) (i.e., computers and communications products and services) drove an increase in technology development and allowed the United States to increase technical exchanges with its trading partners.[1] This edition of *Science and Engineering Indicators* examines many of the same indicators, with additional perspectives provided by international data on service industries and on patenting activity in two new areas, human DNA sequencing and Internet business methods. New data on applications for U.S. patents by residence of inventor have also been added.[2]

Chapter Organization

This chapter begins with a review of industries that rely heavily on research and development (R&D), referred to here as "high-technology industries."[3] High-technology industries are noted for their high R&D spending and performance, which produce innovations that can be applied to other economic sectors. These industries also help train new scientists, engineers, and other technical personnel (see Nadiri 1993; Tyson 1992). Thus, the market competitiveness of a nation's technological advances, as embodied in new products and processes associated with high-technology industries, can serve as an indicator of the economic and technical effectiveness of that country's science and technology (S&T) enterprise.

The global competitiveness of the U.S. high-technology industry is assessed through an examination of domestic and worldwide market share trends. Data on royalties and fees generated from U.S. imports and exports of technological know-how are used to gauge U.S. competitiveness when technological know-how is sold or rented as intangible (intellectual) property. Also presented are new leading indicators designed to identify those developing and transitioning countries with the potential to become more important exporters of high-technology products over the next 15 years.

This chapter explores several other leading indicators of technology development by examining changing emphases in industrial R&D among the major industrialized countries and comparing U.S. patenting patterns with those of other nations in two important technology areas, human DNA sequencing and Internet business models.

The chapter also examines venture capital disbursements in the United States by stage of financing and by technology area. Venture capital is used in the formation and expansion of small high-technology companies.

U.S. Technology in the Marketplace

Most countries acknowledge a symbiotic relationship between investment in S&T and success in the marketplace: S&T support competitiveness in international trade, and commercial success in the global marketplace provides the resources needed to support new S&T. Consequently, the nation's economic health is a performance measure for the national investment in R&D and in science and engineering (S&E).

The Organisation for Economic Co-operation and Development (OECD) currently identifies four industries as *high-technology* (science-based industries whose products involve above-average levels of R&D): aerospace, computers and office machinery, communications equipment, and pharmaceuticals.[4]

High-technology industries are important to nations for several reasons:

- High-technology firms innovate, and firms that innovate tend to gain market share, create new product markets, and/or use resources more productively (National Research Council, Hamburg Institute for Economic Research, and Kiel Institute for World Economics 1996; Tassey 1995).
- High-technology firms develop high value-added products and are successful in foreign markets, which results in greater compensation for their employees (Tyson 1992).
- Industrial R&D performed by high-technology industries benefits other commercial sectors by generating new products and processes that increase productivity, expand business, and create high-wage jobs (Nadiri 1993; Tyson 1992; Mansfield 1991).

[1]This chapter presents data from various public and private sources. Consequently, country coverage will vary by data source. Trend data for the advanced industrialized countries are discussed in all sections of the chapter. When available, more limited data for fast-growing and smaller economies are added to the discussion.

[2]Trends in the number and origin of U.S. patent applications provide a more current, albeit less exact, indication of inventive patterns than that provided by the chapter's examination of U.S. patents granted.

[3]No single preferred methodology exists for identifying high-technology industries, but most calculations rely on a comparison of R&D intensities. R&D intensity, in turn, is typically determined by comparing industry R&D expenditures or the numbers of technical people employed (e.g., scientists, engineers, technicians) with industry value added or the total value of its shipments. In this chapter, high-technology industries are identified using R&D intensities calculated by the Organisation for Economic Co-operation and Development.

[4]In designating these high-technology industries, OECD took into account both direct and indirect R&D intensities for 10 countries: the United States, Japan, Germany, France, the United Kingdom, Canada, Italy, the Netherlands, Denmark, and Australia. Direct intensities were calculated by the ratio of R&D expenditure to output (production) in 22 industrial sectors. Each sector was given a weight according to its share in the total output of the 10 countries using purchasing power parities as exchange rates. Indirect intensity calculations were made using technical coefficients of industries on the basis of input-output matrices. OECD then assumed that, for a given type of input and for all groups of products, the proportions of R&D expenditure embodied in value added remained constant. The input-output coefficients were then multiplied by the direct R&D intensities. For further details concerning the methodology used, see OECD (1993).

The Importance of High-Technology Industries

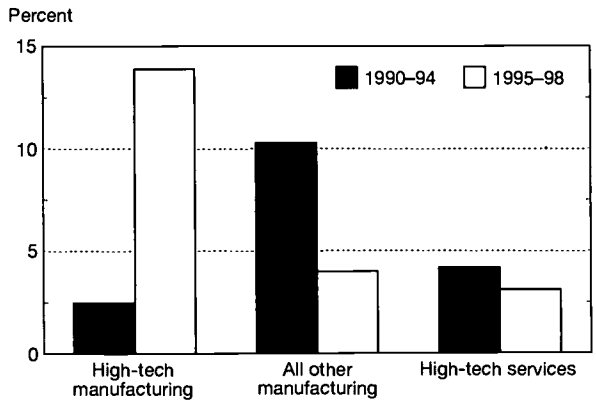
The global market for high-technology goods is growing at a faster rate than that for other manufactured goods, and high-technology industries are driving economic growth around the world.[5] During the 19-year period examined (1980–98), high-technology production grew at an inflation-adjusted average annual rate of nearly 6.0 percent compared with 2.7 percent for other manufactured goods.[6] Global economic activity was especially strong at the end of the period (1995–98), when high-technology industry output grew at 13.9 percent per year, more than three times the rate of growth for all other manufacturing industries. (See figure 6-1 and appendix table 6-1.) Output by the four high-technology industries, those identified as being the most research intensive, represented 7.6 percent of global production of all manufactured goods in 1980; by 1998, this figure rose to 12.7 percent.

During the 1980s, the United States and other high-wage countries devoted increasing resources toward the manufacture of higher value, technology-intensive goods, often referred to as "high-technology manufactures." During this period, Japan led the major industrialized countries in its concentration on high-technology manufactures. In 1980, high-technology manufactures accounted for about 8 percent of total Japanese production, approaching 11 percent in 1984 and increasing to 11.6 percent in 1989. By contrast, high-technology manufactures represented nearly 11 percent of total U.S. production in 1989, up from 9.6 percent in 1980. European nations also saw high-technology manufactures account for a growing share of their total production, although to a lesser degree than seen in the United States and Japan. The one exception was the United Kingdom, where high-technology manufactures rose from 9 percent of total manufacturing output in 1980 to nearly 11 percent by 1989.

[5]This section is based on data reported by WEFA (2000) in its World Industry Service database. This database provides production data for 68 countries and accounts for more than 97 percent of global economic activity.

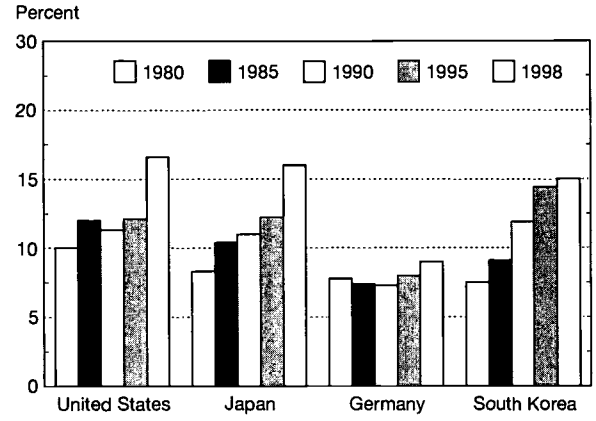
[6]Service-sector industries grew at an inflation-adjusted average annual rate of 3.5 percent during this period.

Figure 6-1.
Global industry sales, average growth rate, by sector



See appendix table 6-1. *Science & Engineering Indicators – 2002*

Figure 6-2.
High-tech industries' share of total manufacturing output



See appendix table 6-1. *Science & Engineering Indicators – 2002*

The major industrialized countries continued to emphasize high-technology manufactures into the 1990s. (See figure 6-2.) In 1998, high-technology manufactures were estimated at 16.6 percent of manufacturing output in the United States, 16.0 percent in Japan, 14.9 percent in the United Kingdom, 11.0 percent in France, and 9.0 percent in Germany.

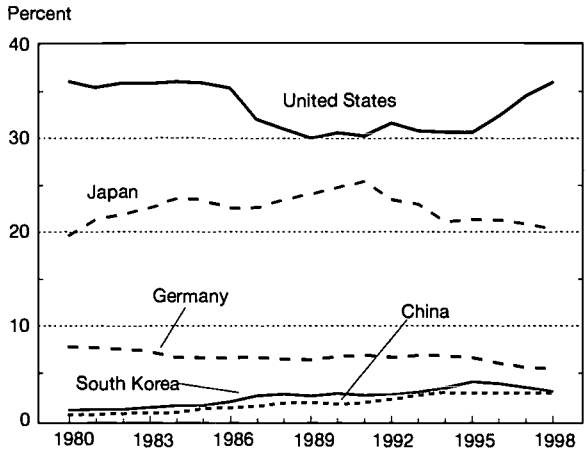
Taiwan and South Korea typify how important R&D-intensive industries have become to newly industrialized economies. In 1980, high-technology manufactures accounted for less than 12 percent of Taiwan's total manufacturing output; this proportion jumped to 16.7 percent in 1989 and reached 25.6 percent in 1998. In 1998, high-technology manufacturing in South Korea (15.0 percent) accounted for about the same percentage of total output as in the United Kingdom (14.9 percent) and almost twice the percentage of total manufacturing output as in Germany (9.0 percent).

Share of World Markets

Throughout the 1980s, the United States was the world's leading producer of high-technology products, responsible for more than one-third of total world production from 1980 to 1987 and for about 30 percent from 1988 to 1995. U.S. world market share began to rise in 1996 and continued moving upward during the following two years. (See figure 6-3.) In 1998, the United States high-technology industry accounted for 36 percent of world high-technology production, a level last reached in the 1980s.

Although the United States struggled to maintain its high-technology market share during the 1980s, Asia's market share followed a path of steady gains. In 1989, Japan accounted for 24 percent of the world's production of high-technology products, moving up 4 percentage points from its 1980 share. Japan continued to gain market share through 1991. Since then,

Figure 6-3.
Country share of global high-tech market: 1980–98



See appendix table 6-1. *Science & Engineering Indicators – 2002*

however, Japan's market share has dropped steadily, falling to 20 percent of world production in 1998 after accounting for nearly 26 percent in 1991.

European nations' share of world high-technology production is much lower and has been declining. Germany's share of world high-technology production was about 8 percent in 1980, about 6.4 percent in 1989, and 5.4 percent in 1998. The United Kingdom's high-technology industry produced 6.7 percent of world output in 1980, dropping to about 6.0 percent in 1989 and 5.4 percent in 1998. In 1980, French high-technology industry produced 6.1 percent of world output; it dropped to 5.3 percent in 1989 and 3.9 percent in 1998. Italy's shares were the lowest among the four large European economies, ranging from a high of about 2.7 percent of world high-technology production in 1980 to a low of about 1.6 percent in 1998.

Developing Asian nations made the most dramatic gains since 1980. South Korea's market share more than doubled during the 1980s, moving from 1.1 percent in 1980 to 2.6 percent in 1989. South Korea's share continued to increase during the early to mid-1990s, peaking at 4.1 percent in 1995. Since 1995, South Korea's market share has dropped each year, falling to 3.1 percent in 1998. Taiwan's high-technology industry also gained world market share during the 1980s and early 1990s before leveling off in the later 1990s. Taiwan's high-technology industry produced just 1.3 percent of the world's output in 1980. This figure rose to 2.4 percent in 1989 and leveled off at 3.3 percent in 1997 and 1998.

Global Competitiveness of Individual Industries

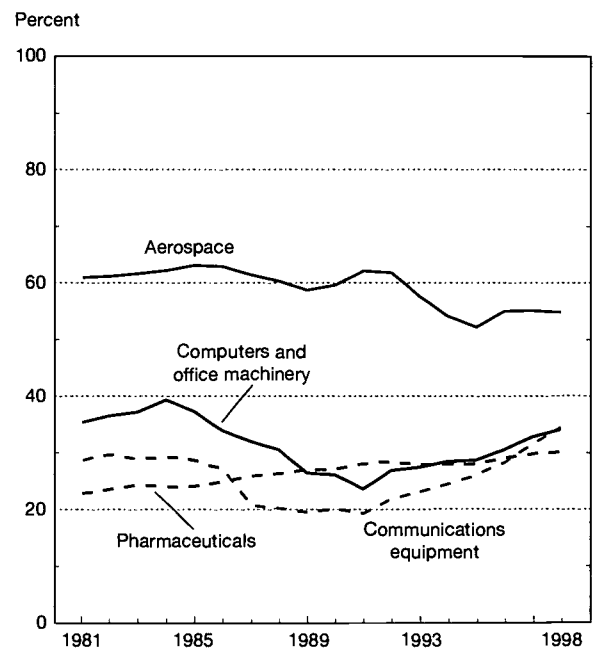
In each of the four industries that make up the high-technology group, the United States maintained strong, if not leading, market positions between 1981 and 1998. Competitive pressures from a growing cadre of high-technology-producing nations contributed to a decline in global market share for two U.S. high-technology industries during the 1980s: computers and office machinery and communications equipment. Both of these U.S. industries reversed their downward trends and gained market share in the mid- to late 1990s, thanks to increased capital investment by U.S. businesses.[7] (See figure 6-4.)

For most of the 19-year period examined, Japan was the world's leading supplier of communications equipment, representing about one-third of total world output. Japan's production surpassed that of the United States in 1981 and held the top position for the next 14 years. In 1995, U.S. manufacturers once again became the leading producer of communications equipment in the world, and they have retained that position ever since. In 1998, the latest year for which data are available, the United States accounted for 34.4 percent of world production of communications equipment, up from 31.5 percent in 1997.

Aerospace, the U.S. high-technology industry with the largest world market share, was the only industry to lose market share in both the 1980s and the 1990s. For most of the 1980s, the U.S. aerospace industry supplied more than 60 percent of world demand. By the late 1980s, the U.S. share of the world aerospace market began an erratic decline, falling to 58.9 percent in 1989 and 52.1 percent by 1995. The United States recovered somewhat during the following three years, supplying about 55 percent of the world market from 1996 to 1998. European aerospace industries, particularly the British

[7]These data are discussed in chapter 8.

Figure 6-4.
U.S. global market share, by high-tech industry: 1981–98



See appendix table 6-1. *Science & Engineering Indicators – 2002*

aerospace industry, made some gains during the period examined. After fluctuating between 8.5 and 10.5 percent during the 1980s, the United Kingdom's industry slowly gained market share for much of the 1990s. In 1991, the United Kingdom supplied 9.7 percent of world aircraft shipments; by 1998, its share had increased to 13 percent.

Of the four U.S. high-technology industries, only the aerospace and pharmaceutical industries managed to retain their number-one rankings throughout the 19-year period; of these two, only the pharmaceutical industry had a larger share of the global market in 1998 than in 1980.

The United States is considered a large, open market. These characteristics benefit U.S. high-technology producers in two important ways. First, supplying a market with many domestic consumers provides scale effects to U.S. producers in the form of potentially large rewards for the production of new ideas and innovations (Romer 1996). Second, the openness of the U.S. market to competing foreign-made technologies pressures U.S. producers to be inventive and more innovative to maintain domestic market share.

Exports by High-Technology Industries

Although U.S. producers benefit from having the world's largest home market as measured by gross domestic product (GDP), mounting trade deficits highlight the need to serve foreign markets as well. U.S. high-technology industries have traditionally been more successful exporters than other U.S. industries and play a key role in returning the United States to a more balanced trade position.

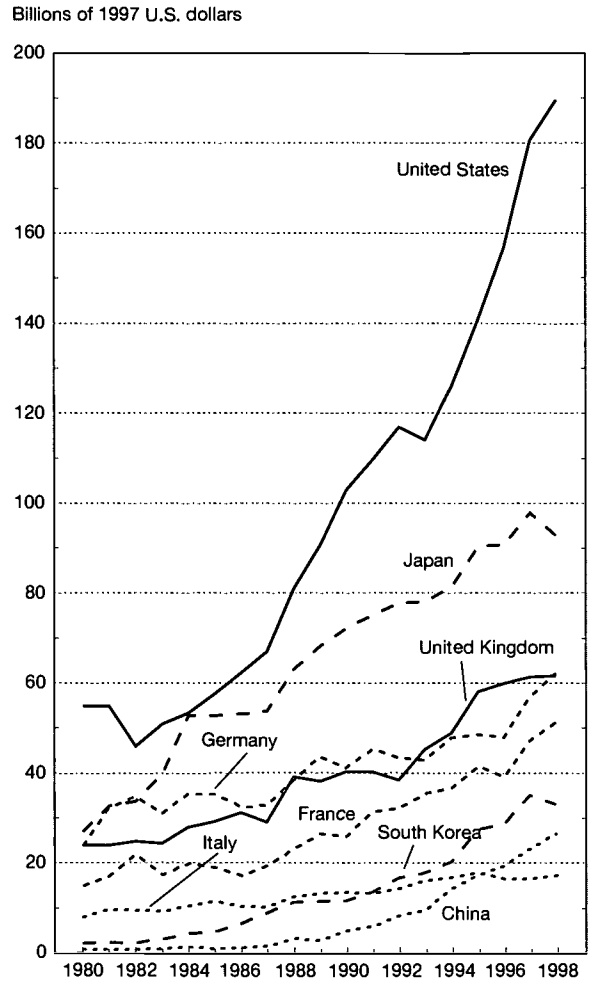
Foreign Markets

Despite its domestic focus, the United States was an important supplier of manufactured products to foreign markets throughout the 1980–98 period. From 1993 to 1998, the United States was the leading exporter of manufactured goods, accounting for about 13 percent of world exports.

U.S. high-technology industries contributed to the strong export performance of the nation's manufacturing industries. (See figure 6-5 and appendix table 6-1.) During the same 19-year period, U.S. high-technology industries accounted for between 19 and 26 percent of world high-technology exports, which was at times twice the level achieved by all U.S. manufacturing industries. In 1998, the latest year for which data are available, exports by U.S. high-technology industries accounted for 19.8 percent of world high-technology exports; Japan was second with 9.7 percent, followed by Germany with 6.5 percent.

The gradual drop in U.S. share during the 19-year period was in part the result of emerging high-technology industries in newly industrialized economies, especially in Asia. In 1980, high-technology industries in Singapore and Taiwan each accounted for about 2.0 percent of world high-technology exports. The latest data for 1998 show Singapore's share reaching 6.4 percent and Taiwan's share reaching 5.0 percent.

Figure 6-5.
High-tech exports: 1980–98



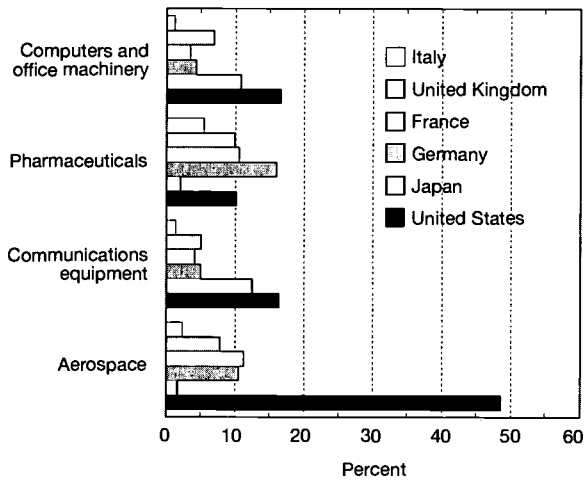
See appendix table 6-1. *Science & Engineering Indicators – 2002*

Industry Comparisons

Throughout the 19-year period, individual U.S. high-technology industries ranked either first or second in exports in each of the four industries that make up the high-technology group. In 1998, the United States was the export leader in three industries and second in only one, pharmaceuticals. (See figure 6-6.)

U.S. industries producing aerospace technologies, computers and office machinery, and pharmaceuticals all accounted for smaller shares of world exports in 1998 than in 1980; only the communications equipment industry improved its share during the period. By contrast, Japan's share of world exports of communications equipment dropped steadily after 1985, eventually falling to 12.5 percent by 1998 from a high of 36.0 percent just 13 years earlier. Several smaller Asian nations fared better: for example, in 1998, South Korea supplied 5.9 percent of world communication product exports, up from just 2.4 percent in 1980, and Singapore supplied 10.6 percent of world office and computer exports in 1998, up from 0.6 percent in 1980.

Figure 6-6.
Export market share in high-tech industries: 1998



See appendix table 6-1. *Science & Engineering Indicators – 2002*

Competition in the Home Market

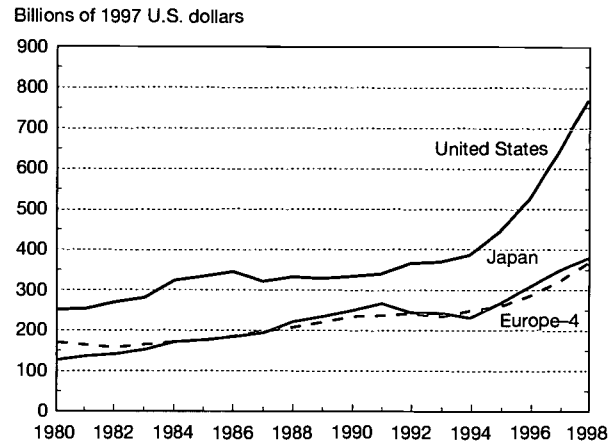
A country's home market is often considered the natural destination for the goods and services domestic firms have produced. Proximity to the customer as well as common language, customs, and currency make marketing at home easier than marketing abroad.

With trade barriers falling, however, product origin may be only one factor among many influencing consumer choice. As the number of firms producing goods to world standards rises, price, quality, and product performance often become equally or more important criteria for selecting products. Thus, in the absence of trade barriers, the intensity of competition faced by producers in the domestic market can approach and, in some markets, exceed that faced in foreign markets. U.S. competitiveness in foreign markets may be the result of two factors: the existence of tremendous domestic demand for the latest technology products and the pressure of global competition, which spurs innovation.

National Demand for High-Technology Products

Demand for high-technology products in the United States far exceeds that in any other single country; in 1998, it was larger (approximately $768 billion) than the combined markets of Japan and the four largest European nations—Germany, the United Kingdom, France, and Italy (about $749 billion). (See figure 6-7.) In 1991, Japan was the world's second largest market for high-technology products, although its percentage share of world consumption has generally declined since then. Even though economic problems across much of Asia have curtailed a long period of rapid growth, Asia continues to be a large market for the world's high-technology exports.

Figure 6-7.
National apparent consumption[1] of high-tech products: 1980–98



[1]Apparent consumption equals gross output plus imports minus exports corrected for implied service costs associated with export sales.

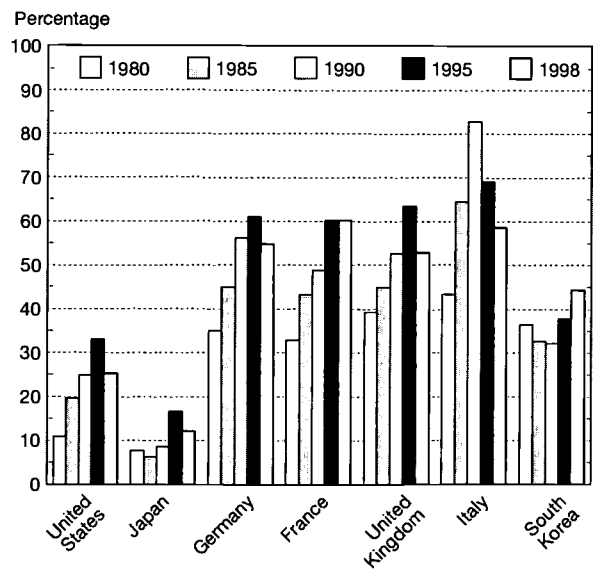
NOTE: Europe–4 refers to the four largest European economies: Germany, France, the United Kingdom, and Italy.

See appendix table 6-1. *Science & Engineering Indicators – 2002*

National Producers Supplying the Home Market

Throughout the 1980–95 period, the world's largest market for high-technology products, the United States, was served primarily by domestic producers, yet demand was increasingly met by a growing number of foreign suppliers. (See figure 6-8.) In 1998, U.S. producers supplied about 75 percent of the home market for high-technology products; in 1995, their share was much lower—about 67 percent.

Figure 6-8.
Import share of domestic high-tech markets



See appendix table 6-1. *Science & Engineering Indicators – 2002*

Other countries, particularly those in Europe, have experienced increased foreign competition in their domestic markets. A more economically unified market has made Europe especially attractive to the rest of the world. Rapidly rising import penetration ratios in Germany, the United Kingdom, France, and Italy during the latter part of the 1980s and throughout much of the 1990s reflect these changing circumstances. These data also highlight greater trade activity in European high-technology markets compared with product markets for less technology-intensive manufactures.

The Japanese home market, the second largest market for high-technology products and historically the most self-reliant of the major industrialized countries, also increased its purchases of foreign technologies over the 19-year period, although slowly. In 1998, imports of high-technology manufactures supplied about 12 percent of Japanese domestic consumption, up from about 7 percent in 1980.

Global Business in Knowledge-Intensive Service Industries

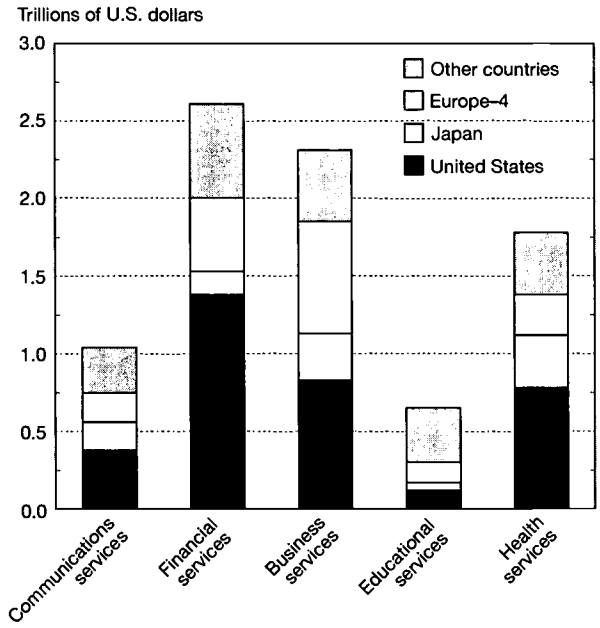
For several decades, revenues generated by U.S. service-sector industries have grown faster than those generated by the nation's manufacturing industries. Data collected by the Department of Commerce show that the service sector's share of the U.S. GDP grew from 49 percent in 1959 to 64 percent in 1997 (National Science Board 2000; appendix table 9-4). Service-sector growth has been fueled largely by "knowledge-intensive" industries—those incorporating science, engineering, and technology in their services or in the delivery of those services. Five of these knowledge-intensive industries are communications services, financial services, business services (including computer software development), educational services, and health services. These industries have been growing faster than the high-technology manufacturing sector discussed earlier. This section presents data tracking overall revenues earned by these industries in 68 countries.[8] (See figure 6-9 and appendix table 6-2.)

Combined sales in 1997 dollars in these five service-sector industries approached $8.4 trillion in 1998, up from $6.8 trillion in 1990 and $4.8 trillion in 1980. The United States was the leading provider of high-technology services, responsible for between 38 and 41 percent of total world service revenues during the entire 19-year period examined.

The financial services industry is the largest of the five service industries examined, accounting for 31 percent of revenues in 1998. The U.S. financial services industry is the world's largest, with 52.9 percent of world revenues in 1998. Japan was second at 5.9 percent, followed by Germany at 4.1 percent.

Business services, which includes computer and data processing and research and engineering services, is the second largest service sector, accounting for nearly 28 percent of revenues in 1998. The U.S. business services industry is the largest in the world, with 36.0 percent of industry revenues in 1998. France is second with 17.1 percent, followed by Japan with 12.9 percent and the United Kingdom with 6.1 percent. Unfortunately, data on individual business services by country are not available.

Figure 6-9.
Global revenues generated by five knowledge-intensive service industries: 1998



NOTE: Europe–4 refers to the four largest European economies: Germany, France, the United Kingdom, and Italy.

See appendix table 6-2. *Science & Engineering Indicators – 2002*

Communications services, which includes telecommunications and broadcast services, is the fourth-largest service industry examined, accounting for 12.3 percent of revenues in 1998. In what many consider the most technology-driven of the service industries, the United States has the dominant position. In 1998, U.S. communications firms generated revenues that accounted for 36.8 percent of world revenues, more than twice the share held by Japanese firms and six times that held by British firms.

Because in many nations the government is the primary provider of the remaining two knowledge-intensive service industries (health services and educational services), and because the size of a country's population affects the delivery of these services, global comparisons are more difficult and less meaningful than those for other service industries. The United States, with the largest population and least government involvement, has the largest commercial industries in the world in both health services and educational services. Japan is second, followed by Germany. Educational services, the smallest of the five knowledge-intensive service industries, had about one-fourth of the revenues generated by the financial services industry worldwide.

[8]Unlike those for manufacturing industries, national data that track activity in many of the hot new service sectors are limited in the level of industry disaggregation available and the types of activity for which national data are collected.

U.S. Trade Balance in Technology Products

Although no single preferred methodology exists for identifying high-technology industries, most calculations rely on a comparison of R&D intensities. R&D intensity, in turn, is typically determined by comparing industry R&D expenditures or the number of technical people employed (e.g., scientists, engineers, and technicians) with industry value added or the total value of its shipments.[9] Classification systems based on R&D intensity, however, are often distorted by including all products produced by particular high-technology industries, regardless of the level of technology embodied in each product, and by the somewhat subjective process of assigning products to specific industries. In contrast, the classification system discussed here allows for a highly disaggregated, more focused examination of technology embodied in traded goods. To minimize the impact of subjective classification, the judgments offered by government experts are reviewed by other experts.

The Bureau of the Census has developed a classification system for exports and imports that embody new or leading-edge technologies. This classification system allows trade to be examined in 10 major technology areas:

- **Biotechnology**—the medical and industrial application of advanced genetic research to the creation of drugs, hormones, and other therapeutic items for both agricultural and human uses.
- **Life science technologies**—the application of nonbiological scientific advances to medicine. For example, advances such as nuclear magnetic resonance imaging, echocardiography, and novel chemistry, coupled with new drug manufacturing, have led to new products that help control or eradicate disease.
- **Opto-electronics**—the development of electronics and electronic components that emit or detect light, including optical scanners, optical disk players, solar cells, photosensitive semiconductors, and laser printers.
- **Information and communications**—the development of products that process increasing amounts of information in shorter periods of time, including fax machines, telephone switching apparatus, radar apparatus, communications satellites, central processing units, and peripheral units such as disk drives, control units, modems, and computer software.
- **Electronics**—the development of electronic components (other than opto-electronic components), including integrated circuits, multilayer printed circuit boards, and surface-mounted components, such as capacitors and resistors, that result in improved performance and capacity and, in many cases, reduced size.
- **Flexible manufacturing**—the development of products for industrial automation, including robots, numerically controlled machine tools, and automated guided vehicles, that permit greater flexibility in the manufacturing process and reduce human intervention.
- **Advanced materials**—the development of materials, including semiconductor materials, optical fiber cable, and videodisks, that enhance the application of other advanced technologies.
- **Aerospace**—the development of aircraft technologies, such as most new military and civil airplanes, helicopters, spacecraft (with the exception of communication satellites), turbojet aircraft engines, flight simulators, and automatic pilots.
- **Weapons**—the development of technologies with military applications, including guided missiles, bombs, torpedoes, mines, missile and rocket launchers, and some firearms.
- **Nuclear technology**—the development of nuclear production apparatus, including nuclear reactors and parts, isotopic separation equipment, and fuel cartridges (nuclear medical apparatus is included in life sciences rather than this category).

To be included in a category, a product must contain a significant amount of one of the leading-edge technologies, and the technology must account for a significant portion of the product's value.

Importance of Advanced Technology Product Trade to Overall U.S. Trade

Advanced technology products accounted for an increasing share of all U.S. trade (exports plus imports) in merchandise between 1990 and 1999. (See text table 6-1 and appendix table 6-3.) Total U.S. trade in merchandise exceeded $1.7 trillion in 1999; of that, $381 billion involved trade in advanced technology products. Trade in advanced technology products accounts for a much larger share of U.S. exports than of imports (29.2 percent versus 17.5 percent in 1999) and makes a positive contribution to the overall balance of trade. After several years in which the surplus generated by trade in advanced technology products declined, exports of U.S. advanced technology products outpaced imports in 1996 and 1997, producing larger surpluses in both years. In 1998 and 1999, the economic slowdown in Asia caused declines in exports and in the surplus generated from U.S. trade in advanced technology products.

Technologies Generating Trade Surpluses

Throughout the 1990s, U.S. exports of advanced technology products exceeded imports in 8 of 11 technology areas.[10] Trade in aerospace technologies consistently produced the largest surpluses for the United States. Those surpluses narrowed in the mid-1990s as competition from Europe's aerospace industry challenged U.S. companies' preeminence both

[9]See footnote 2 for a discussion of the methodology.

[10]Software products is not a separate advanced technology products category; it is included in the category covering information and communications products. To better examine this important technology area, software products was broken out from the information and communications, creating an 11th category.

Text table 6-1.
U.S. international trade in merchandise

Type of trade	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Total trade (billions of U.S.$)	888.3	910.0	979.9	1,045.3	1,176.2	1,325.3	1,410.8	1,556.1	1,587.5	1,714.3
Technology products (%)	17.3	18.1	18.3	18.1	18.6	19.9	20.2	21.0	21.6	22.2
Other merchandise (%)	82.7	81.9	81.7	81.9	81.4	80.1	79.8	79.0	78.4	77.8
Total exports (billions of U.S.$)	393.0	421.9	447.5	464.8	512.4	575.9	611.5	679.7	670.3	684.4
Technology products (%)	24.1	24.1	23.9	23.3	23.6	24.0	25.3	26.4	27.8	29.2
Other merchandise (%)	75.9	75.9	76.1	76.7	76.4	76.0	74.7	73.6	72.2	70.8
Total imports (billions of U.S.$)	495.3	488.1	532.4	580.5	663.8	749.4	799.3	876.4	917.2	1,029.9
Technology products (%)	12.0	13.0	13.5	14.0	14.8	16.7	16.3	16.8	17.1	17.5
Other merchandise (%)	88.0	87.0	86.5	86.0	85.2	83.3	83.7	83.2	82.9	82.5

NOTE: Total trade is the sum of total exports and total imports.

SOURCE: U.S. Bureau of the Census, Foreign Trade Division (2001). Available at <http://www.fedstats.gov>, March 2001.

Science & Engineering Indicators – 2002

at home and in foreign markets. Aerospace technologies generated a net inflow of $25 billion in 1990 and nearly $29 billion in 1991 and 1992; trade surpluses then declined 13 percent in 1993, 9 percent in 1994, and 4 percent in 1995. In 1998, U.S. trade in aerospace technologies produced a net inflow of $39 billion, the largest surplus of the decade, and 1999's surplus was only slightly smaller at $37 billion. Trade is more balanced in five other technology areas (biotechnology, flexible manufacturing technologies, advanced materials, weapons, and nuclear technology), with exports having only a slight edge over imports. Each of these areas showed trade surpluses of less than $3 billion in 1999.

Although U.S. imports of electronics technologies exceeded exports for much of the decade, 1997 saw U.S. exports of electronics exceed imports by $1.1 billion, which jumped to $4.2 billion in 1998 and $9.4 billion in 1999. This turnaround may be attributed in part to Asia's economic problems in 1998 and a stronger U.S. dollar, which may have reduced the number of electronics products imported from Asia in 1998. Imports from Asia recovered to pre-1998 levels in 1999, with the largest jumps in imports coming not from Japan but from South Korea, the Philippines, and Malaysia.

Technologies Generating Trade Deficits

In 1999, trade deficits were recorded in three technology areas: information and communications, opto-electronics, and life science technologies. The trends for each of these technology areas are quite different. Only opto-electronics showed trade deficits in each of the 10 years examined. U.S. trade in life science technologies consistently generated annual trade surpluses until 1998. Life science exports were virtually flat in the last two years of the decade, while imports jumped 24 percent in 1998 and 21 percent in 1999. Interestingly, in a technology area in which the United States is considered to be at the forefront (information and communications), annual U.S. imports have consistently exceeded exports since 1992. Nearly three-fourths of all U.S. imports in this technology area are produced in Asia.[11]

[11]The Bureau of the Census is not able to identify the degree to which this trade is between affiliated U.S. and foreign companies.

Top Customers by Technology Area

Japan and Canada are the largest customers for a broad range of U.S. technology products, with each country accounting for about 11 percent of total U.S. technology exports. Japan ranks among the top three customers in 9 of 11 technology areas, Canada in 7. (See figure 6-10 and appendix table 6-4.) European countries are also important consumers of U.S. technology products, particularly Germany (life science products, opto-electronics, and advanced materials), the United Kingdom (aerospace, weapons, and computer software), and the Netherlands (life science products and weapons).

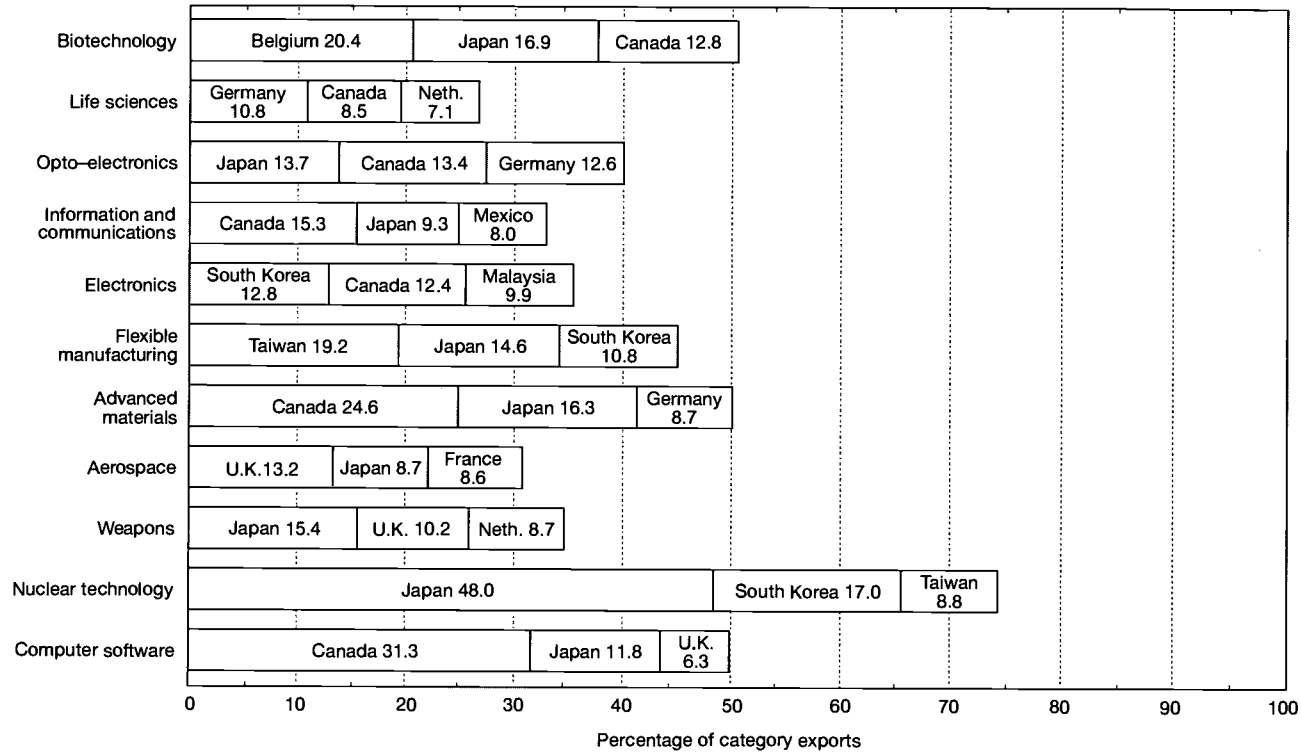
Although Europe, Japan, and Canada have long been important consumers of U.S. technology products, several newly industrialized and emerging Asian economies now also rank among the largest customers. South Korea is a leading consumer in three technology areas (electronics, flexible manufacturing, and nuclear technologies) and Taiwan in two (flexible manufacturing and nuclear technologies).

Top Suppliers by Technology Area

The United States is not only an important exporter of technologies to the world but also a consumer of imported technologies. The leading economies in Asia and Europe are important suppliers to the U.S. market in each of the 11 technology areas. (See figure 6-11 and appendix table 6-5.) Japan is a major supplier in six advanced technology categories; Canada, France, Germany, Taiwan, and the United Kingdom in three. Smaller European countries are also major suppliers of technology to the United States, although they tend to specialize. Belgium was the top foreign supplier of biotechnology products to the United States in 1999, the source for 25.5 percent of imports in this category. Switzerland also was among the top three suppliers of biotechnology products with 11.3 percent.

Many technology products come from developing Asian economies, especially Malaysia, South Korea, and Singapore. Imports from these Asian economies and from other regions into one of the world's most demanding markets indicate that technological capabilities are expanding globally.

Figure 6-10.
Three largest export markets for U.S. technology products: 1999



See appendix table 6-4.

Science & Engineering Indicators – 2002

U.S. Royalties and Fees Generated From Intellectual Property

The United States has traditionally maintained a large trade surplus in intellectual property. Firms trade intellectual property when they license or franchise proprietary technologies, trademarks, and entertainment products to entities in other countries. These transactions generate net revenues in the form of royalties and licensing fees.

U.S. Royalties and Fees From All Transactions

Total U.S. receipts from all trade in intellectual property more than doubled between 1990 and 1999, reaching nearly $36.5 billion in 1999. (See appendix table 6-6.) During the 1987–96 period, U.S. receipts for transactions involving intellectual property were generally four to five times larger than U.S. payments to foreign firms. The gap narrowed in 1997 as U.S. payments increased by 20 percent over the previous year and U.S. receipts rose less than 3 percent. Despite the much larger increase in payments, annual receipts from total U.S. trade in intellectual property in 1997 were still more than 3.5 times greater than payments. This trend continued during the following two years, and by 1999, the ratio of receipts to payments had dropped to about 2.7:1.

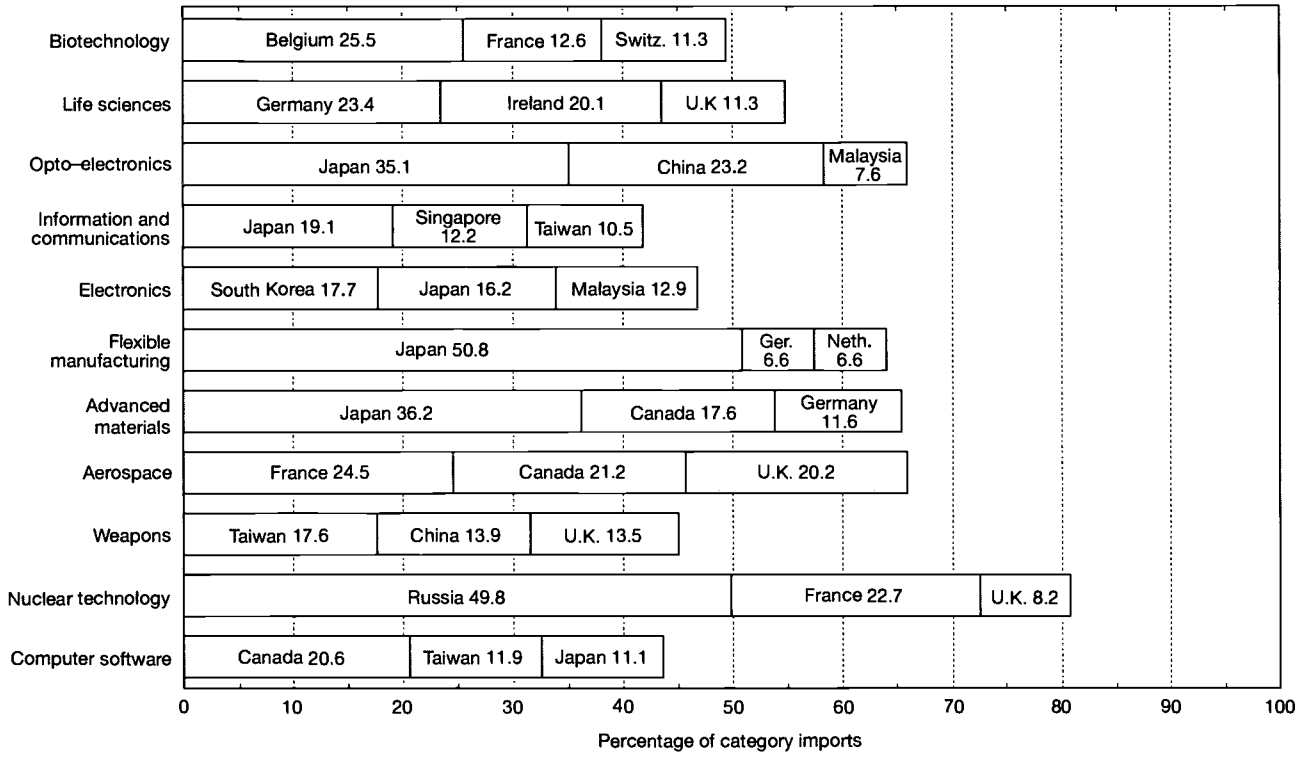
U.S. trade in intellectual property produced a surplus of $23.2 billion in 1999, down slightly from the nearly $24.5 billion surplus recorded a year earlier. (See figure 6-12.) About 75 percent of the transactions involved exchanges of intellectual property between U.S. firms and their foreign affiliates.[12] Exchanges of intellectual property among affiliates have grown at about the same pace as those among unaffiliated firms, except during the late 1990s, when the growth in U.S. firm payments to affiliates exceeded receipts. These trends suggest both a growing internationalization of U.S. business and a growing reliance on intellectual property developed overseas.

U.S. Royalties and Fees From Trade in Technical Knowledge

Data on royalties and fees generated by trade in intellectual property can be further disaggregated to reveal U.S. trade in technical know-how. The following data describe transactions between unaffiliated firms where prices are set through a market-based negotiation. Therefore, they may better reflect the exchange of technical know-how and its market value at a given time than do data on exchanges among affiliated firms. When receipts (sales of technical know-how) consistently exceed payments (purchases), these data may indicate a comparative advantage in the creation of industrial technology. The record of

[12]An *affiliate* refers to a business enterprise located in one country that is directly or indirectly owned or controlled by an entity of another country. The controlling interest for an incorporated business is 10 percent or more of its voting stock; for an unincorporated business, it is an interest equivalent to 10 percent of voting stock.

Figure 6-11.
Top three foreign suppliers of technology products to the United States: 1999



See appendix table 6-5. *Science & Engineering Indicators – 2002*

resulting receipts and payments also provides an indicator of the production and diffusion of technical knowledge.

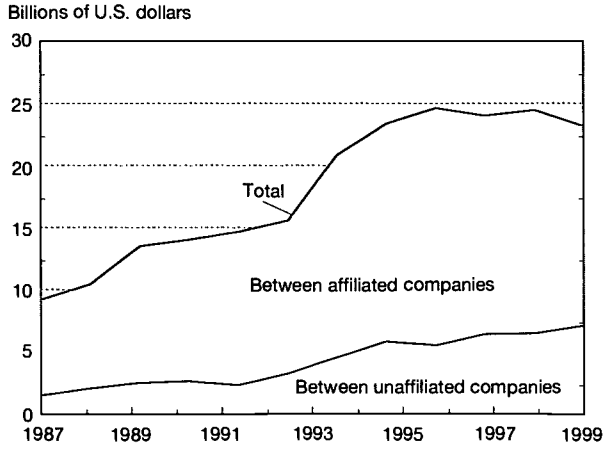
The United States is a net exporter of technology sold as intellectual property, although the gap between imports and exports narrowed during the late 1990s. During the first half of the 1990s, royalties and fees received from foreign firms have been an average of three times the amount U.S. firms pay foreigners to access their technology. Between 1996 and 1998, receipts plateaued at about $3.5 billion. In 1999, receipts totaled nearly $3.6 billion, little changed from the year before but still more than double that reported for 1987. (See figure 6-13 and appendix table 6-7.)

Japan is the world's largest consumer of U.S. technology sold as intellectual property, although its share declined significantly during the 1990s. In 1999, Japan accounted for about 30 percent of all such receipts. At its peak in 1993, Japan's share was 51 percent.

Another Asian country, South Korea, is the second largest consumer of U.S. technology sold as intellectual property, accounting for nearly 14 percent of U.S. receipts in 1999. South Korea has been a major consumer of U.S. technological know-how since 1988, when it accounted for 5.5 percent of U.S. receipts. South Korea's share rose to 10.7 percent in 1990 and reached its highest level, 17.3 percent, in 1995.

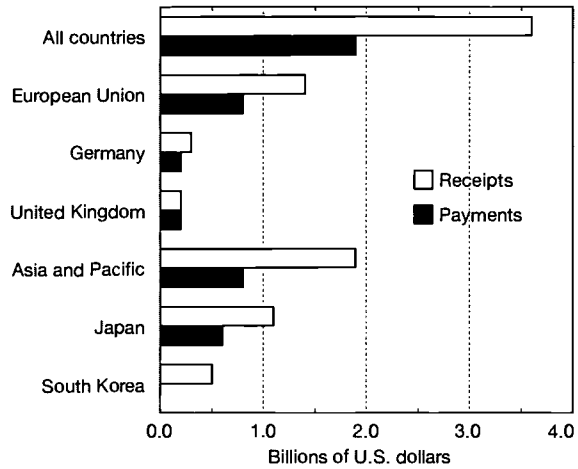
The U.S. trade surplus in intellectual property is driven largely by trade with Asia, but that surplus has narrowed recently. In 1995, U.S. receipts (exports) from technology licensing transactions were nearly seven times the U.S. firm payments (imports) to Asia. That ratio closed to just more than 4:1 by 1997, and the most recent data show U.S. receipts from technology licensing transactions at about 2.5 times the U.S. firm payments to Asia. As previously noted, Japan and South Korea were the biggest customers for U.S. technology sold as intellectual property; together, these countries ac-

Figure 6-12.
U.S. trade balance of royalties and fees: 1987–99



See appendix table 6-6. *Science & Engineering Indicators – 2002*

Figure 6-13.
U.S. royalties and fees generated from the exchange of industrial processes between unaffiliated companies: 1999



See appendix table 6-7. *Science & Engineering Indicators – 2002*

counted for more than 44 percent of total receipts in 1999.

Until 1994, U.S. trade with Europe in intellectual property, unlike trade with Asia, fluctuated between surplus and deficit. In 1994, a sharp decline in U.S. purchases of European technical know-how led to a considerably larger surplus for the United States compared with earlier years. The following year showed another large surplus resulting from a jump in receipts from the larger European countries. In 1999, receipts from European Union (EU) countries represented about 35 percent of U.S. technology sold as intellectual property, more than double the share in 1993. Some of this increase is attributable to increased licensing by firms in Germany, the third largest consumer of U.S. technological know-how. In 1999, Germany's share rose to 9.3 percent, up from 6.9 percent in 1998 and more than double its share in 1993. These latest data show receipts from France and Sweden rising sharply during the late 1990s, causing a considerably larger surplus from U.S. trade with Europe in intellectual property in 1998 and 1999.

U.S. firms have purchased technical know-how from different foreign sources over the years, with increasing amounts coming from Japan, which since 1992 has been the single largest foreign supplier of technical know-how to U.S. firms. About one-third of U.S. payments in 1999 for technology sold as intellectual property were made to Japanese firms. Europe accounts for slightly more than 44 percent of the foreign technical know-how purchased by U.S. firms; the United Kingdom and Germany are the principal European suppliers.[13]

[13]Over the years, France has also been an important source of technological know-how. In 1996, France was the leading European supplier to U.S. firms. Since then, data on France have been suppressed to avoid disclosing individual company operations.

[14]See chapter 2 for the discussion of international higher education trends and chapter 4 for the discussion of trends in international R&D.

New High-Technology Exporters

Several nations have made tremendous technological leaps forward over the past decade. Some of these countries are well positioned to play more important roles in technology development because of their large and continuing investments in S&E education and R&D.[14] However, their success may hinge on other factors as well, including political stability, access to capital, and an infrastructure that can support technological and economic advancement.

This section assesses a group of selected countries and their potential to become more important exporters of high-technology products during the next 15 years, based on the following leading indicators:

- **National orientation**—evidence that a nation is taking action to become technologically competitive, as indicated by explicit or implicit national strategies involving cooperation between the public and private sectors.
- **Socioeconomic infrastructure**—the social and economic institutions that support and maintain the physical, human, organizational, and economic resources essential to the functioning of a modern, technology-based industrial nation. Indicators include the existence of dynamic capital markets, upward trends in capital formation, rising levels of foreign investment, and national investments in education.
- **Technological infrastructure**—the social and economic institutions that contribute directly to a nation's ability to develop, produce, and market new technology. Indicators include the existence of a system for the protection of intellectual property rights (IPR), the extent to which R&D activities relate to industrial application, competency in high-technology manufacturing, and the capability to produce qualified scientists and engineers.
- **Productive capacity**—the physical and human resources devoted to manufacturing products and the efficiency with which those resources are used. Indicators include the current level of high-technology production, the quality and productivity of the labor force, the presence of skilled labor, and the existence of innovative management practices.

This section analyzes 15 economies: 6 in Asia (China, India, Indonesia, Malaysia, the Philippines, and Thailand); 3 in Central Europe (Czech Republic, Hungary, and Poland); 4 in Latin America (Argentina, Brazil, Mexico, and Venezuela); and 2 others (Ireland and Israel) that have shown increased technological activity.[15]

National Orientation

The national orientation indicator identifies nations whose businesses, government, and culture encourage high-technology development. This indicator was constructed using information from a survey of international experts and published

[15]See Porter and Roessner (1991) for details on survey and indicator construction; see Roessner, Porter, and Xu (1992) for information on the validity and reliability testing the indicators have undergone.

data. The survey asked the experts to rate national strategies that promote high-technology development, social influences favoring technological change, and entrepreneurial spirit. Published data were used to rate each nation's risk factor for foreign investment during the next five years (PRS Group 1999).

Ireland and Israel posted the highest overall scores by far on this indicator. (See figure 6-14 and appendix table 6-8.) Although Ireland scored slightly lower than Israel on each of the expert-opinion components, its rating as a much safer place for foreign investment than Israel elevated its composite score.

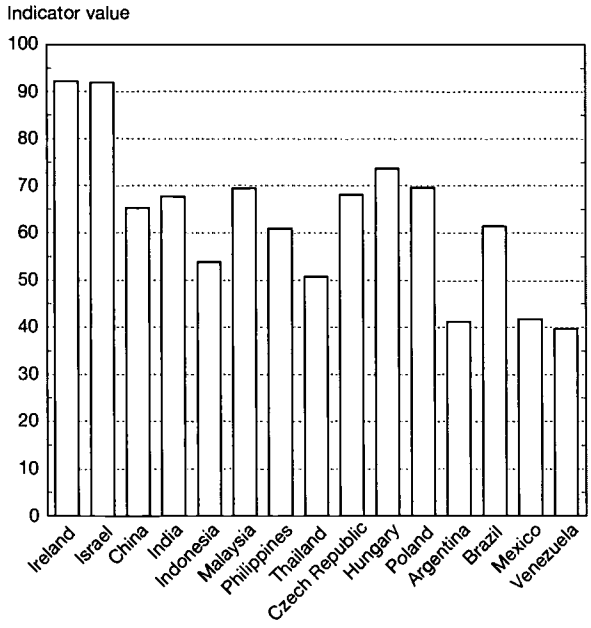
The national orientation of both Ireland and Israel was scored consistently and significantly higher than that of the other countries examined and was well within the range of scores accorded the more advanced economies of Taiwan and Singapore. Hungary, Poland, and Malaysia also scored well, with strong scores in each of the indicator components.

Except for Brazil, the Latin American countries (Argentina, Mexico, and Venezuela) received the lowest composite scores of the economies examined. Two factors contributed to their low scores: they were considered riskier or less attractive sites for foreign investment than the other countries, and the experts did not consider these three countries to be entrepreneurial.

Socioeconomic Infrastructure

The socioeconomic infrastructure indicator assesses the underlying physical, financial, and human resources needed to support modern, technology-based nations. It was built from published data on percentages of the population in secondary school and in higher education and survey data evaluating the mobility of capital and the extent to which foreign businesses are encouraged to invest and do business in that country.[16] (See figure 6-15.)

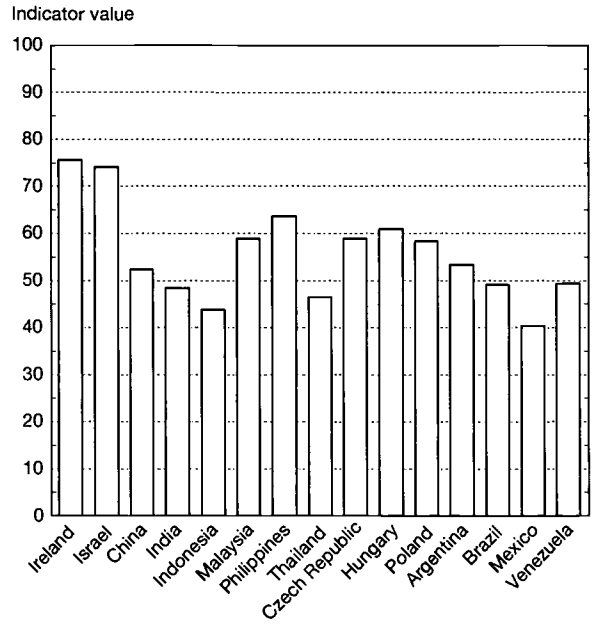
Figure 6-14.
National orientation indicator



NOTE: Raw data were converted into scales of 0–100 for each indicator component.

See appendix table 6-8. *Science & Engineering Indicators – 2002*

Figure 6-15.
Socioeconomic infrastructure indicator



NOTE: Raw data were converted into scales of 0–100 for each indicator component.

See appendix table 6-8. *Science & Engineering Indicators – 2002*

Ireland and Israel again received the highest scores among the emerging and transitioning economies examined. In addition to their strong track records on general and higher education, Ireland's and Israel's scores reflect their high ratings for the mobility of capital and their encouragement of foreign investment. Their scores were similar to those given to Taiwan and South Korea.

Among the remaining nations, the Philippines edged out the three Central European countries, which all posted similar scores. The socioeconomic infrastructure score for the Philippines was bolstered by its strong showing in the published education data and by the experts' higher opinion of its mobility of capital.

Mexico received the lowest composite score of the 15 nations examined. It was held back by low marks on two of the three variables: educational attainment—in particular, university enrollments—and the variable rating of its mobility of capital.

Technological Infrastructure

Five variables were used to develop the technological infrastructure indicator, which evaluates the institutions and resources that help nations develop, produce, and market new

[16]The Harbison-Myers Skills Index (which measures the percentage of the population attaining secondary and higher education) was used for these assessments (World Bank 1999).

technology. This indicator was constructed using published data on the number of scientists in R&D; published data on national purchases of electronic data processing (EDP) equipment; and data from a survey that asked experts to rate each nation's ability to train its citizens locally in academic S&E, make effective use of technical knowledge, and link R&D to industry.

Israel received the highest composite score of the group of newly industrialized or transitioning economies examined here. (See figure 6-16.) Israel's high score on this indicator was based on its large number of trained scientists and engineers, the size of its research enterprise, and its contribution to scientific knowledge, especially compared with Ireland and the smaller, less populous nations in Asia and Central Europe. Ireland received the second highest score, followed by India and China. Ireland's score was bolstered by its large purchases of EDP equipment. India's and China's scores were nearly identical, although India's scores showed more balance across indicator components and more overall strength. China's score was influenced greatly by the two components derived from statistical data: its large purchases of EDP equipment and its large number of scientists and engineers engaged in R&D.

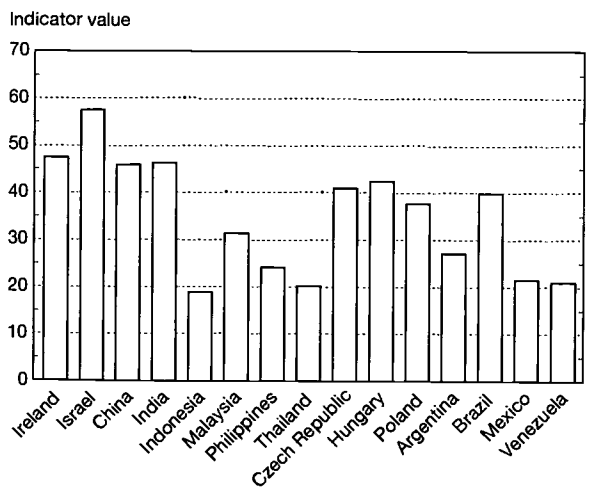
Productive Capacity

The productive capacity indicator evaluates the strength of a nation's current, in-place manufacturing infrastructure as a baseline for assessing its capacity for future growth in high-technology activities. It factors in expert opinion on the availability of skilled labor, numbers of indigenous high-technology companies, and management capabilities, combined with published data on current electronics production in each country.

Ireland scored highest in productive capacity among the 15 developing and transitioning nations examined, receiving high marks for each indicator component. (See figure 6-17.) Ireland's score also was boosted by its prominence in the computer hardware manufacturing industry. India and Israel were second and third, attaining strong scores on each indicator component.

Several developing Asian economies, particularly China and Malaysia, had higher electronics production than did Ireland in 1996, the reference year for the published data. However, they scored lower on indicator components rating their labor pools and management personnel. Mexico's score showed an even greater imbalance than those of China and Malaysia. Although Mexico's production of electronics products—this indicator's published data variable—was greater than Ireland's, scores rating the quality of Mexican labor and management were extremely low. As a result, Mexico received the second lowest score of the 15 countries examined.

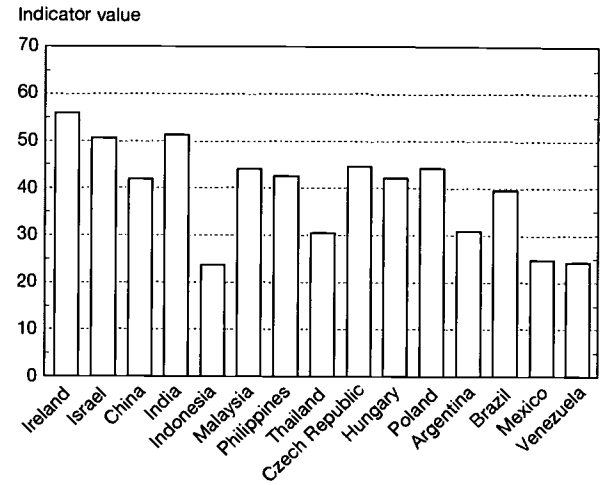
Figure 6-16.
Technological infrastructure indicator



NOTE: Raw data were converted into scales of 0–100 for each indicator component.

See appendix table 6-8. *Science & Engineering Indicators – 2002*

Figure 6-17.
Productive capacity indicator



NOTE: Raw data were converted into scales of 0–100 for each indicator component.

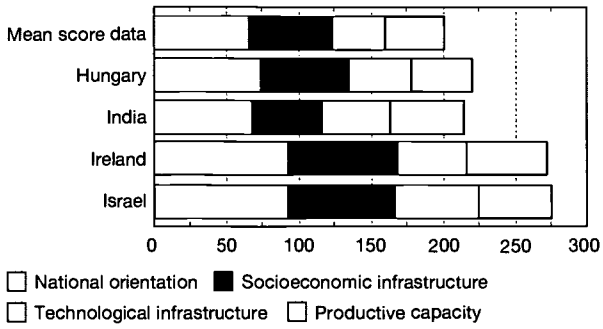
See appendix table 6-8. *Science & Engineering Indicators – 2002*

Findings From the Four Indicators

Based on the set of four leading indicators discussed, Ireland and Israel appear headed toward prominence as exporters of technology products to the global market. Ireland led the group of 15 developing and transitioning countries examined in three of the four leading indicators and received the second highest score in the fourth, technological infrastructure. On that indicator, Israel ranked first because of its large number of trained scientists and engineers, its highly regarded industrial research enterprise, and its contribution to scientific knowledge. Israel placed second on two of the remaining indicators and third on the other. (See figure 6-18.)

Hungary and India also posted strong scores on at least three of the four indicators. Hungary ranked third on the indicator identifying nations that are taking action to become technologically competitive, fourth on the indicator rating socioeconomic infrastructure, and fifth on the technological infrastructure indicator. India scored nearly as well and some-

Figure 6-18.
Composite scores for four new high-tech exporters



NOTE: Raw data were converted into scales of 0–100 for each indicator component.

See appendix table 6-8. *Science & Engineering Indicators – 2002*

times better than Hungary on the leading indicators, but its scores were not as balanced. Hungary's lowest ranking on any of the four indicators was 8th on the productive capacity indicator, while India's lowest ranking was 11th on the socioeconomic indicator. India's large population helped to elevate its scores on several indicators.

These indicators provide a systematic approach for comparing future technological capability on an even wider set of nations than might be available using other indicators. The results highlight a broadening of the group of nations that may compete in high-technology markets in the future while also reflecting the large differences between several of the emerging and transitioning economies and those considered newly industrialized.

International Trends in Industrial R&D

In high-wage countries such as the United States, industries stay competitive in a global marketplace through innovation (Council on Competitiveness 2001). Innovation leads to better production processes and higher quality products, thereby providing the competitive advantage high-wage countries need when competing against low-wage nations.

R&D activities serve as incubators for the new ideas that can lead to new products, processes, and industries. Although they are not the only source of new innovations, R&D activities conducted in industry-run laboratories and facilities are the source of many important new ideas that have shaped modern technology.[17]

U.S. industries that traditionally conduct large amounts of R&D have met with greater success in foreign markets than those that are less R&D intensive, and they have been more supportive of higher wages for their employees. (See "U.S. Technology in the Marketplace" section for a presentation of recent trends in U.S. competitiveness in foreign and domestic product markets.) Moreover, trends in industrial R&D performance are leading indicators of future technological performance. The following section examines these R&D trends, focusing particularly on growth in industrial R&D activity in the top R&D-performing industries in the United States, Japan, and the EU.[18]

R&D Performance by Industry

The United States, the EU, and Japan represent the three largest economies in the industrialized world and are competitors in the international marketplace. An analysis of R&D data can explain past successes in certain product markets, provide insights into future product development, and highlight shifts in national technology priorities.[19]

United States

R&D performance by the U.S. service-sector industries underwent explosive growth between 1987 and 1991, driven primarily by computer software firms and firms performing R&D on a contract basis. In 1987, service-sector industries performed less than 9 percent of all R&D performed by industry in the United States. During the next several years, R&D performed in the service sector raced ahead of that performed by U.S. manufacturing industries, and by 1989, the service sector performed nearly 19 percent of total U.S. industrial R&D, more than double the share held just two years earlier. By 1991, service-sector R&D had grown to represent nearly one-fourth of all U.S. industrial R&D. Since then, R&D performance in U.S. manufacturing industries increased and began growing faster than in the burgeoning service sector. Manufacturers' share inched back up to 80 percent of total U.S. industry R&D by 1996, the latest year for which internationally comparable data are available. Industries making computer hardware, electronics equipment, and motor vehicles led this resurgence in manufacturing-sector R&D. (See figure 6-19 and appendix table 6-9.)

From 1987 to 1992, the U.S. aerospace industry performed the largest amount of R&D, accounting for 14 to 26 percent of total R&D performed by industry. The industry manufacturing electronics equipment (including communications equipment) and the U.S. chemical industry (including pharmaceuticals) followed, each accounting for between 9 and 16 percent of total U.S. R&D. During the mid-1990s, however, the nation's R&D emphasis shifted; the aerospace industry's share declined, and the share for the industry manufacturing communications equipment increased. In 1996 and 1997, the industry manufacturing communications and other electronics equipment was the top R&D performer in the United States.

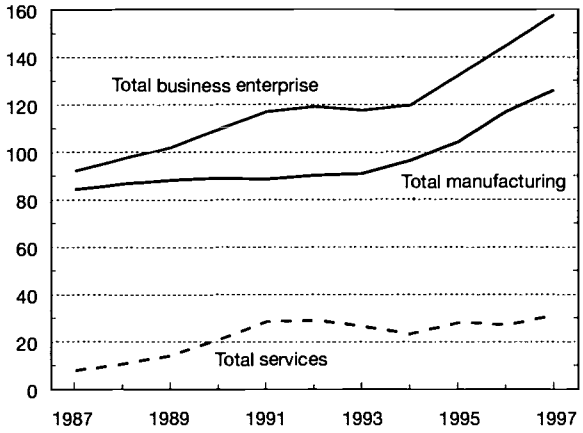
[17]For a discussion of trends in foreign direct investment in R&D facilities, see chapter 4.

[18]This section uses data from OECD's Analytical Business Enterprise R&D database (OECD 2000) to examine trends in national industrial R&D performance. This database tracks all R&D expenditures (both defense- and non-defense-related) carried out in the industrial sector, regardless of funding source. For an examination of U.S. industrial R&D by funding source, see chapter 4.

[19]Industry-level data are occasionally estimated here to provide a complete time series for the 1987–97 period.

Figure 6-19.
U.S. industrial R&D performance: 1987–97

Billions of current PPP $



Top industrial R&D performers and share of total industrial R&D (percents)

1987		1992		1997	
Aerospace	27.1	Services	24.3	Services	19.7
Electronic equipment	15.9	Aerospace	14.8	Electronic equipment	13.0
Chemicals	10.5	Chemicals	12.9	Chemicals	12.1
Computers and office machines	10.1	Computers and office machines	9.6	Computers and office machines	11.6
Motor vehicles	10.1	Electronic equipment	8.9	Aerospace	10.7

PPP = purchasing power parity

See appendix table 6-9. *Science & Engineering Indicators – 2002*

Japan

Unlike the United States, Japan has yet to see a dramatic growth in service-sector R&D. Although R&D in Japan's service-sector industries reached 4.2 percent of the total R&D performed by Japanese industry in 1996 and 4.5 percent in 1997, Japan's industrial R&D performance continues to be dominated by its manufacturing sector. From 1987 to 1995, Japan's manufacturing sector consistently accounted for nearly 98 percent of all R&D performed by Japanese industry. (See figure 6-20 and appendix table 6-10.)[20]

The top industrial R&D performers in Japan during the 1987–97 period reflect that country's long-standing emphases on electronics technology (including consumer electronics and audiovisual equipment), motor vehicles, and electrical machinery. Japan's electronics equipment industry was the leading performer of R&D throughout the period, accounting for nearly 17 percent of all Japanese industrial R&D in 1997. Japan's motor vehicle industry was the second-best R&D performer and has retained that position nearly every year through 1997. Producers of electrical machinery became Japan's second-best R&D-performing industry in 1994 before falling back to the third position, which they have held for several years. In 1997, manufacturers of electrical machinery accounted for nearly 11 percent of all industrial R&D performed in Japan. By comparison, since the early 1970s, U.S. producers of electrical machinery have steadily dropped in rank among the country's top R&D performers.

[20]Revised Japanese R&D data for 1997 are reported in the "International Comparisons" section of chapter 4. Those data include a correction not incorporated here because of the inability to carry the correction backward and revise the complete historical series. The revision does not materially alter the observations discussed in this section.

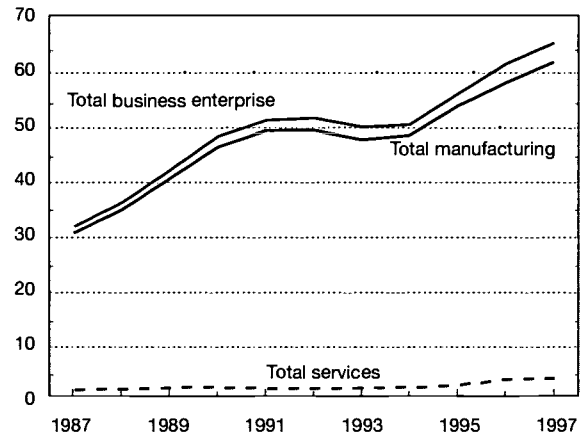
European Union

As in Japan and the United States, manufacturing industries perform the bulk of industrial R&D in the 15-nation EU. The EU's industrial R&D appears to be somewhat less concentrated than that in the United States but more so than that in Japan. Manufacturers of electronics equipment, motor vehicles, and industrial chemicals have consistently been among the top five performers of industrial R&D in the EU. (See figure 6-21 and appendix table 6-11.) In 1997, Germany led the EU in the performance of motor vehicle and industrial chemical R&D, France led in industrial R&D performed by electronics equipment manufacturers, and the United Kingdom led in pharmaceuticals R&D.

R&D within the EU's service sector has doubled since the mid-1980s, accounting for about 11 percent of total industrial R&D by 1997. Large increases in service-sector R&D are apparent in many EU countries, but especially in the United Kingdom (19.6 percent of its industrial R&D in 1997), Italy (15.3 percent), and France (10.0 percent).

Figure 6-20.
Japan industrial R&D performance: 1987–97

Billions of current PPP $



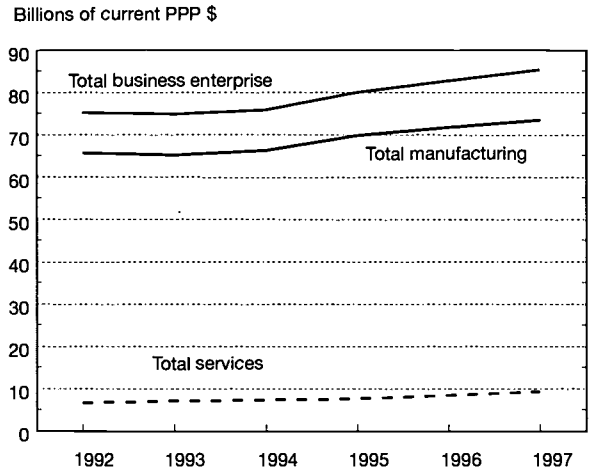
Top industrial R&D performers and share of total industrial R&D (percents)

1987		1992		1997	
Electronic equipment	18.0	Chemicals	16.8	Electronic equipment	16.6
Chemicals	116.9	Electronic equipment	16.7	Chemicals	15.1
Motor vehicles	12.2	Motor vehicles	13.3	Motor vehicles	13.2
Electrical machines	10.3	Office machines	8.6	Electrical machines	10.7
Machinery, N.E.C.	8.2	Machinery, N.E.C.	8.3	Office machines	9.9

PPP = purchasing power parity; N.E.C. = not elsewhere classified

See appendix table 6-10. *Science & Engineering Indicators – 2002*

Figure 6-21.
European Union industrial R&D performance: 1992–97



Top industrial R&D performers and share of total industrial R&D (percents)

1987	1992		1997	
Data not available	Chemicals	19.5	Chemicals	20.7
	Motor vehicles	13.7	Motor vehicles	14.7
	Electronic equipment	10.7	Electronic equipment	12.8
	Aerospace and other transport equipment	10.7	Total services	10.9
	Machinery, N.E.C.	8.8	Aerospace and other transport equipment	8.9

PPP = purchasing power parity; N.E.C. = not elsewhere classified

See appendix table 6-11. *Science & Engineering Indicators – 2002*

Patented Inventions

Inventions have important economic benefits to a nation because they often result in new or improved products, more efficient manufacturing processes, or even new industries. To foster inventiveness, nations assign property rights to inventors in the form of patents, which allow the inventor to exclude others from making, using, or selling the invention. Inventors can obtain patents from government-authorized agencies for inventions judged to be new, useful, and not obvious.

Although the Patent and Trademark Office (PTO) grants several types of patents, this discussion is limited to utility patents only, which are commonly known as patents for inventions. Patenting indicators have several well-known drawbacks, including the following:

- **Incompleteness.** Many inventions are not patented at all, in part because laws in some countries already provide for the protection of industrial trade secrets.
- **Inconsistency across industries and fields.** Industries and fields vary considerably in their propensity to patent inventions; thus, comparing patenting rates among different industries or fields is not advisable (Scherer 1992).
- **Inconsistency in quality.** The importance of patented inventions can vary considerably, although calculating patent citation rates (discussed later in this section and in chapter 5) is one method for mitigating this problem.

Despite these and other limitations, patents provide a unique source of information on inventive activities. Patent data provide useful indicators of technical change and serve as a means of measuring inventive output over time.[21] In addition, information on U.S. patenting by foreign inventors enables measurement of the inventiveness in those foreign countries (Pavitt 1985) and can serve as a leading indicator of new technological competition (Faust 1984).[22]

U.S. Patenting

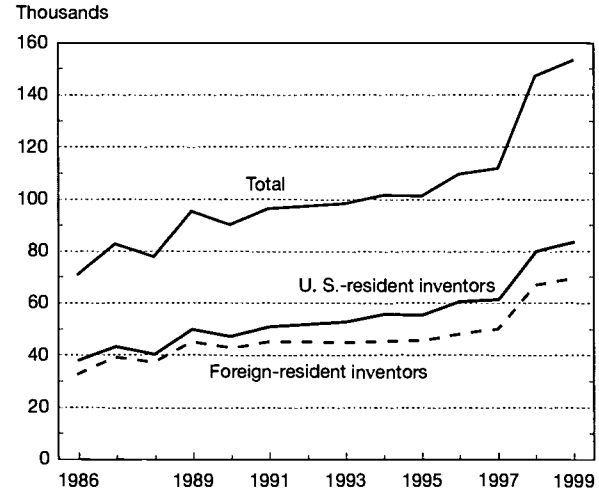
In 1999, more than 153,000 patents were issued in the United States, 4 percent more than that granted a year earlier. This new record number of patents caps off nearly a decade of growth during the 1990s. In 1995, U.S. patents granted fell just short of the previous year's mark, but the upward trend resumed with small increases in U.S. patents granted in 1996 and 1997 before a 32 percent jump in 1998.[23] (See figure 6-22 and appendix table 6-12.)

[21]See Griliches (1990) for a survey of literature related to this point.

[22]It should also be noted that there is concern that patents and other forms of intellectual property may discourage research, its communication, and the diffusion of new technologies. The question arises whether in some respects the extension of intellectual property rights have proceeded too far. To provide answers to guide IPR policy over the next decade and beyond, the Science, Technology and Economic Policy Board (STEP) of theNational Research Council (NRC) has undertaken a project to review the purposes of the IPR legal framework and assess how well those purposes are being served. The Board will identify whether there are current or emerging problems of inadequate or over-protection of IPRs that need attention and will commission research on some these topics.

[23]Although patent applications have been rising, PTO attributes most of the increase in 1998 to greater administrative efficiency and the hiring of additional patent examiners.

Figure 6-22.
U.S. patents granted: 1986–99



See appendix table 6-12. *Science & Engineering Indicators – 2002*

Patents Granted to U.S. Inventors

During the mid-1980s, the share of U.S. patents awarded to U.S. inventors began to decline. Although some observers were concerned that this downward trend indicated a decline in U.S. competitiveness, patenting by U.S. inventors increased by the end of the decade, outpacing patenting by foreign inventors. This upward trend has continued throughout the 1990s, and in 1999, U.S. inventors were awarded nearly 84,000 new patents, an increase of about 4.5 percent over 1998. (See figure 6-22.)

Inventors who work for private companies or the Federal Government commonly assign ownership of their patents to their employers; self-employed inventors typically retain ownership of their patents. Therefore, examining patent data by owner's sector of employment can provide a good indication of the sector in which the inventive work was done. In 1999, corporations owned 80 percent of granted patents.[24] See sidebar, "Top Patenting Corporations." This percentage has gradually increased over the years.[25]

After business entities, individuals are the next largest group of U.S. patent owners. Before 1986, individuals owned, on average, 24 percent of all patents granted to U.S. inventors.[26] Their share has fluctuated downward since then, to a low of 19 percent in 1999. The Federal share of patents averaged 3.3 percent of the total during the period 1963–85, eventually falling to 1.1 percent in 1999, the lowest level ever.[27] U.S. Government-owned patents were encouraged by legislation enacted during the 1980s that called for U.S. agencies to establish new programs and increase incentives to their scientists, engineers, and technicians for the transfer of technology developed in the course of government research.[28]

[24]About 2.2 percent of patents granted to U.S. inventors in 1999 were owned by U.S. universities and colleges. PTO counts these as being owned by corporations. For further discussion of academic patenting, see the chapter 5 section, "Patents Awarded to U.S. Universities."

[25]From 1987 to 1997, corporate-owned patents accounted for between 77 and 79 percent of total U.S.-owned patents. Since 1997, corporations have increased their share each year and, by 1999, represented 82 percent of total U.S.-owned patents.

[26]Before 1986, data are provided as a total for the period 1963–85.

[27]Federal inventors frequently obtain a statutory invention registration (SIR) rather than a patent. The SIR is not ordinarily subject to examination and is less costly to obtain than a patent. Also, the SIR gives the holder the right to use the invention but does not prevent others from selling or using it as well.

[28]The Bayh-Dole University and Small Business Patent Act of 1980 permitted government grantees and contractors to retain title to inventions resulting from federally supported R&D and encouraged the licensing of such inventions to industry. The Stevenson-Wydler Technology Innovation Act of 1980 made the transfer of federally owned or originated technology to state and local governments and to the private sector a national policy and the duty of government laboratories. The act was amended by the Federal Technology Transfer Act of 1986 to provide additional incentives for the transfer and commercialization of federally developed technologies. In April 1987, Executive Order 12591 ordered executive departments and agencies to encourage and facilitate collaborations among Federal laboratories, state and local governments, universities, and the private sector—particularly small business—to aid technology transfer to the marketplace. In 1996, Congress strengthened private-sector rights to intellectual property resulting from these partnerships.

Patents Granted to Foreign Inventors

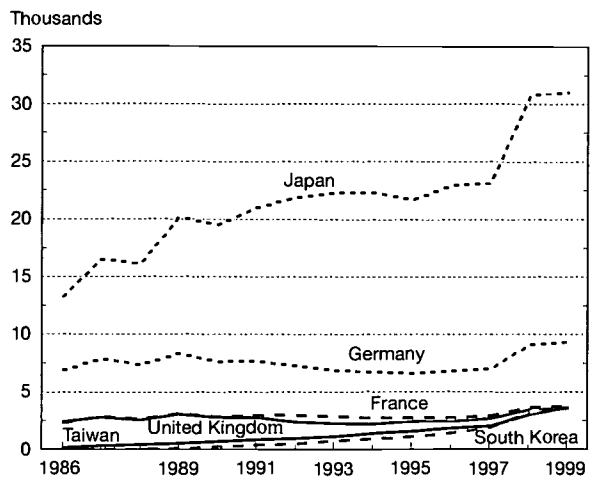
Foreign-origin patents represented 45 percent of all patents granted in the United States in 1999, a share maintained since 1997.[29] During much of the 1980s, foreign-origin patents increased at a faster rate than U.S.-origin patents, reaching a peak of 48 percent of all U.S. patents in 1989. From the following year until 1996, U.S. inventor patenting increased at a faster pace than that of foreign inventors, dropping the foreign share to 44 percent. In 1999, two countries (Japan and Germany) accounted for just more than 58 percent of U.S. patents granted to foreign inventors. The top four countries (Japan, Germany, France, and the United Kingdom) accounted for about 70 percent. (See figure 6-23 and appendix table 6-12.)

Although patenting by inventors from the leading industrialized countries has leveled off or even declined, some Asian economies, particularly Taiwan and South Korea, have stepped up their patenting activity in the United States and are proving to be strong inventors of new technologies.[30] Between 1963 (the year data first became available) and 1985, Taiwan was awarded just 742 U.S. patents. During the 14-year period since then, Taiwan was awarded more than 19,000 U.S. patents. U.S. patenting activity by inventors from South Korea shows a similar growth pattern. Before 1986, South Korea was awarded just 213 U.S. patents; since then, it has been awarded more than 14,000 new patents. In 1998, Taiwan and South Korea surpassed Canada to become the fifth and sixth most active foreigner inventors in the United States. Sweden and the Netherlands also had large increases in U.S. patenting in 1998.

[29]Corporations account for about 80 percent of all foreign-owned U.S. patents.

[30]Some of the decline in U.S. patenting by inventors from the leading industrialized nations may be attributed to the move toward European unification, which has encouraged wider patenting within Europe.

Figure 6-23.
U.S. patents granted to foreign inventors, by residence of inventor: 1986–99



NOTE: Selected economies are the top six recipients of U.S. patents during 1999.

See appendix table 6-12. *Science & Engineering Indicators – 2002*

Top Patenting Corporations

A review of the top patenting corporations in the United States during the past 25 years illustrates the technological transformation achieved by Japan over a relatively short period. In 1973, no Japanese companies ranked among the top 10 patenting corporations in the United States. In 1983, however, 3 of the top 10 were Japanese companies. By 1993, Japanese companies outnumbered U.S. companies, and in 1996, 7 of the top 10 were Japanese companies. The most recent data (1999) show a South Korean company (Samsung Electronics Company), 3 U.S. companies, and 6 Japanese companies among the top 10. (See text table 6-2.) Samsung ranked 4th among patenting corporations in the United States in 1999 after ranking 17th just two years earlier. South Korea's U.S. patenting now emphasizes computer, television and communications, and power generation technologies. Despite their economic problems, South Korea and Japan have achieved continued success in patenting inventions in the United States, illustrating their growing ability to innovate in important technologies.

IBM was awarded more patents than any other U.S. organization in 1999, the seventh consecutive year that the company has earned this distinction. Lucent Technologies joined the top 10 for the first time with 1,153 patents, nearly a quarter more than it received just a year earlier. The only other U.S. company making the top 10, Motorola, dropped from fourth to eighth place with 1,192 patents in 1999, more than 200 fewer than it received in 1998.

Text table 6-2.
Top patenting corporations

Company	Patents
1999	
International Business Machines Corp.	2,756
NEC Corporation	1,842
Canon Kabushiki Kaisha	1,795
Samsung Electronics Co., Ltd.	1,545
Sony Corporation	1,409
Toshiba Corporation	1,200
Fujitsu Limited	1,193
Motorola, Inc.	1,192
Lucent Technologies	1,153
Mitsubishi Denki Kabushiki Kaisha	1,054
1977–96	
General Electric Corp.	16,206
International Business Machines Corp.	15,205
Hitachi Ltd.	14,500
Canon Kabushiki Kaisha	13,797
Toshiba Corporation	13,413
Mitsubishi Denki Kabushiki Kaisha	10,192
U.S. Philips Corporation	9,943
Eastman Kodak Company	9,729
AT&T Corporation	9,380
Motorola, Inc.	9,143

SOURCE: U.S. Patent and Trademark Office, Information Products Division, Technology, Assessment, and Forecast Branch, special tabulations (November 2000).

Science & Engineering Indicators – 2002

Trends in Applications for U.S. Patents

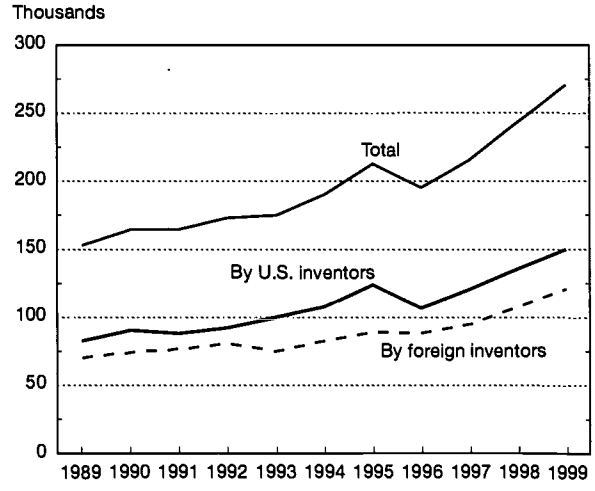
The review process leading up to the official grant of a new patent may take as long as 2 years. Consequently, the examination of year-to-year trends in patents granted will not always reveal the most recent changes in patenting activity. The number of patent applications filed with the PTO provides an earlier, albeit less certain, indication of changes to patterns of inventiveness. Yet, current trends in new patent applications help to revise observations made from the more informative data, presented earlier, on trends in U.S. patents granted.

Patent Applications From U.S. and Foreign Inventors

Applications for U.S. patents reached 270,000 in 1999, an increase of about 11 percent over 1998. These latest data extend what has been nearly a decade of annual increases. During the past 11 years, the only significant decline in patent applications occurred in 1996. (See figure 6-24 and appendix table 6-13.)

U.S. resident patents represented 56 percent of all patents applied for in the United States in 1999, a share maintained since

Figure 6-24.
U.S. patent applications: 1989–99



See appendix table 6-13. *Science & Engineering Indicators – 2002*

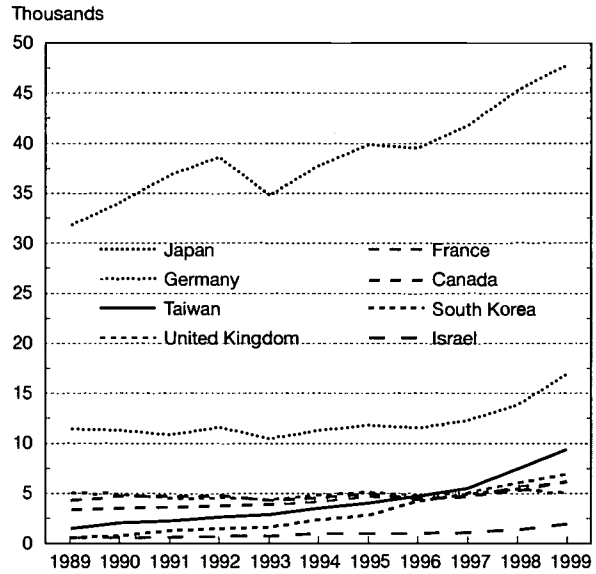
1997. Because patents granted to foreign inventors have generally accounted for about 45–47 percent of total U.S. patents granted, it appears that the success rate for foreign-origin patents is lower than that for those applied for by U.S. inventors.

In 1999, two countries, Japan and Germany, accounted for nearly 44 percent of U.S. patent applications made by foreign inventors. Although patent filings by inventors from the leading industrialized countries have leveled off and have even begun to decline, other countries, particularly Asian countries with the exception of Japan, have stepped up their patenting activity in the United States. This is especially true for Taiwan and South Korea, and the data on recent patent applications indicate that this trend continues.

Since 1997, residents of Taiwan and South Korea have distinguished themselves in the number of applications for U.S. patents. In 1997, the number of patents applied for by residents of Taiwan and South Korea ranked them among the top five for the first time, replacing residents from France and Canada. Residents of Taiwan had moved up further in 1998 to become the third leading source for new U.S. patent applications. In 1999, residents of Taiwan applied for more than 9,000 new patents, an increase of 27 percent from a year earlier and more than 2,400 than that made by residents of the United Kingdom, ranked fourth. If recent patents granted to residents of Taiwan are indicative of the technologies awaiting review, then many of these applications will be for new computer and electronic inventions. Compared with the rising trend in Taiwan's U.S. patent applications, recent filings by inventors from South Korea have not continued at the same pace.

Although less dramatic than that demonstrated by inventors from Taiwan and South Korea, patent applications by inventors from Germany, France, and Israel also increased in 1999. Inventors residing in Israel were particularly active, increasing their applications for U.S. patents by about 39 percent from a year earlier. (See figure 6-25.)

Figure 6-25.
U.S. patent applications filed by selected foreign inventors, by residence of inventor: 1989–99



See appendix table 6-13. *Science & Engineering Indicators – 2002*

Technical Fields Favored by U.S. and Foreign Inventors

A country's distribution of patents by technical area is a reliable indicator of both its technological strengths and its focus on product development. This section compares and discusses the various key technical fields favored by U.S. inventors and the top five foreign inventors patenting in the United States.[31] Patent activity in the United States by inventors from foreign countries can be used to identify a country's technological strengths as well as U.S. product markets likely to see increased competition.

Fields Favored by U.S. and Leading Foreign Inventors

Although U.S. patent activity encompasses a wide spectrum of technology and new product areas, U.S. corporations' patenting emphasizes several technology areas expected to play an important role in the nation's future economic growth (U.S. Office of Science and Technology Policy 1997). In 1999, corporate patent activity reflected U.S. technological strengths in medical and surgical devices, electronics, telecommunications, advanced materials, and biotechnology. (See text table 6-3.)

The 1999 patent data show not only Japan's continued emphasis on photocopying, photography, and consumer electronics technology but also its broader range of U.S. patents in information technology. From improved information storage technology for computers to visual display systems, Japanese inventions are earning U.S. patents in areas that aid in the processing, storage, and transmission of information.

German inventors continue to develop new products and processes in technology areas associated with heavy manufacturing, a field in which it has traditionally maintained a strong presence. The 1999 U.S. patent activity index shows that Germany emphasizes inventions for motor vehicles, printing, new chemistry and advanced materials, and material-handling equipment.

In addition to inventions for traditional manufacturing applications, British patent activity is also high in biotechnology and chemistry. Like the British, the French are quite active in patent classes associated with manufacturing applications and biotechnology. They share the emphasis of U.S. inventors in aeronautics and communications technologies.

[31] Information in this section is based on PTO's classification system, which divides patents into approximately 370 active classes. With this system, patent activity for U.S. and foreign inventors in recent years can be compared by using an activity index. For any year, the activity index is the proportion of patents in a particular class granted to inventors in a specific country divided by the proportion of all patents granted to inventors in that country. Because U.S. patenting data reflect a much larger share of patenting by individuals without corporate or government affiliation than do data on foreign patenting, only patents granted to corporations are used to construct the U.S. patenting activity indices.

Text table 6-3.
Top 15 most emphasized U.S. patent classes for corporations from United States, Japan, and Germany: 1999

United States	Japan	Germany
1. Surgical instruments	Information storage and retrieval	Plant protecting and regulating compositions
2. Biology of multicellular organisms	Television signal processing	Clutches and power-stop control
3. Surgery: light, thermal, and electrical applications	Photocopying	Printing
4. Wells	Electrophotography	Brake systems
5. Data processing	Photography	Metal deforming
6. Digital processing systems	Liquid crystal cells	Bodies and tops for land vehicles
7. Information processing system organization	Crystal growth processes	Winding, tensioning, or guiding devices
8. I/O digital processing systems	Interrelated power delivery controls	Internal combustion engines
9. Surgery (medicators and receptors)	Facsimile	Bleaching and dyeing of textiles
10. Business practice, dataprocessing	Incremental printing of symbolic information	X-ray or gamma-ray systems
11. Computer memory	Music	Machine element or mechanism
12. Computer processing architectures	Brake systems	Electrical transmission systems
13. Aeronautics	Typewriting machines	Land vehicles
14. Electronic digital logic circuitry	Radiation imagery chemistry	Power plants
15. Surgery	Internal combusion engines	Organic compounds

I/O = Input/output

NOTES: Ranking is based on patenting activity of nongovernment U.S. or foreign organizations, which are predominately corporations. Patenting by individuals and governments is excluded.

SOURCE: U.S. Patent and Trademark Office, Office of Information Services, TAF Program, 2001.

Science & Engineering Indicators – 2002

As recently as 1980, Taiwan's U.S. patent activity was concentrated in the area of toys and other amusement devices. By the 1990s, Taiwan was active in communications technology, semiconductor manufacturing processes, and internal combustion engines. The data from 1999 show that Taiwan's inventors have continued to broaden their technology portfolio, emphasizing testing and measuring devices, audio systems, advanced materials, optics, and aeronautics.

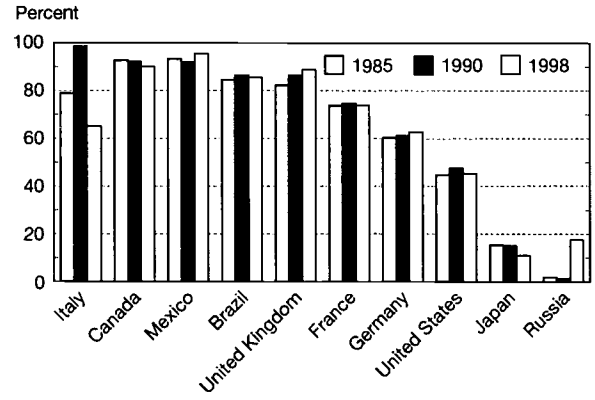
U.S. patenting by South Korean inventors has also reflected that country's rapid technological development. The 1999 data show that South Korean inventors are patenting heavily in television technologies and a broad array of computer technologies that include devices for dynamic and static information storage, data generation and conversion, error detection, and display systems. (See text table 6-4.)

Both South Korea and Taiwan are major suppliers of computers and peripherals to the United States, and recent patenting data show that their scientists and engineers are developing these new technologies and improving existing ones. These new inventions are likely to enhance their competitiveness in the United States and in the global market.

Patenting Outside the United States

In most countries, foreign inventors account for a much larger share of total patent activity than in the United States. When foreign patent activity in the United States is compared with that in 11 other countries in 1985, 1990, and 1998, only Russia and Japan consistently had smaller shares of foreign patent activity. (See figure 6-26.)

Figure 6-26.
Share of total patents awarded to nonresident inventors in selected countries



See appendix tables 6-12 and 6-14.

Science & Engineering Indicators – 2002

Although much attention is given to the level of foreign patenting in the United States, this tends to overshadow the success of U.S. inventors in patenting their inventions around the world. In 1998, U.S. inventors led all other foreign inventors not only in countries neighboring the United States but also in markets such as Germany, Japan, France, Italy, Brazil, Russia, Malaysia, and Thailand. (See figure 6-27 and appendix table 6-14.) Japanese inventors edge out Americans in China and dominate foreign patenting in South Korea. German inventors are also quite active in many of the other countries examined.

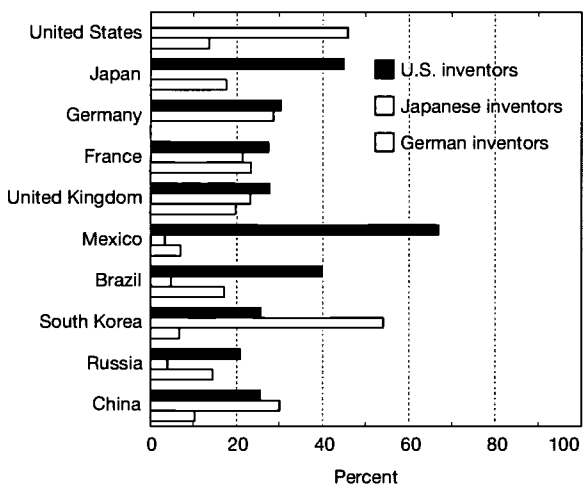
Text table 6-4.
Top 15 most emphasized U.S. patent classes for corporations from South Korea and Taiwan: 1999

South Korea	Taiwan
1. Transmission systems	Semiconductor device manufacturing process
2. Liquid crystal cells, elements and systems	Electrical connectors
3. Refrigeration	Solid state devices
4. Static information storage and retrieval	Music
5. Power delivery controls	Circuit makers and breakers
6. Television signal processing for recording	Substrate etching processes
7. Television	Receptacles
8. Semiconductor device manufacturing process	Electrical systems and devices
9. Dynamic magnetic information storage or retrieval	Chairs and seats
10. Electric heating	Computers
11. Miscellaneous active electrical nonlinear devices	Illumination
12. Electric lamp and discharge devices	Electrical power conversion systems
13. Electric lamp and discharge systems	Static information storage and retrieval
14. Active solid-state devices	Supports
15. Electric power conversion systems	Coded data generation

NOTE: Ranking is based on patenting activity of nongovernmental organizations, which are primarily corporations. Patenting by individuals and governments is excluded.

SOURCE: U.S. Patent and Trademark Office, Office of Information Services, TAF Program, 2001. *Science & Engineering Indicators – 2002*

Figure 6-27.
Patents granted to nonresident inventors in selected countries: 1998



See appendix table 6-14. *Science & Engineering Indicators – 2002*

International Patenting Trends in Two New Technology Areas[32]

This section explores the relative strength of America's inventiveness by examining international patenting patterns in two new technology areas: human DNA sequences and business methods. The analysis is built around the concept of a "patent family," i.e., all the patent documents published in a country associated with a single invention. See sidebar, "International Patent Families As a Basis for Comparison."

Three indicators are used here to compare national positions in each technology area:

- **Trends in international inventive activity.** This indicator is a preliminary measure of the extent and growth of inventive activity considered important enough to be patented outside the country of origin. These data are tabulated by priority year.
- **Number of organizations assigned patents.** The number of organizations in a country that are active in a technology may indicate a country's ability to innovate and its potential for innovative activity. Research by Michael Porter (1990) suggests that the growth of clusters of innovative organizations is associated with national competitiveness. The Council on Competitiveness (2001) also associates clusters of innovation with higher rates of innovation, productivity growth, and new business formation.
- **Highly cited inventions.** Interpatent citations are an accepted method of gauging the technological value or significance of different patents. These citations, provided by the patent examiner, indicate the "prior art" (the technology in related fields of invention) that is taken into account in judging the novelty of the present invention.[33] The number of citations a patent receives from later patents can serve as an indicator of its technical importance or value.

[32]Information presented in this section was developed by Mogee Research & Analysis Associates under contract to the National Science Foundation. (See Mogee April 2001 and Mogee June 2001).

[33]The citations counted are those placed on European Patent Office (EPO) patents by EPO examiners. EPO citations are believed to be a less biased and broader source of citations than those of PTO. See Claus and Higham (1982).

International Patent Families As a Basis for Comparison

A *patent family* consists of all the patent documents associated with a single invention that are published in one country. Although counting patent families gives a rough estimate of a nation's technological activity, international comparisons based solely on numbers of patent families can be misleading because differing national patent laws and customs can result in higher levels of patenting in some countries than in others. In addition, a patent generally offers protection only in the country in which it is issued; to protect an invention in multiple countries, multiple patent applications must be filed. Because it is extremely costly to pursue patent protection in multiple countries, organizations are assumed to seek patent protection abroad only for those inventions they believe will have significant commercial value. Patent families for which protection has been sought in more than one country are counted separately here and called *international patent families*. Counting international patent families makes international comparisons more accurate and theoretically provides a more precise measure of technological activity intended for international use.

Patents in a family are linked together through *priority* details. Priority is established by the application date assigned in the first country in which the invention was filed for protection. Under the Paris Convention, if the invention is filed in another convention country within one year of the original filing, the patent in the second country can claim the original priority. The country in which the priority application was filed is assumed to be the country in which the invention was developed. Similarly, the priority year is the year the priority application was filed.

This study was undertaken to provide data on the growth of patenting in these two technology areas, identify which groups are doing the patenting, and compare the position of the United States with that of other nations. The study examined patenting in more than 40 countries, including the United States, Japan, European countries, and other major industrialized and industrializing countries.

International Patenting of Human DNA Sequences

Whether human DNA sequences should be patentable has been strongly debated for many years.[34] Some have argued that patents on human DNA sequences are necessary to make diagnostic and therapeutic products commercially available. Others argue that giving companies monopoly rights over specific DNA sequences will hinder scientific progress.

Despite the ongoing controversies, patent offices worldwide have issued thousands of patents on human DNA sequences. As researchers move from mapping sequences to decoding their functions and manipulating them for diagnostic and therapeutic purposes, their work will transform the way many diseases are treated. The companies and countries that own key patents will benefit most from these developments. See sidebar, "Patenting of Human DNA Sequences: A Recent Invention."

Number of International Patent Families. Strong, steady growth in the number of international patent families in human DNA sequencing mirrors the growth in total patent families.[35] (See figure 6-28 and appendix table 6-15.) The United States accounts for a slightly higher share of international patent families (72 percent) than total families (69 percent). Overall, 75 percent of all U.S. patent families in this technology are international patent families. In contrast to the United States, only about 51 percent of Japan's total patent families are international patent families. As with total families, Great Britain ranks third in international patent families. China, which has 145 total patent families in this technology, has only 17 international patent families, possibly indicating that their patents are of lesser commercial value.

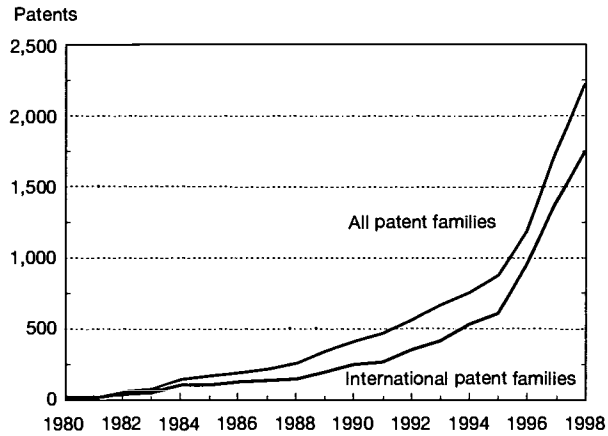
The United States appears to be the market of greatest interest to organizations patenting human DNA sequences, with protection being sought for more than 73 percent of all patented inventions in this field. (See text table 6-5.) Although most countries automatically publish patent applications 18 months after the priority application is filed, during the time period covered by this study, PTO published only granted patents, not applications. For this reason, there are probably additional patent families in this study for which protection

[34]Data on patents covering human DNA sequences were drawn from GENESEQ and the Derwent World Patents Index (DWPI), two on-line databases published by Derwent Publications. GENESEQ is the world's most comprehensive database devoted exclusively to patented sequence information, and each patent record in GENESEQ is reviewed and coded by molecular biologists at Derwent. Patents are included that claim DNA sequences or that refer to DNA sequences in their claims. A search was conducted in GENESEQ for all gene sequence patents that had been coded by the experts as relating to humans. GENESEQ records go back to 1981.

Each GENESEQ record corresponds to a patented sequence, rather than a patent, and gives only the basic patent number covering each sequence. Therefore, the basic patent numbers were mapped from the GENESEQ search into the DWPI, which covers patenting from more than 40 different countries and patent-granting authorities, to retrieve more complete patent family information. Each DWPI record constitutes a patent family, which avoids the problem of double counting inventions patented in more than one country. Using this procedure, 10,759 Derwent records were obtained, with 1980 as the earliest priority year.

[35]Because of the time lag between patent application and publication, data for 1999 should be considered incomplete.

Figure 6-28.
Human DNA sequence patent families worldwide: 1980–98



See appendix table 6-15. *Science & Engineering Indicators – 2002*

has been sought in the United States but for which no patent has yet been granted. Therefore, it is likely that the United States is undercounted in this table.

Europe and Japan also appear to be significant markets for organizations patenting human DNA sequences. Approximately half the patent families in this technology have protection in Europe, and protection has been sought in Japan for about 36 percent. Australia ranks fourth, with nearly 11 percent having sought protection in that country.[36]

Number of Organizations Assigned Patents. The number of technologically active organizations in a country may indicate that nation's current and potential level of innovation.

[36]If a Patent Cooperation Treaty (PCT) application lists Australia as a "designated state," Australia automatically publishes an Australian document, which the PCT applicant may not complete. To avoid spurious counts for protection in Australia, Australia was counted as a patent country only if the patent publication was a "B" (i.e., second stage) document or if no PCT application was on the record.

Text table 6-5.
Total number of patent families seeking patent protection in each country or region during 1980-99: Human DNA Sequences

Country/region	Patent families
Total families	10,759
United States	7,906
Europe	5,393
Japan	3,926
Australia	1,142
Canada	817
South Africa	637
Latin America	578
China	479
South Korea	460

SOURCE: "International Analysis of Human DNA Sequence Patenting," submitted to the National Science Foundation by Mogee Research and Analysis Associates (Reston, VA, April 10, 2001).

Science & Engineering Indicators – 2002

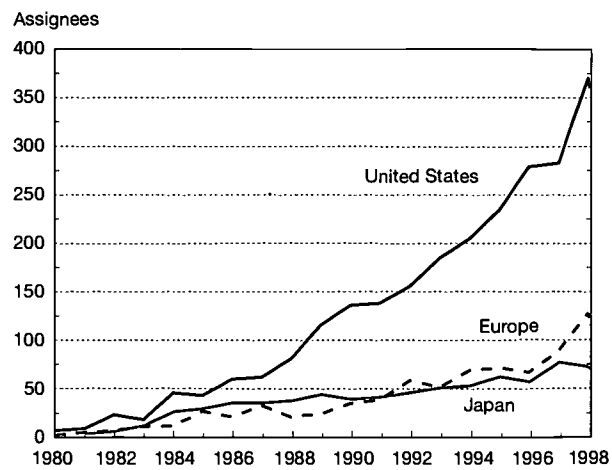
The United States has had the most organizations actively filing patent applications for human DNA sequences every year since 1980. (See figure 6-29 and appendix table 6-16.) Since 1995, the United States has consistently had 3 to 7 times the number of patenting organizations as Japan, which has ranked second every year since 1983. Great Britain has ranked third every year during that time period, except 1988. Although still quite low, patenting organizations in several countries, including Australia, China, Israel, Sweden, and South Korea, have increased significantly in number during the past few years.

Although corporations dominate human DNA patenting overall, the types of organizations actively patenting human DNA sequences vary among priority countries.[37] (See text table 6-6.) The majority of patenting organizations in Germany, France, Israel, and Japan are corporations; few universities, nonprofit organizations, or government agencies file priority applications in these countries. The United States and Great Britain have the largest number of universities seeking patents for human DNA sequences, although far more corporations than universities are active in these countries. Unlike the other major patenting countries, Australia, Canada, and China tend to have as many or more universities than corporations seeking patents for human DNA sequences.

Highly Cited Patents. The size of a country's share of the top-cited patent families is attributable partly to the technological significance of its patents and partly to the total number of patents it has. A country's share of the most highly cited patent families can be expressed as a ratio of its representation among highly cited patent families to its representation among

[37]As in appendix table 6-16, text table 6-6 shows the number of unique organizations filing patent applications, not the number of applications they have filed. In this table, individuals are included if no other type of organization was assigned the patent. If a company was assigned a patent and it was coassigned to the individual, the individual was assumed to be an employee of the company. If two organizations, such as a company and a university, were coassigned a patent, both were counted.

Figure 6-29.
Active assignees for DNA patents, United States, Japan, and Europe: 1980–98



See appendix table 6-16. *Science & Engineering Indicators – 2002*

Patenting of Human DNA Sequences: A Recent Invention

The patenting of genes and gene sequences has a relatively short history. The surge in patenting since 1990 has been fueled by the Human Genome Project, which has generated huge amounts of information on genes and gene fragments. In 2000, the Patent and Trademark Office (PTO) issued about 2,000 patents on full-length genes for all species. Reportedly, more than 3 million expressed sequence tabs (ESTs) and thousands of other partial and whole genes are included in pending patent applications in the United States. Some observers are concerned that patents on gene fragments, such as ESTs and single-nucleotide polymorphisms, might make the fragments unavailable to researchers or force researchers to negotiate a formidable web of licenses to work with the fragments. Such obstacles may hamper not only basic research but also research into cures for diseases.

The patentability of genes and gene sequences in the United States is based on the 1980 Supreme Court decision *Diamond* v. *Chakrabarty*, which ruled that genetically engineered living organisms could be patented. This decision was followed by internal actions by PTO in the mid-1980s that extended patentability to plants and nonhuman animals. In 1995, the U.S. Court of Appeals for the Federal Circuit affirmed that partially published sequences were patentable in a case *(In re Deuel)* used by PTO to support its policy of awarding patents for genes and gene sequences. PTO issued the first patent for an EST in October 1998 to InCyte Pharmaceuticals Inc.

Much of the research community was critical of patenting gene segments, especially when specific functions and applications were not known. Important research groups, such as the Human Genome Organization and the National Institutes of Health, argued that DNA patents should be granted only when specific applications are described or detailed information about the gene is supplied. In response to this criticism, PTO revised its examination guidelines on January 5, 2001. Under the new guidelines, an invention must be supported by "at least one specific, substantial, and credible or a well-established utility." This requirement may reduce the number of patent applications for genes or gene sequences.

In Europe, the European Union Council approved a directive on the legal protection of biotechnological invention in 1998 to harmonize and clarify the laws of the European nations and the European Patent Office. The directive states that a DNA sequence alone, without an indication of its function, is not patentable; the gene sequence must have an industrial application that is disclosed in the patent specification. If a gene sequence is used to produce a protein, the applicant must specify both the protein produced and the protein's function.

Until 1979, the Japanese Patent Office (JPO) took the position that microorganisms were not patentable because there were no industrial applications for them. In 1979, JPO reversed its position and issued a set of Working Standards on microorganisms. According to the Working Standards, DNA molecules were patentable, but patents were granted only to applicants who finished decoding procedures and could describe the DNA functions. In 1999, JPO announced that it would allow patents on DNA fragments if those fragments were shown to be effective for specific purposes, such as diagnosing or curing certain diseases.

Thus, three major patent offices have arrived at a consensus substantially in accord with that of the research community: that DNA fragments for which only sequence or alignment have been identified are not patentable. A DNA fragment is patentable only if it has a specific, useful application and if it meets the additional criteria that all patents must meet; that is, novelty, nonobviousness, and enablement.

the total families in a particular technology. (See text table 6-7.) A value of 1.0 indicates that a country's share of the highly cited families is identical to its share of total families; a value greater than 1.0 in the ratio column indicates that a country is overrepresented, while a score of less than 1.0 indicates that a country's patent families are undercited.

Although during the past 20 years the United States has had the largest number of highly cited patents in this technology by far, its total number of highly cited patents has been about what would be expected based on its overall level of patenting. Japan has been somewhat underrepresented among the most highly cited patents in each of the four time periods. One possible explanation for this is that about half of Japan's patent families are protected only in Japan, and examiners at the European Patent Office (EPO) may be less likely to cite such patents. Great Britain was significantly overrepresented among the most highly cited patents in the 1985–89 time period, but during the last two time periods, Great Britain's share of the most highly cited patents has been about what would be expected based on its level of activity. Germany had about twice as many highly cited patents as would be expected in the 1985–89 and 1990–94 time periods but fewer than would be expected during the last time period. Because these citations come from EPO, one might expect that EPO patents would be overrepresented; however, this occurred in only the 1990–94 time period. EPO priority patents were

Text table 6-6.
Active assignees, by priority country and period: Human DNA Sequences patents

Priority country	1980–84	1985–89	1990–94	1995–99
Australia				
Corporations	1	5	4	16
Universities	3	4	6	16
Not for profits	0	2	2	6
Government agencies	0	0	1	3
Individuals	0	0	0	1
Canada				
Corporations	1	3	2	8
Universities	1	2	4	13
Not for profits	0	0	0	0
Government agencies	0	0	1	0
Individuals	0	0	3	7
China				
Corporations	0	0	1	4
Universities	0	0	0	6
Not for profits	0	0	0	2
Government agencies	0	0	0	5
Individuals	0	0	0	5
Germany				
Corporations	4	9	14	33
Universities	0	0	3	9
Not for profits	0	0	4	8
Government agencies	0	0	1	5
Individuals	0	0	3	38
European Patent Office				
Corporations	1	12	12	40
Universities	1	2	1	16
Not for profits	1	1	2	11
Government agencies	0	1	3	3
Individuals	0	3	3	9
France				
Corporations	1	6	16	20
Universities	0	3	2	3
Not for profits	0	2	3	7
Government agencies	0	3	4	5
Individuals	0	0	10	0
Great Britain				
Corporations	10	29	45	63
Universities	2	0	18	27
Not for profits	3	1	7	9
Government agencies	0	1	8	4
Individuals	0	1	2	4
Israel				
Corporations	1	2	5	12
Universities	0	0	1	2
Not for profits	0	1	0	0
Government agencies	1	0	0	1
Individuals	0	0	0	0
Japan				
Corporations	27	65	93	117
Universities	3	6	2	0
Not for profits	2	4	6	7
Government agencies	1	5	6	9
Individuals	1	11	19	15
United States				
Corporations	52	116	241	412
Universities	13	53	108	163
Not for profits	7	23	48	59
Government agencies	1	7	13	20
Individuals	4	16	31	82

NOTE: Priority country is established by the location of the original patent application.

SOURCE: "International Analysis of Human DNA Sequence Patenting," submitted to the National Science Foundation by Mogee Research and Analysis Associates (Reston, VA, April 10, 2001).

Science & Engineering Indicators – 2002

Text table 6-7.
Priority countries ranked by share of top-cited patents: Human DNA Sequences

Priority country	Share of top cited (percent)	Share of total families (percent)	Ratio top cited to total families
	1980–84		
United States	80.0	56.8	1.4
Great Britain	10.0	10.1	1.0
Japan	10.0	23.6	0.4
	1985–89		
United States	62.3	61.6	1.0
Japan	16.4	23.2	0.7
Great Britain	8.2	4.8	1.7
Germany	3.3	1.8	1.8
Denmark	2.5	0.9	2.8
France	2.5	2.1	1.2
European Patent Office	1.6	2.1	0.8
Israel	1.6	0.8	2.0
Netherlands	0.8	0.5	1.6
Sweden	0.8	0.3	2.7
	1990–94		
United States	69.8	71.9	1.0
Japan	10.8	14.1	0.8
Great Britain	4.7	4.2	1.1
Germany	4.3	2.2	2.0
European Patent Office	2.6	1.4	1.9
France	2.6	1.9	1.4
Australia	1.3	0.7	1.9
Denmark	1.3	0.7	1.9
Israel	1.3	2.0	0.7
Canada	0.9	2.6	0.3
Italy	0.4	1.0	0.4
	1995–99		
United States	76.8	70.3	1.1
Japan	9.8	11.0	0.9
Great Britain	4.8	5.0	1.0
European Patent Office	2.7	2.8	1.0
Germany	2.1	3.2	0.7
Australia	1.8	1.2	1.5
France	1.2	1.3	0.9
Canada	0.3	0.8	0.4
Denmark	0.3	0.3	1.0
Israel	0.3	0.4	0.8

NOTE: Priority country is established by the location of the original patent application.

SOURCE: "International Analysis of Human DNA Sequence Patenting," submitted to the National Science Foundation by Mogee Research and Analysis Associates (Reston, VA, April 10, 2001).

Science & Engineering Indicators – 2002

underrepresented among the most highly cited in the 1985–89 time period and are about what would be expected in the 1995–99 time period. Care should be taken not to read too much into the ratios for countries with low levels of activity because one or two highly cited patents from these countries may make them appear to be overrepresented among the highly cited families.

International Patenting of Internet-Related Business Methods

During the 1990s, the Internet spurred the development of new methods to conduct business, and growing numbers of companies sought patent protection for these new business models.[38] The patenting of Internet business methods has been nearly as controversial as the patenting of human DNA sequences. See sidebar, "Patenting of Internet Business Methods in the United States, Japan, and Europe."

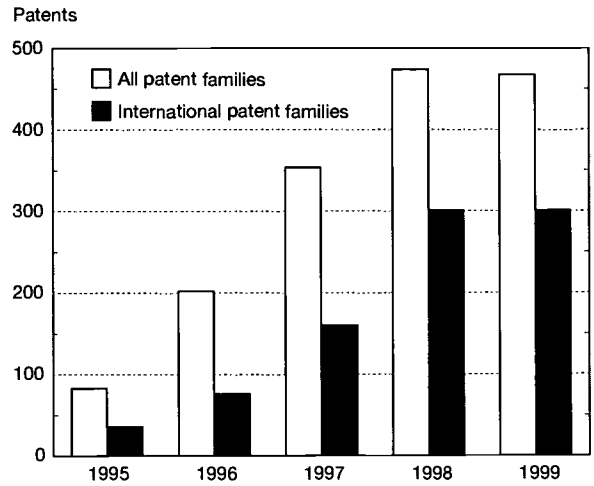
This section examines the growth of patenting of Internet business methods, which nations are doing the patenting, and the position of the United States in global patenting. The data include recent patenting trends in more than 40 countries, although the section focuses primarily on the major actors in this field, the United States, Japan, and Europe.

Number of International Patent Families. Strong, steady growth in the number of international patent families in this technology mirrors the growth in total patent families.[39] (See figure 6-30 and appendix table 6-17.) The United States accounts for a significantly higher share of international patent families (72 percent) than total families (50 percent). Overall, 78 percent of all U.S. patent families in this technology are international patent families. Japan ranks second in international families (7 percent). However, in contrast with the United States, only about 15 percent of all Japanese patent families are international patent families. Great Britain ranks third in international patent families (3.5 percent), followed by Germany (2.2 percent).

The United States appears to be the market of greatest interest to organizations patenting Internet business methods, which sought protection there for more than 52 percent of all patented inventions in this field.[40] (See text table 6-8.) Although most countries automatically publish patent applications 18 months after the priority application is filed, during the time period covered by this study, PTO published only granted patents, not applications; therefore, the United States is probably underrepresented in text table 6-8.

Japan and Europe also appear to be markets of significant interest to organizations patenting Internet business methods. One-third of the patent families in this technology have protection in Japan, and protection has been sought in Europe for fewer than one-third. Canada ranks fourth; only about 6 percent of patent families have protection in that country.

Figure 6-30.
Internet-related business method patent families worldwide



See appendix table 6-17. *Science & Engineering Indicators – 2002*

Text table 6-8.
Total number of patent families seeking patent protection in each country or region during 1980-99: Internet-related business methods

Country/Region	Patent families
United States	847
Japan	530
Europe	505
Canada	90
China	68
South Korea	67
Australia	61
Latin America	49
Taiwan	21
South Africa	15
Israel	14
New Zealand	6
Other	24

SOURCE: "International Analysis of Internet-Related Business Methods Patenting," submitted to National Science Foundation by Mogee Research and Analysis Associates (Reston, VA, June 7, 2001).

Science & Engineering Indicators – 2002

[38]Data for this section were drawn from DWPI, which covers patenting from more than 40 different countries and patent-granting authorities. Each DWPI record constitutes a patent family, thus avoiding the problem of double counting inventions that are patented in more than one country.

DWPI began comprehensive coverage of Japanese patenting in this technology area in 1996. Therefore, the search was limited to records with an earliest priority year of 1995. (Most priority applications filed in 1995 would not be published, and hence appear in the database, until 1996 or later. Priority applications filed before 1995 could be published before 1996 and consequently miss some Japanese patents.)

The set of Internet-related business method patent families was formed from the intersection of the set of business method patents with the set of Internet patents. Only the records with priority years from 1995 through the present were selected for this analysis.

[39]Because of the time lag between patent application and publication, data for 1999 and 2000 should be regarded as incomplete.

[40]Any family with either an EPO patent or a patent in any European country was counted as having protection in Europe. Only the top countries and regions (those where protection has been sought for more than five total patent families) are presented in text table 6-8. "Latin America" refers to patents filed in Mexico, Brazil, or Argentina.

Patenting of Internet Business Methods in the United States, Japan, and Europe

Patent applications worldwide for methods of conducting business on the Internet grew rapidly in the late 1990s. Because business methods and algorithms were not considered patentable in the United States, Europe, or Japan, these applications quickly became controversial.

In the United States, business methods were excluded from patentability based on a series of court decisions beginning in the early 20th century. The Court of Appeals of the Federal Circuit struck down these exclusions in *State Street Bank & Trust Co. v. Signature Financial Group, Inc.* (1998) and *AT&T Corp.* v. *Excel Communications* (1999). As a result of these two cases, software or software-enabled inventions are considered patentable if they can be shown to have a practical application. According to some observers, these decisions left open the possibility that "pure" business methods (i.e., those without hard technology, such as computers), are patentable.

The ensuing surge in patent applications for business methods led to high-profile patent litigation cases and fueled a debate over whether business methods should be patentable at all, and, if so, whether business methods that are merely computerized versions of known business techniques or do not involve hard technology should be patentable. Behind these questions lurked the perennial disagreement over whether patents in general, and these patents in particular, help or hurt innovation.

A related issue was whether patents for business methods being granted by the Patent and Trademark Office (PTO) met the general criteria of novelty, utility, and nonobviousness. Critics accused PTO of granting patents for business methods that were obvious or overly broad. PTO responded by hiring examiners with expertise in business practices, improving search methods and resources, and expanding quality review sampling.

Congress contributed to the debate by including provisions in the 1999 American Inventors Protection Act to protect companies using business methods they did not believe were patentable that were later patented by another company. In 2000, the Business Method Patent Improvement Act (H.R. 5364) was introduced in the House of Representatives to make these patents more difficult to obtain and easier to challenge. The bill covers patents for both software- and nonsoftware-enabled business methods. The bill did not pass in 2000 but was reintroduced as H.R. 1333 in 2001.

The European Patent Office (EPO) as well as many European national patent offices formally exclude patents for software and business methods. Article 52(2) of the European Patent Convention expressly excludes software and business methods from the list of patentable inventions. This exclusion has had little practical effect on software inventions because a product or method that is of "technical character" may be patentable even if it involves software. Because determining "technical effect" is difficult, EPO has granted very few business method patents.

In late 2000, EPO changed its practice regarding business methods patents after a decision by the Board of Appeal. In a case involving IBM, the Board stated: "a computer program product is not excluded from patentability if, when run on a computer, it produces a 'technical effect' that goes beyond the normal physical interactions between program and computer." Despite the change in EPO practice, a November 2000 Diplomatic Conference to revise the European Patent Convention failed to delete the exclusion on software patenting, reflecting the disagreement remaining in Europe on this issue.

In December 2000, the Japanese Patent Office (JPO) published new policies and examination standards on patenting of algorithms and business methods that use algorithms. Previously, JPO excluded inventions classified as mathematical algorithms, natural laws, mathematical expressions of natural laws, or inventions that result in "mere processing of information by a computer" unless the application showed how the invention used the computer's resources in the processing. Current JPO policy considers most business methods inventions as forms of software inventions: "An invention, whether it is business-related or not, can be subject to a patent as a software-related invention if it meets certain requirements, such as involving information processing that uses computer hardware resources in order to solve a problem." Pure business methods per se, however, are not patentable: "The systematization of existing human transactions shall be deemed as not involving an inventive step and thus lack patentability, if it can be realized by routine application of usual system analysis and system design technologies, since it would be within the exercise of ordinary creative ability expected of a person skilled in the art to which the invention pertains."

In June 2000, the members of the Trilateral Patent Offices (PTO, EPO, and JPO) released a comparative examination of hypothetical computer-implemented business method patent claims. Despite the differences in their systems, the offices tended to make the same judgment on whether an application should be patented. The report concluded that a technical aspect is necessary for a computer-related business method to be eligible for patenting. EPO and JPO require that this technical aspect, typically a computer-related aspect, be expressed in the claim, whereas PTO allows it to be implicitly in the claim. The offices also confirmed that mere automation of a business process that had been known as a manual process, by way of using a well-known automation method, is not considered patentable. Thus, although the rules governing patenting of Internet business methods in the United States, Japan, and Europe are beginning to converge, important differences remain.

Number of Organizations Assigned Patents. The number of organizations in a country that are active in a technology may indicate that country's level of technological capability.[41]

Every year since 1995, the United States has had the most organizations actively filing patent applications for Internet business methods. (See figure 6-31 and appendix table 6-18.) During 1997–99, the United States averaged between 100 and 200 active assignees per year, two to four times the number of patenting organizations as Japan, which has ranked second in the number of active patenting organizations every year since 1995 and now has about 50 organizations per year filing priority applications in this technology. Trailing well behind are Germany, Great Britain, and Australia; these countries have between 3 and 10 organizations filing priority applications each year.

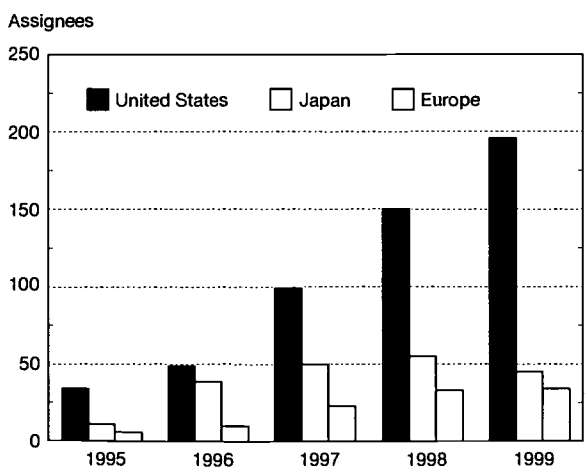
Text table 6-9 shows that in every country covered by this study, almost all the assignees are corporations or individual inventors. The United States is the only country in which universities consistently patent Internet business methods.[42] South Korea and Japan show occasional patenting activity from government agencies in this field. EPO, Finland, and Sweden show less activity from individuals than the other patent offices covered.

Highly Cited Patents. Since 1995, the United States has accounted for about 50 percent of all patent families for Internet business methods but more than 71 percent of the highly cited patent families. (See text table 6-10.) Thus, the United States has about 40 percent more of the highly cited patents in this field than one would expect based on its overall level of activity. This indicates not only that the United States is generating large numbers of patents in this field but also that these patents have technological significance for those inventions that follow. Unlike the United States, Japan has been significantly underrepresented among the most highly cited patents in this technology relative to its overall level of activity. Although Japan accounts for about 27 percent of all patent families, it accounts for only 6.8 percent of the cited families. One possible explanation for this is that about 85 percent of Japan's patent families are protected only in Japan, and such patents may be less likely to be cited by EPO examiners. Among the other countries that account for at least 2 percent of total patent families in this technology, Germany is significantly overrepresented among the cited patent families with about 50 percent more cited families than would be expected based on its overall level of patenting activity. Canada is significantly underrepresented among the cited patents, and Great Britain has about the number of cited patents expected based on its overall level of activity in this field. Care should be taken not to read too much into the ratios for countries with low levels of activity because one or two highly cited patents from these countries may make them appear to be overrepresented among the highly cited families.

[41]This refers to the number of unique organizations that have filed patent applications, not the number of applications they have filed. Data for 1999 and 2000 should be considered incomplete because of the 18-month time lag between the date a patent application is filed and the date it is published.

[42]Like those presented for human DNA sequence patents discussed earlier, data reflect the number of unique organizations filing patent applications, not the number of applications they have filed. Individuals are counted only if no other type of organization also was on the patent.

Figure 6-31.
Active assignees for Internet-related business methods patents, United States, Japan, and Europe



See appendix table 6-18. *Science & Engineering Indicators – 2002*

Venture Capital and High-Technology Enterprise

One of the most serious challenges to new entrepreneurs is capital, or the lack thereof. Venture capitalists typically make investments in small, young companies that may not have access to public or credit-oriented institutional funding. Venture capital investments can be long term and high risk, and they may include hands-on involvement in the firm by the venture capitalist. Venture capital can aid the growth of promising small companies and facilitate the introduction of new products and technologies, and it is an important source of funds for the formation and expansion of small high-technology companies. This section examines investments made by U.S. venture capital firms by stage of financing and by technology area.

The latest data show total venture capital under management rising vigorously each year from 1996 through 2000. The largest one-year increase occurred in 1999, when the pool of venture capital jumped to nearly $145.2 billion, a 72.5 percent gain from the previous year. In 2000, once again, the pool of venture capital grew sharply, rising 60.9 percent to $233.7 billion, more than six times the amount managed only five years earlier.[43]

The amount of capital managed by venture capital firms grew dramatically during the 1980s as venture capital emerged as an important source of financing for small, innovative firms. (See text table 6-11.) By 1989, the capital managed by venture capital firms totaled nearly $33.5 billion, up from almost $4.1 billion in 1980. The number of venture capital firms also grew

[43]According to a recent report from the National Venture Capital Association (2001), new money coming into venture capital funds slowed down during the last quarter of 2000 following several quarters of lackluster returns to investors in venture captial funds.

Text table 6-9.
Active assignees, by priority country and priority year: Internet-related business methods patents

Priority country	1995	1996	1997	1998	1999	2000
Australia						
Corporations	2	2	3	7	10	0
Universities	0	0	0	0	0	0
Not for profits	0	0	0	0	0	0
Government agencies	0	0	1	0	0	0
Individuals	0	1	2	1	3	0
Canada						
Corporations	1	0	3	5	3	0
Universities	0	0	0	1	0	0
Not for profits	0	0	0	0	0	0
Government agencies	0	0	0	0	0	0
Individuals	3	0	1	3	3	0
Germany						
Corporations	2	2	2	8	10	2
Universities	0	0	0	0	0	0
Not for profits	0	0	1	0	0	0
Government agencies	0	0	0	0	0	0
Individuals	0	1	2	7	7	2
European Patent Office						
Corporations	1	0	2	4	1	0
Universities	0	0	0	0	0	0
Not for profits	0	0	0	0	0	0
Government agencies	0	0	0	0	0	0
Individuals	0	0	1	0	0	0
Finland						
Corporations	1	2	0	3	7	0
Universities	0	0	0	0	0	0
Not for profits	0	0	0	0	0	0
Government agencies	0	0	0	0	0	0
Individuals	0	0	1	0	1	0
France						
Corporations	0	1	3	5	2	0
Universities	0	0	0	0	0	0
Not for profits	0	0	0	0	0	0
Government agencies	0	0	0	0	0	0
Individuals	2	1	1	3	2	0
Great Britain						
Corporations	1	2	7	8	8	1
Universities	0	0	0	0	0	0
Not for profits	0	0	0	0	0	0
Government agencies	0	0	0	0	0	0
Individuals	0	1	1	3	6	0
Japan						
Corporations	11	39	49	54	44	4
Universities	0	0	0	0	0	0
Not for profits	0	0	0	0	0	0
Government agencies	0	0	0	1	1	0
Individuals	0	7	5	5	7	1
South Korea						
Corporations	2	1	3	4	0	0
Universities	0	0	0	0	0	0
Not for profits	0	0	0	0	0	0
Government agencies	1	0	1	1	0	0
Individuals	1	0	0	2	10	0
Sweden						
Corporations	0	1	6	2	2	0
Universities	0	0	0	0	0	0
Not for profits	0	0	0	0	0	0
Government agencies	0	0	0	0	0	0
Individuals	0	0	0	2	0	0
United States						
Corporations	33	47	98	148	195	1
Universities	1	1	1	2	1	0
Not for profits	0	1	0	0	0	0
Government agencies						
Individuals	8	22	47	34	33	0
Other						
Corporations	2	3	7	21	13	2
Universities	0	2	0	0	0	0
Not for profits	0	1	0	1	0	0
Government agencies						
Individuals	3	1	10	13	13	4

NOTE: Priority country is established by the location of the original patent application.

SOURCE: "International Analysis of Internet-Related Business Methods Patenting," submitted to National Science Foundation by Mogee Research and Analysis Associates (Reston, VA, June 7, 2001).

Science & Engineering Indicators – 2002

Text table 6-10.
Priority countries ranked by share of top-cited patents: Internet-related business methods, 1995-99

Priority country	Share of top cited (%)	Share of total families (%)	Ratio top cited to total families
United States	71.2	50.3	1.4
Japan	6.8	27.1	0.3
Germany	5.5	3.6	1.5
Finland	4.1	0.9	4.4
European Patent Office	2.7	0.9	2.9
Great Britain	2.7	3.0	0.9
Australia	1.4	2.2	0.6
Canada	1.4	1.4	1.0
Denmark	1.4	0.1	11.2
Ireland	1.4	0.4	3.7
Netherlands	1.4	0.9	1.6

NOTE: Priority country is established by the location of the original patent application.

SOURCE: "International Analysis of Internet-Related Business Methods Patenting," submitted to National Science Foundation by Mogee Research and Analysis Associates (Reston, VA, June 7, 2001).

Science & Engineering Indicators – 2002

Text table 6-11.
Venture capital under management in United States: 1980–2000
(Millions of U.S. dollars)

Year	New capital committed	Total venture capital under management
1980	2,073.6	4,071.1
1981	1,133.2	5,685.7
1982	1,546.4	7,758.7
1983	4,120.4	12,201.2
1984	3,048.5	15,759.3
1985	3,040.0	19,330.6
1986	3,613.1	23,371.4
1987	4,023.9	26,998.5
1988	3,491.9	29,539.2
1989	5,197.6	33,466.9
1990	2,550.4	34,000.9
1991	1,488.0	31,587.2
1992	3,392.8	30,557.3
1993	4,115.3	31,894.0
1994	7,339.4	34,841.3
1995	8,426.7	38,465.0
1996	10,467.2	46,207.2
1997	15,175.6	59,614.5
1998	25,292.6	84,180.1
1999	60,138.4	145,195.6
2000	93,436.1	233,666.1

SOURCE: Special tabulations provided by Venture Economics (Newark, NJ, March 2001).

Science & Engineering Indicators – 2002

during the 1980s from around 448 in 1983 to 670 in 1989.

In the early 1990s, the venture capital industry slowed as investor interest waned and the amount of venture capital disbursed to companies declined. The number of firms managing venture capital also declined during the early 1990s. The slowdown was short lived, however; investor interest picked up in 1992 and the pool of venture capital has grown steadily since then.

California, New York, and Massachusetts together account for about 65 percent of venture capital resources. Venture capital firms tend to cluster around locales considered to be hotbeds of technological activity as well as in states where large amounts of R&D are performed (Venture Economics Information Services (VEIS) 1999).[44] See sidebar, "Business Incubators Nurture Future Entrepreneurs on U.S. Campuses."

Venture Capital Commitments and Disbursements

Several years of high returns on venture capital investments have stimulated increased investor interest. This interest soared after 1995, with new commitments rising 24.2 percent in 1996 to nearly $10.5 billion and then rising 45.0 percent the following year. By 2000, new commitments reached $93.4 billion, more than 10 times the amount available in 1995. Pension funds remain the single largest supplier of committed capital, supplying 41 percent in 2000. (See text table 6-12.) Banks and insurance companies are the next largest source, supplying 23 percent of committed capital, followed closely by endowments and foundations at 21 percent (VEIS 1999).[45]

Starting in 1994, new capital raised exceeded capital disbursed by the venture capital industry. In each of the following years, that gap has grown larger, creating surplus funds available for investments in new or expanding innovative firms. As early as 1990, firms producing computer software or providing computer-related services received large amounts of new venture capital, but they became the clear favorite beginning in 1996. (See figure 6-32 and appendix table 6-19.) In 1990, software companies received 17.4 percent of all new venture capital disbursements, nearly twice the share going to computer hardware companies and biotechnology companies. That share rose to about 27.1 percent in 1993 and then fluctuated between 16.4 and 27.1 percent until 1998, when software companies received more than one-third of all venture capital disbursements. Telecommunications companies also attracted large amounts of venture capital during the 1990s, edging out software companies for the lead in 1992 and 1994. Medical and health care companies received a large share of venture capital throughout the 1990s, reaching a high of 17.8 percent in 1994 before dropping to 13.6 percent in 1998. Computer hardware companies, an industry highly favored by the venture capitalists during the 1980s, received only 2.4 percent of total venture capital disbursements in 2000.

The latest data include a new category that makes comparisons with previous years more difficult. In the late 1990s, the Internet emerged as a key new tool for business, and com-

[44]Data on U.S. R&D performance by state are presented in chapter 4.
[45]Based on information contained in Venture Economics (1999).

Text table 6-12.
Capital commitments by limited partner type: 1990–2000
(Billions of dollars)

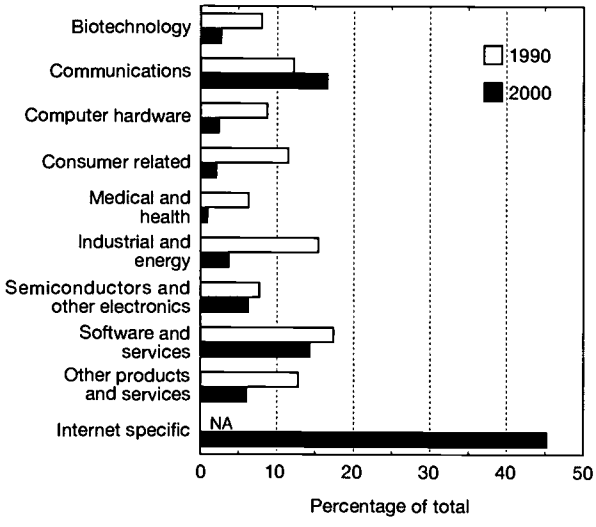
Limited partner type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Total commitment ...	2.55	1.49	3.39	4.12	7.34	8.43	10.47	15.18	25.29	60.14	93.44
Pension funds	1.34	0.63	1.41	2.43	3.36	3.12	5.74	5.77	15.03	26.16	37.47
Financial and insurance	0.24	0.08	0.49	0.43	0.70	1.62	0.30	0.91	2.59	9.32	21.77
Endowments and foundations	0.32	0.36	0.63	0.44	1.57	1.65	1.18	2.43	1.58	10.34	19.72
Individuals and families	0.29	0.18	0.37	0.30	0.87	1.36	0.68	1.82	2.83	5.77	11.03
Corporations	0.17	0.06	0.11	0.34	0.67	0.35	1.98	3.64	2.97	8.54	3.46
Foreign investors	0.19	0.17	0.38	0.18	0.18	0.32	0.59	0.61	0.29	NA	NA

NA = not available

SOURCE: Special tabulations provided by Venture Economics (Newark, NJ, March 2001).

Science & Engineering Indicators – 2002

Figure 6-32.
U.S. venture capital disbursements, by industry category



NA = not available

See appendix table 6-19.

Science & Engineering Indicators – 2002

panies developing Internet-related technologies drew venture capital investments in record amounts. Beginning in 1999, investment dollars disbursed to Internet companies were classified separately in the statistics that track venture capital investment trends. Before 1999, some of these investments would have been classified as going to companies involved in computer hardware, computer software, or communications technologies.

In 1999, Internet companies became the leading recipients of venture capital funds, collecting 41.7 percent of all venture capital disbursed. The latest data show their share increasing to 45.2 percent in 2000. Computer software companies, the leader through much of the 1990s, drew 12.9 percent of all venture capital disbursed in 1999 and 14.3 percent in 2000. The share of investments going to communications companies averaged 16.5 percent in 1999 and 2000.

Venture Capital Investments by Stage of Financing

The investments made by venture capital firms may be categorized by the stage at which the financing is provided (VEIS 1999). Early-stage financing involves the following:

- **Seed financing**—usually involves a small amount of capital provided to an inventor or entrepreneur to prove a concept. Seed financing may support product development but rarely is used for marketing.
- **Startup financing**—provides funds to companies for use in product development and initial marketing. This type of financing usually is provided to companies that are newly organized or have been in business for a short time and have not yet sold their product in the marketplace. Generally, such firms have already assembled key management, prepared a business plan, and conducted market studies.
- **First-stage financing**—provides funds to companies that have exhausted their initial capital and need funds to initiate commercial manufacturing and sales.

Later stage financing includes the following:

- **Expansion financing**—includes working capital for the initial expansion of a company; funds for major growth expansion (involving plant expansion, marketing, or development of an improved product); and financing for a company expecting to go public within six months to a year.
- **Acquisition financing**—provides funds to finance the purchase of another company.

♦ **Management/leveraged buyout**—includes funds to enable operating management to acquire a product line or business from either a public or private company. These companies often are closely held or family owned.[46]

Most venture capital disbursements are directed to later stage investments. Since 1982, later stage investments captured between 59 and 79 percent of venture capital disbursements, with the high and low points both reached in the 1990s. In 2000, later stage investments represented 78 percent of total disbursements. (See figure 6-33 and appendix table 6-20.) Capital for company expansions attracted the most investor interest by far; this financing stage alone attracted more than half of all venture capital disbursed since 1995. In 2000, venture capital funds to finance company expansions accounted for 61 percent of total disbursements. Nearly half (48.1 percent) of the $55.2 billion disbursed by venture capital funds to finance expansions of existing businesses in 2000 went to Internet companies.

Contrary to expectations, only a relatively small amount of venture capital helps struggling inventors or entrepreneurs prove a concept or develop their products. During the 21-year period examined, such seed money never accounted for more than 6 percent of all venture capital disbursements and most often represented between 2 and 4 percent of the annual totals.[47] The latest data show the share of all venture capital disbursements classified as seed financing falling to its lowest level ever, representing just 1.4 percent of all venture capital in both 1999 and 2000. Nevertheless, nearly $1.3 billion in seed money was disbursed by venture capital funds in 2000, up from $710.7 million in 1999 and $312.5 million in 1995.

Computer software, telecommunications technologies, and medical and health-related firms were the largest recipients of venture capital seed-type financing during the late 1990s.

[46]For the acquisition financing and management/leveraged buyout categories, data include only capital disbursements made by a venture capital firm and do not include such investments made by a buyout firm.

[47]A study of new firms in the southwestern United States found that many were able to obtain substantial amounts of initial capital through strategic alliances with more established firms (Carayannis, Kassicieh, and Radosevich 1997). The study indicated that embryonic firms raised more than $2 million, on average, in early-stage financing through such strategic alliances.

Business Incubators Nurture Future Entrepreneurs on U.S. Campuses

The term "business incubator" can describe a wide range of institutions whose purpose is to help develop new and nurture established small business enterprises. According to data compiled by the National Business Incubation Association (NBIA), in 1980 as few as 12 business incubators were operating in North America; in 1998, there were more than 800 (National Business Incubation Association 2001).

Business incubators can be operated by universities, colleges and community colleges, for-profit businesses and economic development agencies, local governments, or a combination of all these organizations. Business incubators seek to encourage new entrepreneurs by consolidating, usually under one roof, many of the services critical to successful business development, including management advice, networking with other business owners, technical support, and access to financing.

In 1998, according to data compiled by NBIA:

♦ 40 percent of incubators were technology focused.

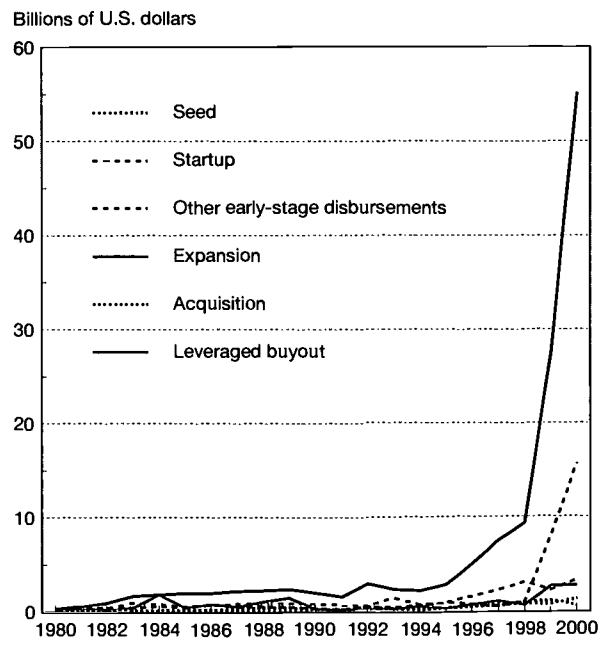
♦ 45 percent were urban, 36 percent were rural, and 19 percent were suburban.

♦ 27 percent were affiliated with universities and colleges either directly or as part of joint efforts among governments, private developers, and nonprofit agencies.

More than half of all incubators operating in 1998 were sponsored by government and nonprofit organizations. These incubators tend to focus on local economic development and job creation. Such "targeted" incubators accounted for about 9 percent of the total in 1998.

Data on numbers and characteristics of business incubators operating in the United States come from NBIA's website. The NBIA database offers the most current and complete data available but, according to its own estimates, likely understates the numbers of business incubators operating in 1998.

Figure 6-33.
U.S. venture capital disbursements, by stage of financing, 1980–2000



See appendix table 6-20. *Science & Engineering Indicators – 2002*

(See appendix table 6-21.) Computer software firms received the most seed money from 1996 to 1998 before relinquishing the top position to Internet companies in 1999 and 2000. Investments in Internet companies represented 60.8 percent of all seed money from venture capital funds in 1999 and 43.7 percent in 2000.

Communications firms gained favor with forward-looking venture capitalists in 2000, attracting 26.2 percent of all seed-stage investments disbursed by venture capital funds that year, up from just 5.0 percent in 1999. The shares of venture capital seed money going to computer software companies fell to 11.3 percent in 1999 and to 10.5 percent in 2000.

With more than 80 percent of seed money going to either Internet, communications, or computer software companies, seed money for companies involved in other technologies declined. Biotechnology, which in 1998 received 11.9 percent of the venture capital disbursed as seed money, saw its share drop to 6.3 percent in 1999 and 0.9 percent in 2000. Medical and health-related firms fared better than biotechnology firms, yet they saw their share drop from 20 percent in both 1997 and 1998 to 6.9 percent in 1999 and 2.9 percent in 2000.

Chapter Summary: Assessment of U.S. Technological Competitiveness

Based on various indicators of technology development and market competitiveness, the United States continues to lead, or to be among the leaders, in all major technology areas. Advances in information technologies (i.e., computers and telecommunications products) continue to influence new technology development and dominate technical exchanges between the United States and its trading partners.

Although economic problems continue to hamper further progress, Asia's status as both a consumer and developer of high-technology products is enhanced by the development taking place in many Asian economies, particularly Taiwan and South Korea. Several smaller European countries also exhibit growing capacities to develop new technologies and to compete in global markets.

The current position of the United States as the world's leading producer of high-technology products reflects its success in both supplying a large domestic market and serving foreign markets. This success in the international marketplace may be the result of a combination of factors: the nation's long commitment to investments in S&T; the scale effects derived from serving a large, demanding domestic market; and the U.S. market's openness to foreign competition. In the years ahead, these same market dynamics may also benefit a more unified Europe and Latin America and a rapidly developing Asia and complement their investments in S&T.

Beyond these challenges, the rapid technological development taking place around the world also offers new opportunities for the U.S. S&T enterprise. For U.S. businesses, rising exports of high-technology products and services to Asia, Europe, and Latin America are already apparent and should grow in the years ahead. The same conditions that create new business opportunities—the growing global technological capacity and the relaxation of restrictions on international business—can also create new research opportunities. The well-funded institutes and technology-oriented universities that are being established in many technologically emerging areas of the world will advance scientific and technological knowledge and lead to new collaborations between U.S. and foreign researchers.

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Chapter 7
Science and Technology: Public Attitudes and Public Understanding

Highlights

- **In National Science Foundation (NSF) surveys conducted since 1979, about 90 percent of U.S. adults report being very or moderately interested in new scientific discoveries and the use of new inventions and technologies.** Those with more years of formal education and those who have taken more courses in science and mathematics are more likely than others to express a high level of interest in science and technology (S&T).

- **News about S&T, however, does not attract much public interest.** According to Pew Research Center surveys, only about 2 percent of the most closely followed news stories of the past 15 years were about scientific breakthroughs, research, and exploration. The leading science-related news event of 2000 was the announcement that scientists had completed mapping the human genome. However, only 16 percent of the public claimed to be following that story very closely. Twenty-eight percent said they were closely following news about the Microsoft antitrust court case, an event that may more of a business than a technology story, although the outcome could have a major impact on innovation in the software industry.

- **The number of people who feel either well informed or moderately well informed about S&T is relatively low.** In 2001, less than 15 percent of NSF survey respondents described themselves as well informed about new scientific discoveries and the use of new inventions and technologies; a substantial minority, approximately 30 to 35 percent, thought that they were poorly informed. People are feeling less informed than they used to. A recent downward trend is particularly noticeable for the five S&T-related issues included in the NSF survey.

- **Most Americans do not know a lot about S&T.** The general public's ability to answer basic questions about science has hardly changed. For instance, in 2001, only about 50 percent of NSF survey respondents knew that the earliest humans did not live at the same time as dinosaurs, that it takes Earth one year to go around the Sun, that electrons are smaller than atoms, and that antibiotics do not kill viruses. However, the number answering the last item correctly rose from 40 percent in 1995 to 51 percent in 2001, an increase that may be attributable to widespread media coverage of an important public health issue, antibiotic-resistant bacteria.

- **For the first time, a majority (53 percent) of NSF survey respondents answered "true" to the statement "human beings, as we know them today, developed from earlier species of animals," bringing the United States more in line with other industrialized countries in response to this question.** Although a majority (60 percent) of people surveyed in a Gallup poll were opposed to the Kansas State Board of Education's decision to delete evolution from the state's science standards (a decision that was later reversed), more than two-thirds favored teaching both evolution and creationism in U.S. public school classrooms.

- **A majority of Americans (about 70 percent) lack a clear understanding of the scientific process.** Although more than 50 percent of NSF survey respondents in 2001 had some understanding of probability, and more than 40 percent were familiar with how an experiment is conducted, only one-third could adequately explain what it means to study something scientifically. Understanding how ideas are investigated and analyzed is a sure sign of scientific literacy. Such critical thinking skills can also prove advantageous in making well-informed choices at the ballot box and in other daily living activities.

- **All indicators point to widespread support for government funding of basic research.** In 2001, 81 percent of NSF survey respondents agreed with the statement: "Even if it brings no immediate benefits, scientific research that advances the frontiers of knowledge is necessary and should be supported by the Federal Government."

- **Data from the NSF survey show a gradual decline in public support for genetic engineering over the past 15 years.** The shift can be seen most clearly among the college educated and those classified as attentive to S&T. In no year has a majority of Americans agreed that the benefits of genetic engineering outweighed the harmful results. In 2001, 40 percent of those surveyed thought that the benefits outweighed the harmful results, down from 49 percent in 1985. However, the number of people who think the harms outweigh the benefits has also declined in most years, from 39 percent in 1985 to 33 percent in 2001. Concurrently, the percentage saying that the benefits are equal to the harms increased from 12 percent in 1985 to 28 percent in 2001.

- **In the 2001 NSF survey, 61 percent of respondents reported that they supported genetically modified food production;** 36 percent said that they were opposed. In addition, 89 percent said that they supported genetic testing to detect inherited diseases (9 percent were opposed), and 47 percent said that they supported cloning animals, about the same as the percentage opposing the technology.

- **Anti-biotechnology sentiments are much more common in Europe than in the United States.** In addition, the number of people harboring negative perceptions of biotechnology has increased in both Europe and Canada during the past few years, especially when compared with attitudes in the United States. These latest findings are from an international study conducted in late 1999 and early 2000 in the United States, Europe, and Canada.

- **On a 10-question "pop quiz" on biotechnology, most Americans, Europeans, and Canadians gave the incorrect answer (true) to the statement "ordinary tomatoes do not contain genes, while genetically modified tomatoes do," and fewer than half the respondents in each region knew that animal genes can be transferred into plants.** On the same quiz, Americans and Canadians seemed to know more than Europeans about the science of biotechnology; they averaged 6.2 and 6.1 correctly answered questions, respectively, compared with Europeans, who averaged 5.4 correctly answered questions. In responding to another question in this quiz, about half of Americans, Europeans, and Canadians knew that more than half of human genetic makeup is identical to that of chimpanzees.

- **In response to surveys conducted in late 1999 and early 2000, about half of the Americans thought that genetic engineering would "improve our way of life in the next 20 years."** The corresponding statistics for Europe and Canada were 38 and 50 percent, respectively. However, a sizable minority of Americans (29 percent) said the opposite, that genetic engineering "will make things worse" during the next 20 years, compared with 31 percent of Europeans and 40 percent of Canadians. In all three surveys, biotechnology ranked sixth among the seven technologies that respondents were asked about (only nuclear energy ranked lower). In contrast, more than 80 percent of Americans and Canadians said that solar energy, computers, and telecommunications would improve our way of life in the next 20 years. The corresponding European percentages were somewhat lower but still greater than 70 percent. In addition, approximately 70 percent of Americans, Canadians, and Europeans each thought that the Internet would improve their lives during the next 20 years.

- **Data from the 2001 NSF survey show that Americans have been listening to what scientists and others have been saying about global climate change.** Nearly 80 percent believe in the existence of global warming, and 53 percent of those surveyed said that the possibility of global warming should be treated as a very serious problem.

- **Most adults learn about the latest developments in S&T primarily from watching television.** Although the Internet is affecting what Americans know about these subjects, only 9 percent identified it as their main source of information about S&T, compared with those who identified television (44 percent) or newspapers and magazines (16 percent). However, according to a 2000 Pew Research Center survey, the Internet is displacing network news shows in certain types of households. Also, according to the 2001 NSF survey, the Internet is the preferred resource when seeking information about specific scientific issues, indicating that encyclopedias—and every other information resource—have lost a substantial number of customers to the Internet.

- **Access to the Internet at home is an indicator of both attitudes toward and knowledge of S&T.** Those who have home computers hooked up to the World Wide Web seem to harbor fewer reservations about S&T and have more knowledge of science and the scientific process than their non-access counterparts.

- **Few characters on prime time entertainment shows are scientists.** According to a recent study, the percentage of prime time television characters who are scientists was less than 2 percent in each year during the mid-1990s. Even though scientists seldom show up on the small screen, the appearance of women and minorities as scientists is even more rare. The reverse was true for foreign nationals, however, because they are more likely to portray scientists than other types of characters on television.

- **Most people believe that scientists and engineers lead rewarding professional and personal lives, although a stereotypical image of these professions, deeply rooted in popular culture, exists and has been difficult to dislodge.** For example, 25 percent of those surveyed thought that scientists were apt to be odd and peculiar people, and 29 percent thought that scientists have few other interests but their work. In addition, a majority (53 percent) of those surveyed agreed with the statement "scientific work is dangerous."

- **Belief in pseudoscience, including astrology, extrasensory perception (ESP), and alien abductions, is relatively widespread and growing.** For example, in response to the 2001 NSF survey, a sizable minority (41 percent) of the public said that astrology was at least somewhat scientific, and a solid majority (60 percent) agreed with the statement "some people possess psychic powers or ESP." Gallup polls show substantial gains in almost every category of pseudoscience during the past decade. Such beliefs may sometimes be fueled by the media's miscommunication of science and the scientific process.

- **Alternative medicine, defined here as any treatment that has not been proven effective using scientific methods, has been gaining in popularity.** One study documented a 50 percent increase in expenditures for alternative therapies and a 25 percent increase in the use of alternative therapies between 1990 and 1997. Also, more than two thirds of those responding to the NSF survey said that magnetic therapy was at least somewhat scientific, although no scientific evidence exists to support claims about its effectiveness in treating pain or any other ailment.

Introduction

Chapter Overview

Americans are highly supportive of science and technology (S&T), but lack knowledge of them. That is the major finding of the National Science Foundation's (NSF's) biennial surveys of Public Attitudes Toward and Understanding of Science and Technology. The most recent survey in this series was conducted in early 2001.[1]

Statistics on Americans' lack of knowledge of such subjects as history, geography, mathematics, and science receive a considerable amount of media attention and are regularly cited in speeches given by various educators and policymakers. Even late night talk show hosts make fun of Americans' inability to answer simple questions. Although it is true that many Americans do not do well when quizzed on their knowledge of science and other subjects, it is not always clear how important this deficiency is. For instance, it has been noted that Americans are hardly unique; citizens in other countries perform just as poorly in tests of their basic knowledge of the world around them (Gup 2000). Also, a case can be made that most people do not need to know the answers to be able to function in their daily lives and serve as productive members of society. However, strong critical thinking and problem-solving skills—the ability to evaluate information and make sound decisions—do play an important role in people's lives.[2]

Chapter Organization

The chapter begins with a discussion of the public's interest in and knowledge of S&T. The level of interest in S&T is an indicator of both the visibility of the science and engineering (S&E) community's work and the relative importance accorded S&T by society. The first section also contains data on the level of public understanding of both basic science concepts and the scientific process.

In the second section, public attitudes toward S&T are examined. Data on public attitudes toward Federal funding of scientific research and public confidence in the science community are included. In addition, this section contains information on public perceptions of the benefits and harms (or costs) of scientific research, genetic engineering, space exploration, the use of animals in scientific research, global warming, and attitudes toward math and science education.

The next sections feature discussions on the public image of the science community, including public perceptions of scientists and science occupations, and where Americans get information about S&T. Finally, interest in science fiction and the relationship between science and pseudoscience, including concerns about belief in paranormal phenomena, are examined in the last section of the chapter.

In addition, results of surveys sponsored by organizations other than NSF are discussed throughout each section.[3]

Public Interest in and Knowledge of S&T

Most people say they are interested in S&T. When asked in a survey about their level of interest, few people will admit to having no interest. This is the usual pattern that shows up in NSF surveys in which approximately 9 out of every 10 adults interviewed by telephone report they are either very or moderately interested in new scientific discoveries and the use of new inventions and technologies. (See appendix table 7-1.)

Despite the expression of interest in S&T, few people (less than 15 percent in 2001) feel very well informed about these subjects. And, available evidence suggests that their lack of confidence in their knowledge is justified, because a substantial number of people appear to be unable to answer simple science-related questions.

In this section, four topics will be covered:

- public interest in S&T and other issues,
- the public's sense of feeling well informed about S&T and other issues,
- the "attentive" public for S&T policy, and
- public understanding of S&T.

[1]Of the 15 *Indicators* volumes published since 1972, 14 have included a chapter on public attitudes toward and understanding of S&T. The surveys for the 1972, 1974, and 1976 *Indicators* contained a block of 20 items inserted into an omnibus national personal interview survey conducted by Opinion Research Corporation of Princeton, New Jersey. The 1979 survey was designed by Miller and Prewitt (1979) and analyzed by Miller, Prewitt, and Pearson (1980); the personal interviews were conducted by the Institute for Survey Research at Temple University. Additional national surveys were undertaken for the 1982, 1985, 1987, 1991, and 1993 *Indicators* reports, with telephone interviews conducted by the Public Opinion Laboratory of Northern Illinois University. The chapter for *Science Indicators—1985* was based on a national telephone survey conducted by the Public Opinion Laboratory for Professor George Gerbner of the Annenberg School of Communication at the University of Pennsylvania. In 1995, 1997, and 1999, the Chicago Academy of Sciences conducted surveys that continued the core of attitude and knowledge items from previous *Indicators* studies and included telephone interviews with a random-digit sample of 2,006 adults in 1995, 2,000 in 1997, and 1,882 in 1999. Interviews for the 1995 survey were conducted by the Public Affairs Division of Market Facts Incorporated. The interviews for the 1997 and 1999 surveys were conducted by the National Opinion Research Center. The 2001 survey was conducted by ORC Macro and included telephone interviews with a random-digit sample of adults. The results can be found in past volumes of *Indicators*.

In general, the response rate for previous NSF surveys has been 70 percent or higher. However, for the 1999 and 2001 surveys, the response rates were 66 and 39 percent, respectively. Moreover, the highly educated were overrepresented in the 2001 survey, and those with little education, underrepresented. For more information on the 1999 survey methodology, see Miller, Kimmel, and Hess (2000), and for more information on the 2001 survey, see Duffy, Muzzy, and Robb (2001).

[2]In a recent survey, workers rated critical thinking skills as more important than job-specific skills such as computer skills (Hebel 2000).

[3]Every effort was made to include relevant data from sources other than NSF. However, it should be noted that not many survey organizations regularly or even occasionally collect information on public attitudes toward or understanding of S&T.

Public Interest in S&T and Other Issues

Surveys conducted by NSF and other organizations consistently show that Americans are interested in S&T issues. Among those who participated in the 2001 NSF survey, 47 percent said that they were *very interested* in new scientific discoveries, and 43 percent reported that they were *very interested* in the use of new inventions and technologies. About 45 percent said that they were *moderately interested* in these issues, and about 10 percent reported *no interest*. (See appendix table 7-1 and figure 7-1.)

Nearly everyone is interested in new medical discoveries. Year after year, more people express interest in this subject than in any other. In 2001, about two-thirds of the NSF survey respondents reported they were *very interested* in new medical discoveries.[4] None of the other survey items, except local school issues, received such a high percentage of *very interested* responses. Local school issues ranked second, with 59 percent of the respondents saying they were *very interested* in this topic. (See appendix table 7-1.)

In 2001, the level of interest in S&T came close to an all-time high. On a scale ranging from 0 to 100,[5] the average level of public interest in new scientific discoveries was 69. Between 1985 and 1995, the index scores for this item ranged from 61 in 1992 to 67 in 1995. (See figure 7-2 and appendix table 7-2.)

The interest index for new inventions and technologies tracks quite closely with that for new scientific discoveries. It has been no lower than 64 since 1983. In 2001, the index level for this item was 66. The highest score ever recorded for this item was 69 in 1997. (See figure 7-2 and appendix table 7-2.)

New medical discoveries is the only issue that has consistently produced interest index scores in the 80s. Scores for environmental pollution and local school issues have been in the 70s for the past 10 years. Interest in environmental pollution seems to have gradually subsided, dropping from 80 in 1990 to 70 only 11 years later. During the same period, interest in local school issues increased from 67 in 1990 to 74 in 2001. Despite all the newsworthy events taking place in space during the past few years, interest in space exploration declined, dropping from 55 in 1997 to 50 in 2001. (See "Public Attitudes Toward Space Exploration.")

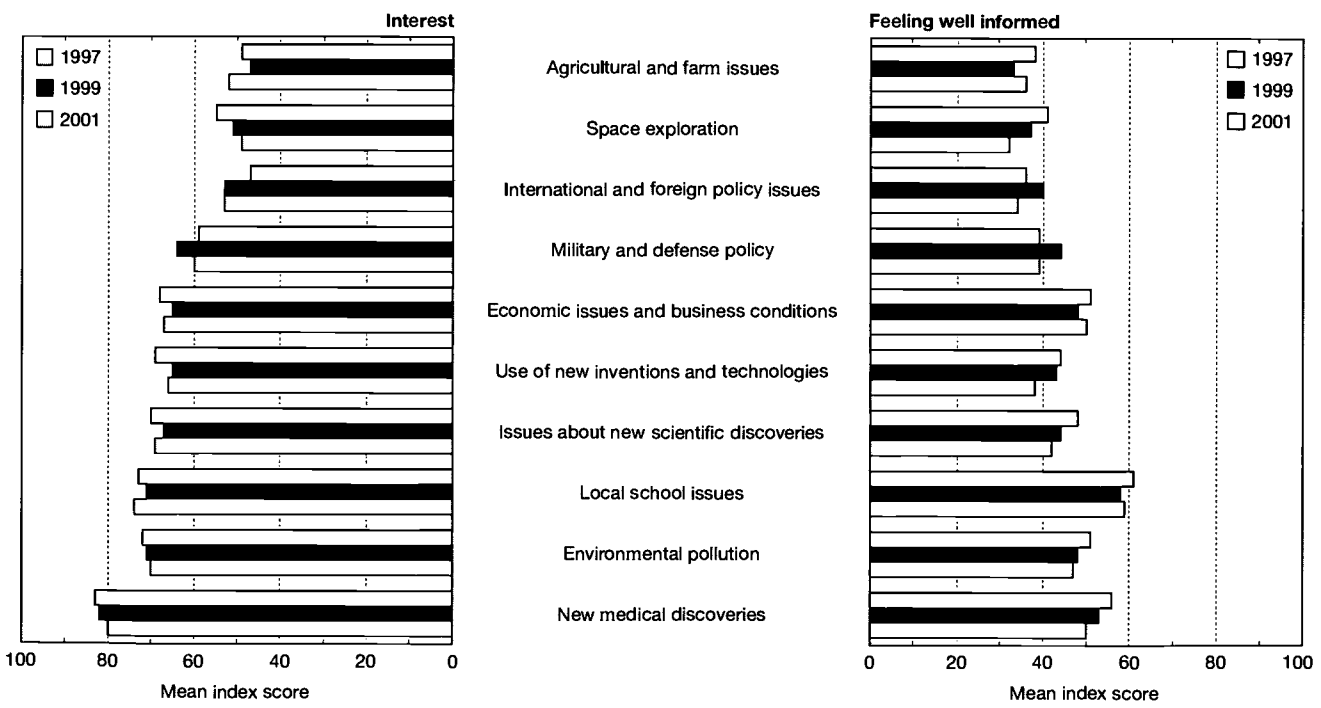
Are People as Interested in S&T Issues as They Assert?

When asked about their interest in S&T issues, few survey respondents admit being uninterested. However, there is reason to believe that their level of interest may not be as high as the data indicate. Surveys conducted by the Pew Research Center show crime, health, sports, and community affairs as the four types of news followed most closely by the

[4]Americans not only are interested in new medical discoveries, but also strongly support government-sponsored medical research. In a Research!America (2000) poll, 65 percent of those surveyed said they supported doubling spending on such research during the next five years.

[5]Responses were converted to index scores ranging from 0 to 100 by assigning a value of 100 for a "very interested" response, a value of 50 for a "moderately interested" response, and a value of 0 for a "not at all interested" response. The values for each issue were then averaged to produce an index score reflecting the average level of interest for the given issue.

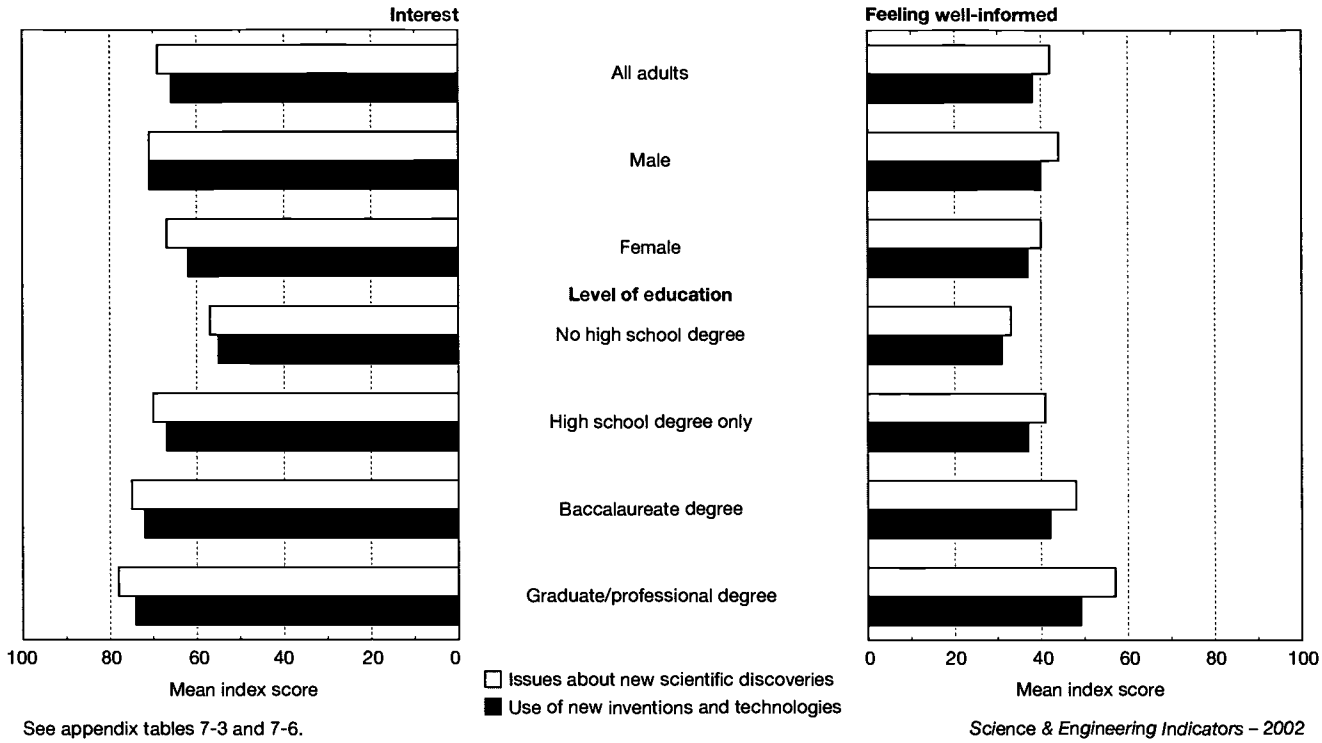
Figure 7-1.
Indices of public interest in and feeling well informed about public policy issues: 1997, 1999, and 2001



See appendix tables 7-2 and 7-5.

Science & Engineering Indicators – 2002

Figure 7-2.
Indices of public interest in and feeling well informed about scientific and technological issues, by sex and level of education: 2001



See appendix tables 7-3 and 7-6.

Science & Engineering Indicators – 2002

American public; S&T ranks only seventh. (See text table 7-1 and sidebar "Leading News Stories of 2000.") Still, interest in news about S&T is only part of the story. The millions of people who visit science museums every year are also demonstrating interest in science without necessarily being interested in science news. (See "Where Americans Get Information About Science and Technology.") In addition, the number of science-related books on best seller lists seems to be increasing (Lewenstein 2001).[6]

In addition, S&T issues are rarely selected in most national polls designed to determine the top public priorities in the United States. For example, according to one recent poll from 2000, the leading public priorities are (1) improving the educational system, (2) keeping the economy strong, (3) securing Social Security, (4) reducing crime, and (5) securing Medicare (Pew Research Center for the People and the Press 2000a). In the same poll, protecting the environment ranked ninth, just ahead of national defense. Science did not rank among the top 14. However, when survey participants are specifically given the opportunity to rank S&T in the context of other issues, their priorities can change. In such a poll, 50 percent of those surveyed said that "more money for science

Text table 7-1.
News followed by American public: 2000

Type of news	Percentage following very closely: All	Internet users	Non-Internet users
Crime	30	25	35
Health	29	26	31
Sports	27	28	25
Community	26	22	30
Religion	21	17	27
Local government	20	19	22
Science and technology	18	22	14
Washington news	17	17	17
Entertainment	14	14	17
International affairs	14	15	14
Business and finance	14	17	10
Consumer news	12	13	11
Culture and arts	10	11	8

NOTE: Responses are to the following question: Please tell me how closely you follow this type of news either in the newspaper, on television, or on radio: very closely, somewhat closely, not very closely, or not at all closely?

SOURCE: Pew Research Center for the People and the Press, "Internet Sapping Broadcast News Audience: Investors Now Go Online for Quotes, Advice," Biennial Media Consumption survey (Washington, DC, June 11, 2000). Available at <http://www.people-press.org/media00rpt.htm>.

Science & Engineering Indicators – 2002

[6]The first science-related books on the *Publishers Weekly* best seller list to sell more than a half million copies were Carl Sagan's *Cosmos* in 1980 and Stephen Hawking's *Brief History of Time* in 1988. The success of *Cosmos* led to Sagan receiving a $2 million advance for his science fiction novel *Contact*, the largest advance up until that time for a work of fiction that had yet to be written (Lewenstein 2001).

research and engineering" was *very important*, and 44 percent said *somewhat important,* ranking this issue ahead of tax cuts (50 and 35 percent, respectively) and campaign finance reform (29 and 36 percent, respectively) (Research! America 2001). As in many other polls, however, education and Social Security/Medicare were ranked ahead of every other issue in terms of importance, with 85 and 72 percent, respectively, of those surveyed saying those two public agenda items were *very important.*

Most polls, especially those conducted during the 2000 presidential campaign, show education to be one of the public's top priorities (Gallup Poll Editors 2001). Thus, it is not surprising to see the NSF interest index score for local school issues jumping three points between 1999 and 2001 from 71 to 74, displacing environmental pollution as the public's second highest priority (after new medical discoveries).

Leading News Stories of 2000

Few science or technology stories attract much public interest. According to the Pew Research Center's surveys, which track public interest in specific domestic and international news stories, the leading science-related news story of 2000 was the announcement that scientists had completed mapping the human genome (Pew Research Center for the People and the Press 2000c). However, only 16 percent of those interviewed reported that they were following this story very closely. In contrast, 61 percent said they were closely following the recent increase in gas prices, putting that issue at the top of the list of leading news stories of 2000, followed by the terrorist attack on the USS Cole, at 44 percent.* Rounding out the top 10, at number 10, was the Super Bowl; 31 percent of those surveyed reported they were closely following that story, nearly twice as many as the number who said they were closely following the human genome story.

The Federal court ruling ordering the breakup of Microsoft (since overturned) attracted almost as much interest as the Super Bowl story; 28 percent said they were closely following the Microsoft story.† However, this news may have been more of a business story than a technology story, although a case can be made that the court decision will have a major effect on innovation in the software industry. The Microsoft case spotlights an issue that has long been a fertile subject for study and debate among economists, which is the effect of antitrust policy on innovation.

Death and/or destruction usually lead Pew's list of the top 10 stories each year (although 2000 was somewhat of an exception). In fact, most of the science-related stories on the list of the most closely followed stories of the past 15 years are about natural disasters, e.g., earthquakes, floods, and other weather-related stories. Only about 2 percent of the 776 stories on the list are about scientific breakthroughs, research, and exploration (Pew Research Center for the People and the Press 2000d).

*Although the increase in gas prices received less press coverage than the election, this story hits closer to home for most people. This is the highest recorded interest in gas prices since the Persian Gulf War in 1990.

†According to a Gallup poll, although about half the public believes Microsoft is a monopoly, most people do not think the company should be broken up (Moore 2001).

Sex as an Indicator of Interest in S&T Issues

Men express more interest than women in new scientific discoveries and the use of new inventions and technologies. (See figure 7-2.) The 9-point gap is particularly large for the latter but smaller than the 14-point gap for space exploration. Men also express more interest than women in economic and business conditions, military and defense policy, and international and foreign policy. Women are more interested than men in new medical discoveries and local school issues; the differences are 11 and 10 points, respectively. (See appendix table 7-3.)

Level of Education as an Indicator of Interest in S&T Issues

Level of formal education and number of mathematics and science courses completed are associated with interest in new scientific discoveries and the use of new inventions and technologies. (See figure 7-2 and appendix table 7-3.) A relationship also exists between education and level of interest in international and foreign policy, space exploration, and economic issues and business conditions. There does not seem to be a relationship between education and level of interest in new medical discoveries, military and defense policy, or environmental pollution. (See appendix table 7-3.)

In addition, people who have college degrees follow S&T stories more closely than those who do not. For example, in the July 2000 Pew Research Center survey, 25 percent of those who had college degrees said they were closely following the human genome announcement. Among those who did not have college degrees, fewer than 12 percent were closely following the story. In contrast, during the same month, 23 percent of the latter group said they were closely following the story about the Philadelphia police beating a carjacking suspect. Only 16 percent of those who had college degrees claimed to be following that story very closely (Pew Research Center for the People and the Press 2000c).

Data for the United Kingdom

Although comparable data for the European Union, Japan, and Canada have not been collected since the late 1980s or early 1990s (these data were included in previous editions of *Indicators*), several items used in the U.S. survey were replicated in a 2000 survey of U.K. residents (Office of Science and Technology and The Wellcome Trust 2000). The data show that British residents express less interest than their counter-

parts in the United States in new medical discoveries, environmental issues, new inventions and technologies, and new scientific discoveries. (See text table 7-2.)

In addition, U.K. survey participants were asked to rate (on a 5-point scale) their interest in, and to assess the benefits of, 11 disciplines or technologies. Rankings by level of interest and perceived benefits were similar. For example: Two health-related items, new medicines and heart and other transplants, were at the top of both lists: 35 and 28 percent, respectively, of the respondents said they were *very interested* in these topics. Respondents were also most likely to judge these items as beneficial; 61 and 56 percent, respectively, categorized them as *very beneficial.*

Ranking next in terms of both interest and perceived benefits were research into climate change as well as computing and the Internet (both with 20 percent *very interested* and 29 percent *very beneficial* responses). Respondents also saw telecommunications as being highly beneficial. In addition to the 28 percent who judged these technologies as being very beneficial, another 52 percent gave this item a "4" on the 5-point scale, placing it just behind new medicines and heart and other transplants in terms of the total percentage scoring this category beneficial. However, only 16 percent of the respondents said they were very interested in telecommunications. New and faster methods of transportation rounded out the top six categories.

Five items received the lowest scores under both criteria. In order of perceived benefits were human fertility testing, new methods of food production and manufacture, space research and astronomy, genetic testing, and cloning. Respondents expressed more interest, however, in space and food than in the other biology-related categories.

The Public's Sense of Being Well Informed about S&T Issues

In general, most Americans feel that they are not well informed about S&T issues. In fact, for all issues included in the 2001 NSF survey, the level of feeling well informed was considerably lower than the level of expressed interest. For example, in the 2001 NSF survey, nearly half of the respondents said they were *very interested* in new developments in science and technology. Yet fewer than 15 percent of respondents described themselves as *very well informed* about new scientific discoveries and the use of new inventions and technologies; approximately 30 percent considered themselves *poorly informed.* (See appendix table 7-4.) Consequently, the corresponding index scores[7] were lower than the interest index scores for those same issues. (See figure 7-1.)

In 2001, three issues exhibited index scores in the 50s (local school issues, economic issues and business conditions, and new medical discoveries); two exhibited scores in the 40s (environmental pollution and issues about new scientific discoveries); and the other five exhibited scores in the 30s. (See appendix table 7-5.)

The NSF survey shows that people are feeling less informed than they used to. This downward trend is particularly noticeable for the five S&T-related issues included in the survey: between 1997 and 2001, index scores fell 5 or more points for four issues (new medical discoveries, new scientific discoveries, the use of new inventions and technologies, and space exploration) and 4 points for environmental pollution.

Sex as an Indicator of Feeling Well Informed About S&T Issues

Men were more likely than women to feel well informed about 6 of the 10 issues included in the 2001 NSF survey. By far the widest gap, 13 points, was in space exploration. Military and defense policy and economic issues and business conditions had gender gaps of 10 and 9 points, respectively. Other items (for example, issues about new scientific discoveries and international and foreign policy issues) had gender gaps of 7 or fewer points. (See appendix table 7-6.)

[7]Responses were converted to index scores ranging from 0 to 100 by assigning a value of 100 for a "very well informed" response, a value of 50 for a "moderately well informed" response, and a value of 0 for a "poorly informed" response. The values for each issue were then averaged to produce an index score reflecting the average level of feeling informed for the given issue.

Text table 7-2.
Interest in science-related topical issues, United States and United Kingdom: 2000/2001
(Percent)

	Very interested		Moderately interested		Not interested	
Issue	U.S.	U.K.	U.S.	U.K.	U.S.	U.K.
New medical discoveries	66	46	31	41	3	13
Environmental issues	50	35	43	47	7	17
New inventions and technologies	46	24	46	50	8	26
New scientific discoveries	50	22	45	49	6	28

NOTES: Data for United States collected in 2001; data for United Kingdom collected in 2000.

SOURCES: National Science Foundation, 2001 Survey of Public Attitudes Toward and Understanding of Science and Technology (Arlington, VA, 2001); Office of Science and Technology and The Wellcome Trust, "Science and the Public: A Review of Science Communication in the United Kingdom" (London, UK, March 2000).

Science & Engineering Indicators – 2002

In contrast, women were more likely than men to feel well informed about two issues in the survey: local school issues and new medical discoveries. For these issues, the disparity in index scores between the two sexes was 10 and 7 points, respectively.

Level of Education as an Indicator of Feeling Well Informed About S&T Issues

As expected, in general, the more education an individual has, and the more mathematics and science courses the individual has completed, the better informed that person believes he or she is. The relationship between education and feeling well informed is evident for new scientific discoveries, the use of new inventions and technologies, space exploration, economic issues and business conditions, and international and foreign policy issues, but not for the other issues in the survey. (See appendix table 7-6.)

The "Attentive Public" for S&T Issues

It may not be easy to pinpoint exactly the audience for issues pertaining to S&T policy. It is probably safe to say that members of the S&E workforce, especially those in the academic community, are interested in and well informed about various S&T policy issues. However, the number of members in this community is relatively small. (See chapter 3, "Science and Engineering Workforce," and chapter 5, "Academic Research and Development.")

In addition to scientists and engineers and those who work in science policy, other members of the public are interested in S&T and probably pay attention to news reports about new scientific discoveries and new inventions and technologies. Also, some people are attentive because a particular S&T-related issue or event is affecting their daily lives. This type of situation was portrayed in the popular movie *Erin Brockovich,* in which the main character, who was not a scientist or even well educated, embarked on a mission to learn everything she could about a scientific issue that was at the center of a court case. Although the science community took umbrage at the way scientific evidence was portrayed in the film (Kolata 2000), the movie illustrates how people become informed and attentive when their health and well-being are at stake.

Classifying the Public as Attentive, Interested, or Residual

It is important to identify the audience for S&T issues so that the attitudes of this group can be compared with those of everyone else. Therefore, it is useful to classify the public into three groups:

- The *attentive public* consists of those who (1) express a high level of interest in a particular issue; (2) feel very well informed about the issue; and (3) read a newspaper on a daily basis, read a weekly or monthly news magazine, or read a magazine relevant to the issue.[8]
- The *interested public* consists of those who claim to have a high level of interest in a particular issue but do not feel very well informed about it.
- The *residual public* consists of those who are neither interested in nor feel very well informed about a particular issue.

Given these criteria, there is an attentive public for every policy issue. The corresponding groups differ in size and composition. For example, data for 2001 showed that, for most issues covered by the NSF survey, fewer than 10 percent of the public could be considered attentive. Local school issues had, by far, the largest audience, followed by new medical discoveries, economic and business conditions, and environmental pollution. In 2001, 31, 14, 12, and 10 percent, respectively, of all survey respondents were classified as attentive to those subjects. (See appendix table 7-7.)

Identifying the Attentive Public for S&T Issues

People likely to be attentive to S&T issues are identified by combining the attentive public for new scientific discoveries with the attentive public for new inventions and technologies. In 2001, 10 percent of the population met the criteria, down from 14 percent in 1997. In 2001, 48 percent of the population could be classified as the interested public for S&T issues; the residual public constituted 42 percent of the total. (See appendix table 7-7.)

Sex and Level of Education as Identifiers of the Attentive Public for S&T Issues

Men were more likely than women to be attentive to S&T issues. (See figure 7-3 and appendix table 7-8.) In addition, a direct correlation exists between attentiveness to S&T issues, years of formal education, and the number of science and mathematics courses completed during high school and college. In 2001, only 3 percent of people lacking high school diplomas were classified as attentive to S&T issues, compared with 23 percent of those who had graduate and/or professional degrees. Similarly, 7 percent of those having limited coursework in science and mathematics were attentive to S&T issues compared with 18 percent of those who had completed nine or more high school and college courses in science or mathematics.

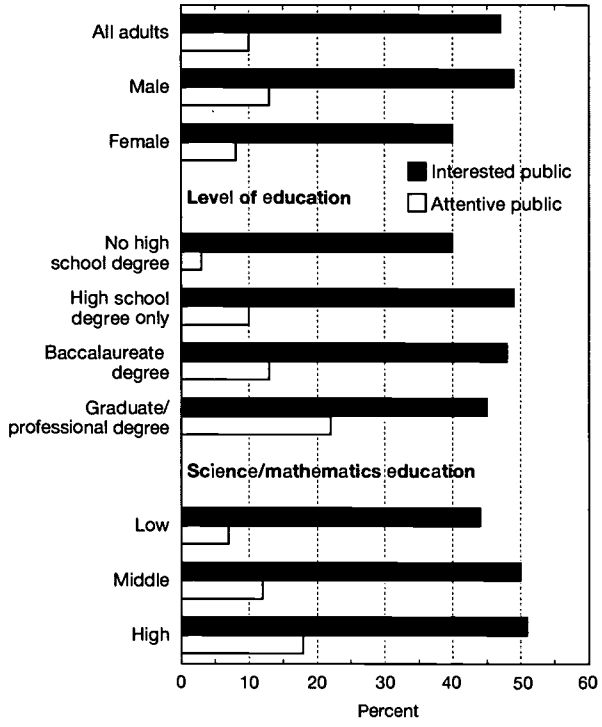
Public Understanding of S&T

Science literacy in the United States is fairly low.[9] The majority of the general public knows a little, but not a lot, about S&T. For example, most Americans know that Earth travels around the Sun and that light travels faster than sound. However, few can successfully define *molecule.* In addition, most Americans are unfamiliar with the scientific process.

[8]For a general discussion of the concept of issue attentiveness, see Miller, Pardo, and Niwa (1997).

[9]It is useful to draw a distinction between *science literacy* and *scientific literacy.* Science literacy refers to the possession of technical knowledge. In contrast, scientific literacy involves not simply knowing the facts but also thinking logically, drawing conclusions, and making decisions based on careful scrutiny and analysis of the facts (Maienschein 1999).

Figure 7-3.
Public attentiveness to science and technology issues, by sex and level of education: 2001



NOTES: "Attentive" public are people who (1) express high level of interest in a particular issue; (2) feel well informed about that issue, and (3) read a newspaper on a daily basis, read a weekly or monthly news magazine, or frequently read a magazine highly relevant to the issue. "Interested" public are people who express high level of interest in a particular issue but do not feel well informed about it. The attentive public for science and technology is a combination of the attentive public for new scientific discoveries and the attentive public for new inventions and technologies. Anyone who is not attentive to either of these issues, but who is a member of the interested public for at least one of these issues, is classified as a member of the interested public for science and technology. Survey respondents were classified as having a "high" level of science/mathematics education if they took nine or more high school and college math/science courses. They were classified as "middle" if they took six to eight such courses, and "low" if they took five or fewer.

See appendix table 7-8. *Science & Engineering Indicators – 2002*

People who have knowledge of basic science facts, concepts, and vocabulary may have an easier time following news reports and participating in public discourse on various issues pertaining to S&T. Even more important than having basic knowledge may be an appreciation for the nature of scientific inquiry. Understanding how ideas are investigated and analyzed can be valuable for staying abreast of important issues, participating in the political process, and assessing the validity of other types of information. (See "Science Fiction and Pseudoscience.") According to a science journalist:

> Without a grasp of scientific ways of thinking, the average person cannot tell the difference between science based on real data and something that resembles science—at least in their eyes—but is based on uncontrolled experiments, anecdotal evidence, and passionate assertions...[W]hat makes science special is that evidence has to meet certain standards (Rensberger 2000, p. 61).

The NSF survey contains a series of questions designed to assess public knowledge and understanding of basic science concepts and terms. The survey includes 18 such questions: 13 true or false, 3 multiple choice, and 2 open-ended questions that asked respondents to define in their own words *DNA* and *molecule*. In addition, the survey includes questions designed to test public understanding of the scientific process, including knowledge of what it means to study something scientifically, how experiments are conducted, and probability.

Understanding Science Facts, Concepts, and Vocabulary

The percentage of correct responses to most of the NSF survey questions pertaining to basic science facts, concepts, and vocabulary has remained nearly constant. (See appendix table 7-9.) For example, more than 70 percent of those surveyed knew that:

- Plants produce oxygen.
- The continents have been moving for millions of years and will continue to move.
- Light travels faster than sound.
- Earth goes around the Sun (and not vice versa).
- Not all radioactivity is manmade.

In contrast, about half the respondents knew that:

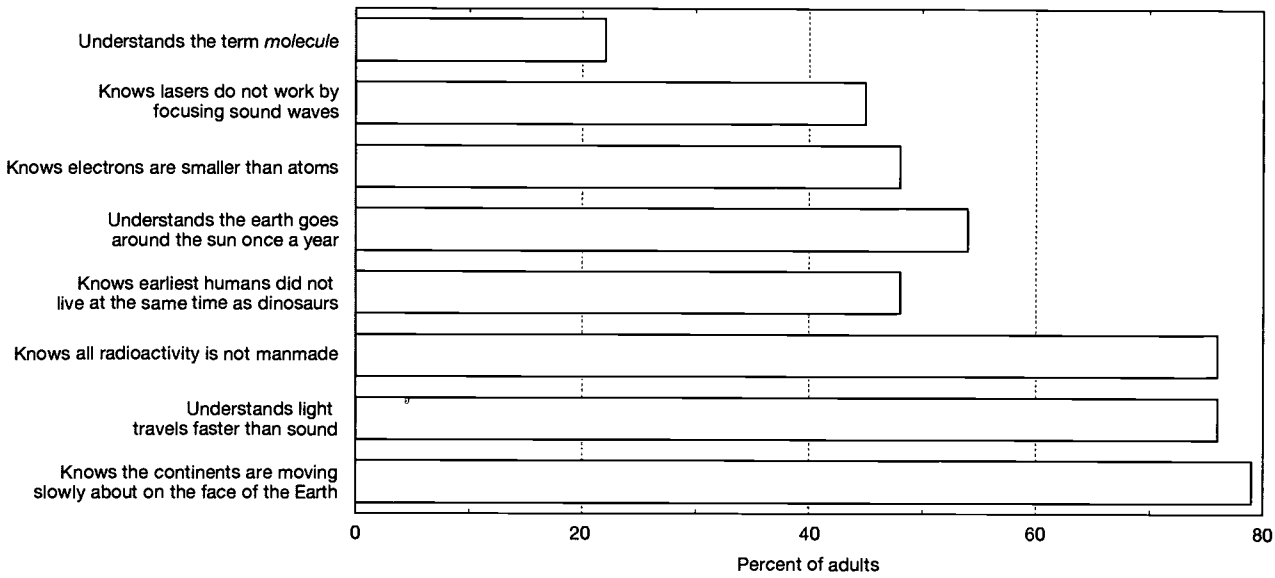
- The earliest humans did not live at the same time as dinosaurs.
- It takes Earth one year to go around the Sun.
- Electrons are smaller than atoms.
- Antibiotics do not kill viruses.
- Lasers do not work by focusing sound waves. (See figure 7-4 and appendix table 7-10.)

A strong, positive relationship exists between number of correctly answered questions and level of formal education, number of science and mathematics courses completed, and attentiveness to S&T. For example, those who did not complete high school answered an average of 50 percent of the questions correctly compared with scores of 63 percent for high school graduates, 77 percent for college graduates, and 80 percent for those who earned graduate or professional degrees. (See appendix table 7-9.)

In addition, only 22 percent of respondents were able to define *molecule*, and 45 percent gave an acceptable definition for *DNA*.[10] Although the percentage of correct responses

[10]These percentages are higher than those recorded in past NSF surveys. The increase may be attributable to a different technology being used to record responses to open-ended questions. For the first time, in 2001, respondents' answers were recorded on audiotape instead of being manually typed into a computer by the interviewer. Thus, the coders worked from sound files of actual responses rather than hand-typed text. Probably as a result of having more complete information from each respondent, more respondents were classified as having provided an acceptable definition of these terms. See Miller and Kimmel (2001) and Duffy, Muzzy, and Robb (2001).

Figure 7-4.
Public understanding of scientific terms and concepts: 2001



See appendix table 7-10.

Science & Engineering Indicators – 2002

to these questions was considerably lower than that for most of the short-answer questions, it is noteworthy that the percentage of correct responses increased in the late 1990s.

A higher percentage of men than women answered every question but three correctly. The gender gap was 20 or more points for four questions:

- Lasers work by focusing sound waves (61 percent of men compared with 30 percent of women).
- Light travels faster than sound (89 percent of men compared with 65 percent of women).
- Earth takes one year to go around the Sun (66 percent of men compared with 42 percent of women).
- Earth goes around the Sun and not vice versa (86 percent of men compared with 66 percent of women).

More women than men answered the following questions correctly:

- The father's gene decides whether the baby is a boy or a girl (72 percent of women compared with 58 percent of men).
- Antibiotics do not kill viruses (55 percent of women compared with 46 percent of men).

For the first time, a majority of all survey respondents answered the antibiotic question correctly (although a majority of men missed it). The growing resistance of bacteria to antibiotics has received widespread media coverage during the past few years. In identifying the main cause of the problem, the overprescribing of antibiotics, it is almost always mentioned that antibiotics are ineffective in killing viruses. In addition, parents of young children, especially those prone to ear infections, have been warned by their pediatricians about this problem. Although the message still has not reached a large segment of the population, the percentage of those answering correctly has been rising, from 40 percent in 1995 to 51 percent in 2001.

During most of the 20th century, probably the most contentious issue in science teaching has been whether evolution is taught or not taught in U.S. public school classrooms. The latest major dispute in this long-running battle was the Kansas State Board of Education's 1999 decision to delete evolution from the state's science standards. This event received widespread coverage in the press and sparked an outcry in the science community.[11] In addition, most of the public was not happy with the decision; 60 percent of Americans were opposed to the school board's action.[12] Moreover, most Kansans also felt the same way.[13] Thus, it was not too surprising when two board members who had voted for the change were defeated in the next election by candidates who supported the teaching of evolution. Subsequently, the reconstituted Kansas School Board reversed the decision.

The attention received by the Kansas controversy may be responsible for a change in response to the "evolution" question. For the first time, a majority of survey respondents an-

[11]The National Science Board issued a statement in August 1999 on the Kansas action (NSB 1999).

[12]According to the results of this survey (People for the American Way Foundation 2000), opponents of the school board action were more likely to be better educated, younger, and residents of the Northeast.

[13]In an October 1999 poll, sponsored by the *Kansas City Star* and the *Wichita Eagle* (1999), 52 percent of the participants disagreed with the Kansas State Board of Education's decision; 57 percent agreed with the statement: "Students in science classes in public schools should study and be tested on the idea of evolution, the theory that living creatures have common ancestors and have changed over time."

swered *true* to the statement "human beings, as we know them today, developed from earlier species of animals," representing a major change in response to this question[14] and bringing the United States more in line with other industrialized countries in response to this question (Gendall, Smith, and Russell 1995).

Gallup polls taken during the past 20 years consistently show a plurality (45 percent in February 2001) of Americans agreeing with the statement: "God created human beings pretty much in their present form at one time within the last 10,000 years or so" (Brooks 2001).

In addition, two-thirds of those surveyed (68 percent) favor teaching this belief (known as creationism) along with evolution in public schools, although 29 percent are opposed. However, 55 percent are opposed to teaching creationism *instead* of evolution (*Gallup News Service* 2000).

A study conducted for the People for the American Way Foundation took a closer look at the question of teaching evolution and found an overwhelming majority of Americans (83 percent) agreeing that it should be taught in the classroom. However, there is also strong support for teaching creationism. A detailed breakdown of the survey findings shows a wide range of opinion on the issue:

- 20 percent favor teaching only evolution and nothing else in public schools;
- 17 percent want only evolution taught in science classes but say that religious explanations can be discussed in other classes;
- 29 percent do not have a problem with creationism being discussed in science classes but believe it should be discussed as a "belief," not a scientific theory;
- 13 percent believe that both evolution and creationism should be taught as scientific theories in science class;
- 16 percent want no mention of evolution at all;
- 4 percent are in favor of teaching both evolution and creationism but are unsure about how to do it; and
- 1 percent have no opinion (People for American Way Foundation 2000).

Understanding the Scientific Process

The NSF survey also includes questions intended to determine how well the public understands the scientific process. Respondents are asked to explain what it means to study something scientifically.[15] In addition, respondents are asked questions pertaining to the experimental evaluation of a drug and about probability.[16]

In 2001, 33 percent of respondents provided good explanations of what it means to study something scientifically.[17] A large minority (43 percent) answered the experiment questions correctly, including the question(s) that focused on the use of control groups. A majority (57 percent) answered the four probability questions correctly. (See appendix table 7-11.)

A combination of each survey participant's responses to the three items is used to estimate his or her overall level of understanding of the scientific process. To be classified as "understanding the scientific process," a respondent must answer all the probability questions correctly and either provide a "theory testing" response to the question about what it means to study something scientifically or provide a correct response to the open-ended question by explaining why it is better to test a drug using a control group. In 2001, 30 percent of respondents met these criteria. (See footnote 10, figure 7-5, and appendix table 7-11.)

Public Attitudes Toward S&T, Scientific Research, Federal Funding of Scientific Research, and Specific Science-Related Issues

In general, Americans express highly favorable attitudes toward S&T. In 2001, overwhelming majorities of NSF survey respondents agreed with the following statements:

- "Science and technology are making our lives healthier, easier, and more comfortable." (86 percent agreed and 11 percent disagreed)
- "Most scientists want to work on things that will make life better for the average person." (89 percent agreed and 9 percent disagreed)
- "With the application of science and technology, work will become more interesting." (72 percent agreed and 23 percent disagreed)
- "Because of science and technology, there will be more opportunities for the next generation." (85 percent agreed and 14 percent disagreed) (See appendix table 7-12.)

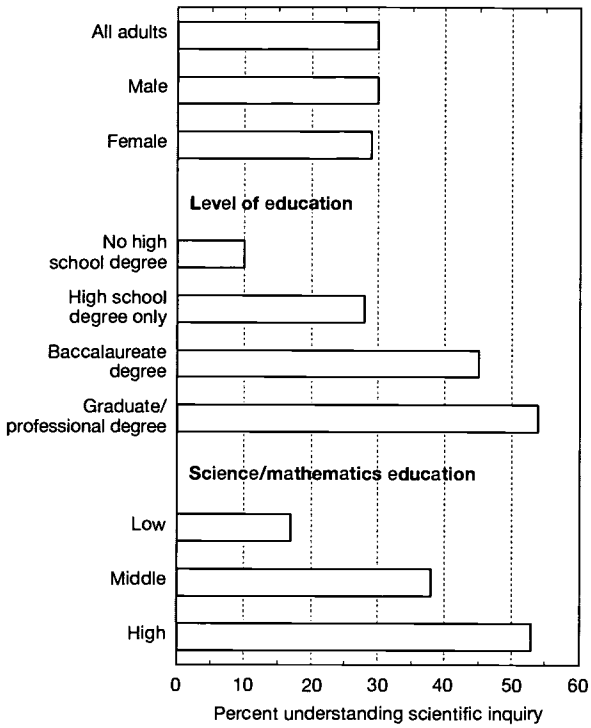
[14]For example, the comparable percentages for 1985, 1990, 1995, and 1999 were 45, 45, 44, and 45 percent, respectively.

[15]The question was: "When you read news stories, you see certain sets of words and terms. We are interested in how many people recognize certain kinds of terms, and I would like to ask you a few brief questions in that regard. First, some articles refer to the results of a scientific study. When you read or hear the term scientific study, do you have a clear understanding of what it means, a general sense of what it means, or little understanding of what it means?" If the response is "clear understanding" or "general sense": "In your own words, could you tell me what it means to study something scientifically?"

[16]The question pertaining to experimental evaluation was: "Now, please think of this situation. Two scientists want to know if a certain drug is effective in treating high blood pressure. The first scientist wants to give the drug to 1,000 people with high blood pressure and see how many experience lower blood pressure levels. The second scientist wants to give the drug to 500 people with high blood pressure, and not give the drug to another 500 people with high blood pressure, and see how many in both groups experience lower blood pressure levels. Which is the better way to test this drug? Why is it better to test the drug this way?" The text of the probability question was: "Now think about this situation. A doctor tells a couple that their 'genetic makeup' means that they've got one in four chances of having a child with an inherited illness. Does this mean that if their first three children are healthy, the fourth will have the illness? Does this mean that if their first child has the illness, the next three will not? Does this mean that each of the couple's children will have the same risk of suffering from the illness? Does this mean that if they have only three children, none will have the illness?"

[17]Correct explanations of scientific study include responses describing scientific study as theory testing, experimentation, or rigorous, systematic comparison.

Figure 7-5.
Public understanding of nature of scientific inquiry: 2001



NOTE: Survey respondents were classified as having a "high" level of science/mathematics education if they took nine or more high school and college math/science courses. They were classified as "middle" if they took six to eight such courses, and "low" if they took five or fewer.

See appendix tables 7-11. *Science & Engineering Indicators – 2002*

In addition, Americans seem to have more positive attitudes toward S&T than their counterparts in the United Kingdom and Japan.[18] (See text table 7-3.)

Despite these positive indicators, a sizable segment, although not a majority, of the public has some reservations concerning science and especially technology. For example, in 2001, approximately 50 percent of NSF survey respondents agreed with the following statement: "We depend too much on science and not enough on faith" (46 percent disagreed). In addition, 38 percent agreed with the statement: "Science makes our way of life change too fast" (59 percent disagreed). (See appendix table 7-12.)

Over time these percentages have remained nearly constant, with only slight variation from survey to survey. For example, since 1983, at least 80 percent of survey respondents have agreed that "science and technology are making our lives healthier, easier, and more comfortable." The percentages have ranged from 84 percent in 1983 and 1990 to 90 percent in 1999. Similarly, the percentage disagreeing that "we depend too much on science and not enough on faith" has ranged from 39 percent in 1985 to 48 percent in 1997. (See appendix table 7-13.)

In addition, an increasing number of people believe that the benefits of scientific research outweigh any harmful results. (See "Public Attitudes Toward Scientific Research.") The concerns that do exist are related to the effect of technology on society. For example, in 2001, a sizable minority, 44 percent, agreed with the statement that "people would do better by living a simpler life without so much technology." (See appendix table 7-14.) Also, about 30 percent of respondents agreed that "technological discoveries will eventually destroy the Earth" and that "technological development creates an artificial and inhumane way of living." (See appendix tables 7-15 and 7-16.)

The existence of public concern about the effect of technology on society does not negate the fact that the vast majority of Americans have highly favorable opinions of technology and are highly appreciative of the role of S&T in the history and economic success of the United States. Results from various surveys show the following:

- More than 90 percent think science and technology have been important "in establishing the United States' influence in the world" and "to America's economic success in the 20th century"; 60 percent think they have been very important. Also, 90 percent believe that science and technology have changed life during the past 100 years for the better, and more than 70 percent say they were more likely to vote for a candidate "who places a high priority on strengthening science and technology" (Bayer/NSF 2000).
- Eighty-nine percent think science and technology will play a major role "if life is going to be better in this country in the future (Pew Research Center for the People and the Press 1999a)." More people gave this response for science and technology than for any other item in the survey, including medical advances, which got the second highest vote of confidence. Also, the 89 percent statistic represents a substantial increase over the corresponding 77 percent recorded in the 1996 version of the survey.[19]
- Americans also believe that advancements in science and technology were the nation's and the government's greatest achievements during the 20th century. The space program tops the list of those achievements, followed by technology in general, and computers. More than 70 percent of those surveyed said that the invention of airline travel and television were a change for the better; more than 80 percent gave the same response for the highway system and computers; and more 90 percent put the automobile and radio in the "change-for-the-better" category.

[18]In a 1998 study conducted in Japan, 81 percent of those surveyed agreed that "advancements in science and technology are too rapid to keep up with," and 84 percent agreed that "science and technology can be abused or misused." The comparable percentages in 1995 were 54 and 78 percent, respectively. In addition, in 1998, only 58 percent agreed that there are more positive than negative aspects to science and technology (up from 52 percent in 1995) (Prime Minister's Office 1995; "Public Opinion Survey on Future Science and Technology" 2001).

[19]However, it should be noted that the percentage of people identifying "the pace of technological change" as a major threat to "our country's future well-being" rose from 29 percent in 1996 to 35 percent in 1999.

Text table 7-3.
International comparison of attitudes toward science and technology (S&T)

Attitude	Agree (percent) U.S. (2001)	U.K. (2000)	Japan (1995)
S&T are making our lives healthier, easier, and more comfortable.	86	67	51
In general, scientists want to make life better for the average person.	89[a]	67	45[b]
Because of S&T, there will be more opportunities for the next generation.	85	77	NA
We depend too much on science and not enough on faith	51	38	53
It is important to know about science in my daily life.	84[c]	59	71[c]
Even if it brings no immediate benefits, scientific research that advances the frontiers of knowledge is necessary and should be supported by the Government.	82[d]	72	80
Science makes our lives change too fast.	38	44	NA
The benefits of science are greater than the harmful effects.	72	43	64[e]

[a]Phrased as, "Most scientists want to work on things that will make life better for the average person."

[b]Those disagreeing that "there are a lot of scientists who have no interest in either human beings or society."

[c]Only "disagree" data available.

[d]The U.S. question refers to support by the Federal Government.

[e]Those disagreeing with the statement, "I cannot find any value in the activities of scientists and engineers."

SOURCES: This table is reproduced from The Office of Science and Technology and The Wellcome Trust report, "Science and the Public: A Review of Science Communication in the United Kingdom" (London, UK, March 2000). U.S. data have been updated from the National Science Foundation 2001 Survey of Public Attitudes Toward and Understanding of Science and Technology (Arlington, VA, 2001).

Science & Engineering Indicators – 2002

The only technologies not receiving strong public endorsement were nuclear energy and nuclear weapons. Among technologies introduced in the past decade, Americans are the most enthusiastic about communication technologies, such as email, the Internet, cellular phones, and cable TV, and the least enthusiastic about fertility drugs, Prozac, Viagra, and the cloning of sheep (Pew Research Center for the People and the Press 1999b).

♦ Eighty-seven percent agree that "technology in general makes a positive contribution to society"; only 3 percent think that it makes a negative contribution (American Association of Engineering Societies 1998).

Trends in Attitudes Toward S&T

To track trends in public attitudes toward S&T, an Index of Scientific Promise and an Index of Scientific Reservations were developed.[20] In addition, the ratio of the Promise Index to the Reservations Index is a useful indicator of current and changing attitudes toward S&T. The ratio fell from 1.46 in 1999 to 1.30 in 2001 largely because of a decline in the Index of Scientific Promise. Thus, although people still have highly positive attitudes toward S&T, their attitudes may have been somewhat less positive in 2001 than they were two years earlier. The change occurred across all education groups and among both sexes. (See appendix table 7-17.)

Public Attitudes Toward Scientific Research

An overwhelming majority of Americans consistently believe that the benefits of scientific research outweigh any harmful results. In 2001, 47 percent of NSF survey respondents said that the benefits *strongly* outweighed the harms, and 25 percent said that the benefits *slightly* outweighed the harms. These percentages have remained nearly constant during the past two

[20]The Index of Scientific Promise and the Index of Scientific Reservation are factor scores converted to a 0–100 scale. The Index of Scientific Promise includes agreement/disagreement responses to the following survey items: "science and technology are making our lives healthier, easier, and more comfortable"; "most scientists want to work on things that will make life better for the average person"; "with the application of science and new technology, work will become more interesting"; and "because of science and technology, there will be more opportunities for the next generation." The Index of Scientific Reservation includes agreement/disagreement responses to the following survey items: "we depend too much on science and not enough on faith"; "it is not important for me to know about science in my daily life"; and "science makes our way of life change too fast." A factor analysis verified the existence of a two-factor structure. The lowest possible factor score (strong disagreement with all of the items) was set to 0, and the highest possible factor score (strong agreement with all of the items) was set to 100. All factor scores between the highest and the lowest were placed on the 0–100 scale accordingly.

decades, as has the percentage of respondents taking the opposite view that the harms outweigh the benefits. However, the most recent data show the latter (which had been in the teens for most of the past two decades) declining from 15 percent in 1999 to 10 percent in 2001. Concurrently, the percentage of respondents saying the benefits were *equal* to the harmful results increased from 11 percent in 1999 to 19 percent in 2001. (See figure 7-6 and appendix table 7-18.)

Men express greater confidence than women that the benefits of scientific research outweigh the harmful results. About three-fourths of the men, compared with approximately two-thirds of the women, agreed that the benefits outweighed the harms. Level of education is also strongly associated with a positive response to this question. Those who did not complete high school were less likely than those with more formal education to believe that the benefits outweighed the harms, although it should be noted that even 55 percent of this group said the benefits outweighed the harms. The corresponding percentages for high school graduates and for those having at least a bachelor's degree were 70 and 87 percent, respectively. (See appendix table 7-18.)

Public Attitudes Toward Federal Funding of Scientific Research

All indicators point to widespread support for government funding of basic research. In 2001, 81 percent of NSF survey respondents agreed with the following statement: "Even if it brings no immediate benefits, scientific research that advances the frontiers of knowledge is necessary and should be supported by the Federal Government."[21] (See appendix table 7-19.) The level of agreement with this statement has consistently been in the 80-percent range. In 2000, 72 percent of U. K. residents agreed with the statement, as did 80 percent of Japanese residents (in 1995). (See text table 7-3.)

If the stability and lack of variation of this measure of public support for basic research are noteworthy, so is the consistently small number of people who have the opposite viewpoint. In 2001, 16 percent disagreed with the statement; the same level of disagreement had been recorded two years earlier. (See appendix table 7-20.)

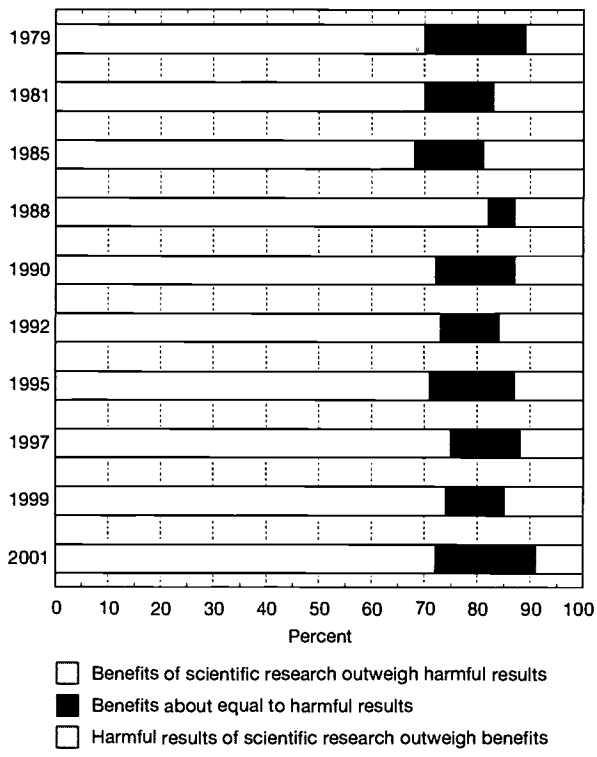
Although there is strong evidence that the public supports the government's investment in basic research, few Americans are able to name the two agencies that provide most of the Federal funds for this type of research. In a recent survey, only 5 percent identified the National Institutes of Health (NIH) as the agency that "funds most of the taxpayer-supported medical research performed in the United States," and only 3 percent named NSF as "the government agency that funds most of the basic research and educational programming in the sciences, mathematics and engineering." (Research!America 2001).[22]

In addition, those with more positive attitudes toward S&T were more likely to express support for government funding of basic research. In 2001, 93 percent of those who scored 75 or higher on the Index of Scientific Promise agreed that the Federal Government should fund basic scientific research compared with only 68 percent of those with relatively low index scores. (See figure 7-7 and appendix table 7-20.)

In 2001, only 14 percent of NSF survey respondents thought the government was spending too much on scientific research; 36 percent thought the government was not spending enough, a percentage that has grown steadily since 1990, when 30 percent chose that answer.[23] (See appendix table 7-21.) Men are more than likely than women to say the government is spending too little in support of scientific research (40 versus 33 percent in 2001). (See appendix table 7-22.)

To put the response to this item in perspective, at least 65 percent of those surveyed thought the government was not spending enough on other programs, including programs to improve health care, help senior citizens, improve education, and reduce pollution. Only the issues *space exploration* and *national defense* received less support for increased spending than scientific research.

Figure 7-6.
Public assessment of scientific research: 1979–2001



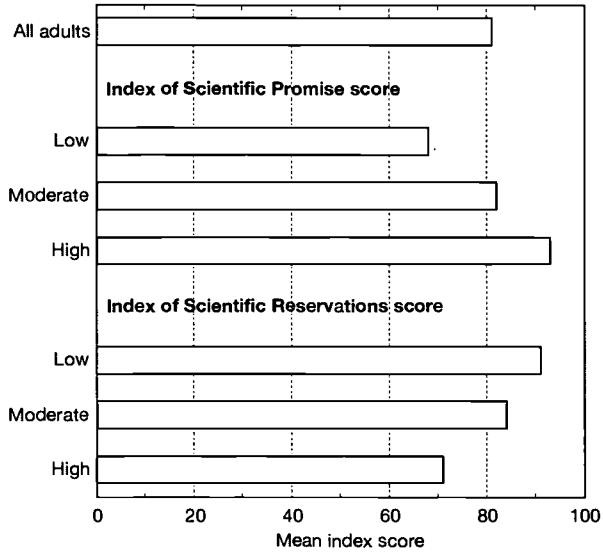
See appendix table 7-18. *Science & Engineering Indicators – 2002*

[21]Another recent poll used almost identical wording and produced a similar result: 78 percent of those surveyed agreed with the statement, 19 percent disagreed, and 3 percent were not sure. In the same poll, 86 percent felt that it was very important that the United States maintain its leadership in scientific research (Research!America 2001).

[22]In the same survey, 64 percent could name the FDA (Food and Drug Administration) and 22 percent knew the name of the CDC (Centers for Disease Control and Prevention) (Research!America 2001).

[23]In a another survey, 41 percent of respondents said they would increase spending on scientific research if they were making up the budget for the federal government; 10 percent said they would decrease spending; and 46 percent said they would keep it the same (Pew Research Center for the People and the Press 2001).

Figure 7-7.
Support for Federal governmental funding of basic scientific research, by level of general support for or reservations about science and technology: 2001



See appendix table 7-20. *Science & Engineering Indicators – 2002*

In 2001, 48 percent of those surveyed thought spending on space exploration was excessive, the highest percentage for any item in the survey—and nearly double the number of those who felt that the government was spending too much on national defense.[24] In contrast, the latter has been falling steadily, from 40 percent in 1990 to 25 percent in 2001. (See appendix table 7-21 and "Public Attitudes Toward Space Exploration.")

Sex as an Indicator of Support for Federal Funding of Scientific Research

Men express more support for Federal funding of scientific research than women. The most recent data show that 86 percent of men and 77 percent of women who responded to the survey agreed that the Federal Government should support basic research. (See appendix table 7-19.)

Level of Education as an Indicator of Support for Federal Funding of Scientific Research

Support for federally funded basic research is tied to education level. In 2001, about 80 percent of those surveyed who had not completed college agreed that the Federal Government should support scientific research compared with about 90 percent of those who had completed college. (See appendix table 7-19.)

[24]CNN/USA Today/Gallup polls show Americans having generally positive views of NASA but little interest in increasing the agency's budget. In December 1999, 16 percent of those surveyed thought NASA's funding should be increased, 49 percent thought it should remain at the current level, and 24 percent thought it should be reduced. In addition, 10 percent thought that funding for the space program should be eliminated entirely. Since Gallup began surveying the public about this subject (in 1984), no more than a quarter of those surveyed have favored an increase in NASA's budget (Carlson 2001).

Public Attitudes Toward Specific Science-Related Issues

Public Attitudes Toward Genetic Engineering

There is no question that genetic engineering has become a hot issue. From the nationwide recall of taco shells containing an unapproved form of genetically modified corn to scientists promising to clone humans in the not-too-distant future, genetic engineering has been the source of a growing number of concerns in recent years. Americans, like their counterparts in other countries, have been trying to understand and weigh the risks and benefits of this issue. In the case of agricultural products, the benefits of expanded yields, reduced perishability, and decreased need for chemical pesticides have been counterbalanced by perceived health and environmental risks and a threat to consumers' ability to make choices about what they eat (Hopkin 2001).

The conventional wisdom that biotechnology[25] is not a contentious issue, including the assumption that opposition is limited to an extremist "fringe," may no longer be true (Priest 2000). The battle for the hearts and minds of the American public is certainly under way:

- Media coverage of agricultural biotechnology increased more than eightfold between 1997 and 2000 (Shanahan, Scheufele, and Lee 2001).
- The PBS documentary series *Frontline* produced "Harvest of Fear," a two-hour special on the subject that aired in April 2001. (See <http://www.pbs.org/wgbh/harvest>.)
- The Biotechnology Association of America spent $7.5 million on political advertising in 2000, more than any other special interest group except one (Goldstein 2001).

Despite the exposure of this issue in the media, the most recent data show that 70 percent of the public consider themselves "not very well informed" or "not informed at all" about modern biotechnology; the corresponding statistic for Europeans is 80 percent (Priest 2000, Gaskell et al. 2000). Available data, however, indicate that awareness is increasing (Shanahan, Scheufele, and Lee 2001).

Even though most people do not consider themselves well informed about biotechnology, there is no shortage of researchers studying public opinion, including an international effort to compare attitudes in the United States, Europe, and Canada (Gaskell and Bauer 2001).[26] In the 2000 U.S. survey, participants were asked to assess six biotechnology applications, which are listed here in rank order from the one receiving the least opposition to the one receiving the most: genetic testing for inherited disease, engineering of bacteria to pro-

[25]Throughout this chapter, the terms *genetic engineering* and *biotechnology* are used interchangeably. A distinction is maintained only to reflect the specific term used in a particular survey and/or by a particular author.

[26]The 1997 U.S. survey was conducted by Jon D. Miller, Chicago Academy of Sciences, and the 2000 U.S. survey was conducted by Susanna Priest, Texas A&M University. The 1996 and 1999 Canadian surveys were conducted by Edna Einsiedel, University of Calgary. The 1997 and 1999 European studies were undertaken by George Gaskell, Martin Bauer, and Nick Alum for the European Commission.

duce pharmaceuticals, genetic engineering of pest-resistant crops, food biotechnology, organ transplants, and animal cloning. In the European survey, genetically modified (GM) food received more negative responses than any other application. (See sidebar "Public Attitudes Toward Biotechnology.")

The 2001 and earlier NSF surveys suggest that the American public is somewhat ambivalent about genetic engineering. Although the evidence is not entirely conclusive, the NSF surveys show the following:

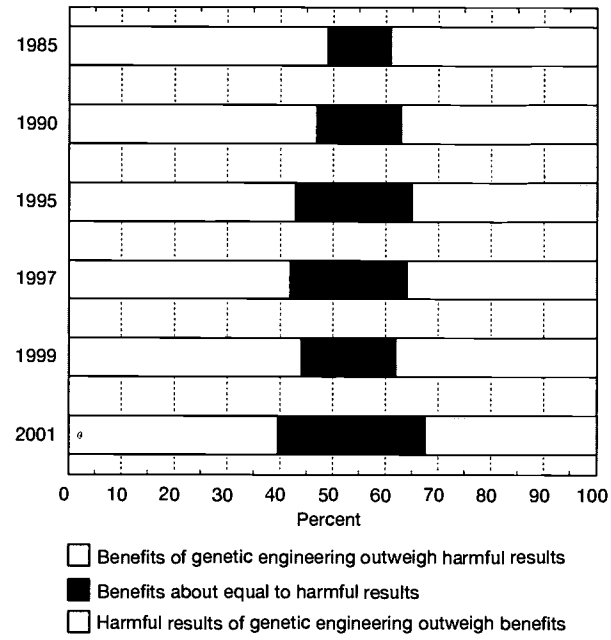
- Support for genetic engineering has never been very high. That is, in no year has a majority of respondents agreed that the benefits outweigh the harmful results.
- Support for genetic engineering has gradually declined during the past 15 years. In 2001, 40 percent of those surveyed thought the benefits outweighed the harms, down from 49 percent in 1985.

The ambiguity in the survey results becomes apparent when one looks at the data on the number of people who think the harms outweigh the benefits. This statistic has also declined in most years, from 39 percent in 1985 to 33 percent in 2001. Consequently, the declining numbers in both the benefits-greater-than-harms and harms-greater-than-benefits categories was offset by a growing number of respondents who think the benefits are equal to the harms. The percentage in this group grew from 12 percent in 1985 to 28 percent in 2001.[27] (See figure 7-8 and appendix table 7-23.)

Men have always had more favorable attitudes than women toward genetic engineering. The gender gap has usually been at least 10 points. In 2001, 45 percent of men and 34 percent of women responding to the survey said that the benefits of genetic engineering outweighed the harmful results. (See appendix table 7-23.)

College graduates are more likely than high school graduates to tout the benefits of genetic engineering. That is, they are both more likely than others to believe that the benefits are greater than the harms and less likely to say that the harms outweigh the benefits.[28] In 2001, 48 percent of survey respondents who had earned college degrees agreed that the benefits outweighed the harms compared with 37 percent of those who had earned only high school degrees and 39 percent of those who had not graduated from high school. Also, 25 percent of the college graduates thought the harms outweighed the benefits compared with 36 percent of high school graduates. The drop in support for genetic engineering during the past 15 years occurred among both high school and college graduates.

Figure 7-8.
Public assessment of genetic engineering: 1985–2001



See appendix table 7-23. *Science & Engineering Indicators – 2002*

Until 2001, the majority (at least 60 percent) of people classified as attentive to science and technology (who may or may not be college graduates) agreed that the benefits of genetic engineering outweighed the harmful results. This statistic dropped from 64 percent in 1999 to 49 percent in 2001. In addition, there was a substantial increase in those saying the harmful results outweighed the benefits, from 20 percent in 1995 to 30 percent in 2001.

Public Attitudes Toward Space Exploration

Public support for space exploration rose during the 1990s, then slipped in 2001. The most recent data show 45 percent of the public agreeing that the benefits of space exploration outweigh the costs, down from 49 percent in 1999. Not since 1985 (before the *Challenger* accident), have more than 50 percent of respondents to NSF's public attitudes survey stated that the benefits of the space program exceeded the costs. The drop in support during the mid-1980s, from 54 percent in 1985 to 47 percent three years later, was particularly dramatic. NSF survey data suggest that most of the public is having difficulty recognizing the benefits of the space pro-

[27]Other researchers have noted that survey participants "have seen more and more risks in agricultural biotechnology as time goes by" and that "the use of biotechnology or genetic modification in food production seems much more acceptable to the public when it is used to enhance food safety than when it is used to improve food quality" (Shanahan, Scheufele, and Lee 2001). In response to one survey, the percentage of people who said that biotechnology would provide benefits for themselves and their families within the next five years fell from 78 percent in March 1997 to 63 percent in October 1999, and 59 percent in May 2000. However, this statistic rose to 64 percent in January 2001 (International Food Information Council 2000). In response to yet another survey, conducted in July 2001, 30 percent of those surveyed thought that foods that have been produced using biotechnology pose a serious health hazard to consumers. The same survey showed that 52 percent of respondents supported the use of biotechnology in agriculture and food production; surveys conducted in 2000 and 1999 produced similar statistics—48 and 51 percent, respectively (Saad 2001).

[28]Another survey produced similar findings (for food biotechnology)—those who did not complete college were less likely than those with college and postgraduate degrees to support biotechnology in food production. For example, 65 percent of those with graduate degrees reported that they supported the technology compared with 59 percent of those with just college degrees, 54 percent of those with some college, and 44 percent of those who had never attended college (Saad 2001).

Public Attitudes Toward Biotechnology

Anti-biotechnology sentiments are much more common in Europe than in the United States.* In addition, the number of people harboring negative attitudes toward biotechnology has increased in both Europe and Canada during the past few years, especially when compared with attitudes in the United States. These are the latest findings from a recent international study conducted in the United States, Europe, and Canada (Gaskell and Bauer 2001; Miller et al. 1999).**

Assessment of Selected Biotechnology Applications

The 1999 and 2000 surveys, which replicate earlier ones conducted in 1996 and 1997, asked respondents to assess the usefulness, risk, and moral acceptability of several applications of biotechnology and to indicate whether they would encourage the use of each application.

Two sets of questions pertained to agricultural applications of biotechnology, including genetic engineering of:

- foods, for example, to make them higher in protein, increase their shelf-life, or improve their taste, and
- crops, for example, to make them more resistant to insect pests.

The three surveys show that Europeans have the least favorable attitudes toward these applications and Americans have the most favorable attitudes, with Canadians placing somewhere in between. For example, in 2001:

- 46 percent of Europeans agreed that genetically modified (GM) food was useful, compared with 57 percent of Canadians and 69 percent of Americans;
- 60 percent of the Europeans agreed that GM food was risky; the corresponding percentages for Canadians and Americans were 58 and 49 percent, respectively;
- only 40 percent of Europeans said that GM food was morally acceptable compared with 55 percent of Canadians and 60 percent of Americans; and
- only 34 percent of Europeans would encourage the production of GM food compared with 48 percent of Canadians and 58 percent of Americans.†

The pattern of responses was similar for attitudes toward GM crops and other plants, although the results reflected somewhat more support for this application of biotechnology. (See figure 7-9.)

What is particularly noteworthy about these data is that they indicate a dramatic drop in support in both Europe and Canada since the surveys were conducted in 1996. In contrast, attitudes in the United States toward GM foods are almost identical to those in 1997, with one slight exception: the proportion of U.S. survey respondents agreeing that GM foods are morally acceptable dropped from 65 percent to 60 percent between 1997 and 2000.‡ Consequently:

- the gap in attitudes between Europeans and Americans, which was not particularly large in the mid-1990s, is now quite wide, and
- Canadians and Americans, who used to harbor similar attitudes, no longer do so; Canadian attitudes now more closely resemble those of Europeans.

The international study included questions pertaining to the following medical applications of biotechnology:

- introducing human genes into bacteria to produce medicines or vaccines (for example, to produce insulin for diabetics), and
- using genetic testing to detect inherited diseases.

Attitudes toward these two medical applications in all three regions were more positive than those for the two agricultural applications. For example, more than 80 percent of Americans and Canadians and 70 percent of Europeans agreed that introducing human genes into bacteria to produce medicines or vaccines was useful. Similarly, at least 75 percent of Americans and Canadians and almost 60 percent of Europeans thought this application was morally acceptable and should be encouraged. However, a pattern similar to that for the agricultural applications should be noted. Between 1997 and 2000, U.S. support for introducing human genes into bacteria to produce medicines and vaccines remained strong while Eu-

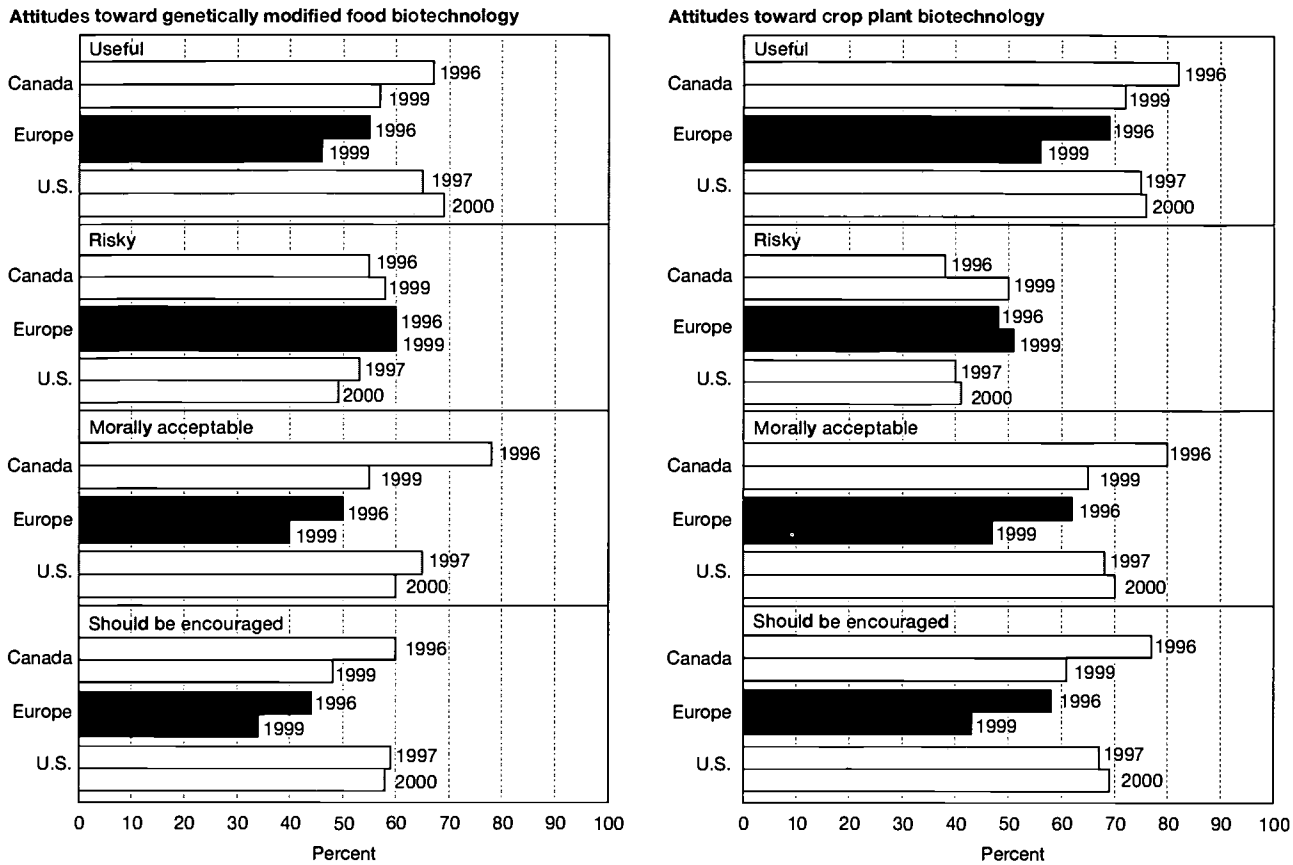
*In the view of a longtime observer of European culture and politics, Europeans seem to be more fearful than Americans of perceived health risks associated with new technologies. Concerns that seem to cause much more consternation in Europe than in the United States—in addition to those about genetically modified organisms (GMOs)—are pork and beef raised with growth hormones; phthalates in plastic toys; measles, mumps, and rubella vaccine; cellular phones; and "economy-class syndrome." The recent experience with bovine spongiform encephalopathy (BSE) or "mad cow" disease, a real health risk, seems to have affected trust in the rest of the food supply, especially anything resulting from new technologies such as GMOs. In addition, there is also an anti-American aspect to the situation. Because American companies are the source of many of the new technologies: "[T]he negative response may tie in with the aversion to globalization among the working class and the anti-Americanism that is never far from the surface among Europe's intelligentsia. People think GMO crops...all come from the U.S." (Reid 2001).

**Seventeen countries were included in the European study, and it should be noted that negative attitudes were more prevalent in some countries than others. (See Gaskell and Bauer 2001.)

†In response to the 2001 NSF survey, 61 percent said that they supported GM food production; 36 percent said that they were opposed. Men (70 percent), college graduates (68 percent), and those classified as attentive to science and technology were more likely than others to favor this application of biotechnology. (See appendix table 7-24.)

‡The 2000 U.S. survey showed that genetically engineered food was of less concern to those surveyed than all other areas of food-related concern, such as bacterial contamination, the use of artificial preservatives, poor nutritional quality, the use of chemical pesticides, diseases from animals that pass to humans, and general food safety (Priest 2000).

Figure 7-9.
Attitudes toward genetcally modified food and crop biotechnologies in Canada, Europe, and the United States



SOURCES: Gaskell, G., and Bauer, M.W. (editors) *Biotechnology 1996–2000,* National Museum of Science and Industry (U.K.) and Michigan State University Press. The 1999 and 2000 surveys were conducted by George Gaskell, Martin Bauer, and Nick Alum for the European Commission; Susanna Priest, Texas A&M University; and Edna Einsiedel, University of Calgary. The 1997 U.S. survey was conducted by Jon D. Miller, Chicago Academy of Sciences.

Science & Engineering Indicators – 2002

ropean and Canadian support declined. (See figure 7-10.)

Using genetic testing to detect inherited diseases has the most support across all three regions. For example, at least 80 percent of those surveyed in Canada and the United States agreed that this application was useful and its use should be encouraged.* Moreover, support increased in recent years in both countries. In contrast, it fell in Europe during the same period. In other words, although the residents of all three regions shared similar (highly supportive) sentiments in 1996 and 1997, that is no longer the case. In 1999, 74 percent of Europeans agreed that genetic testing was useful, down from 83 percent in 1996. In addition, 65 percent of Europeans said its use should be encouraged, down from 76 percent in 1996. (See figure 7-10.)

The 1999/2000 surveys also asked respondents in all three regions to assess the usefulness, risk, and moral acceptability of "cloning animals such as sheep whose milk can be used to make drugs and vaccines." Nearly half (47 percent) of European respondents agreed this that application was useful compared with 57 percent of Canadians and 61 percent of Americans. Similarly, only 36 percent of Europeans thought that this application was morally acceptable and would encourage its use, compared with just less than 50 percent of Americans and Canadians.† However, more Americans and Canadians (58 and 61 percent, respectively) than Europeans (54 percent) assigned risk to the use of this application.

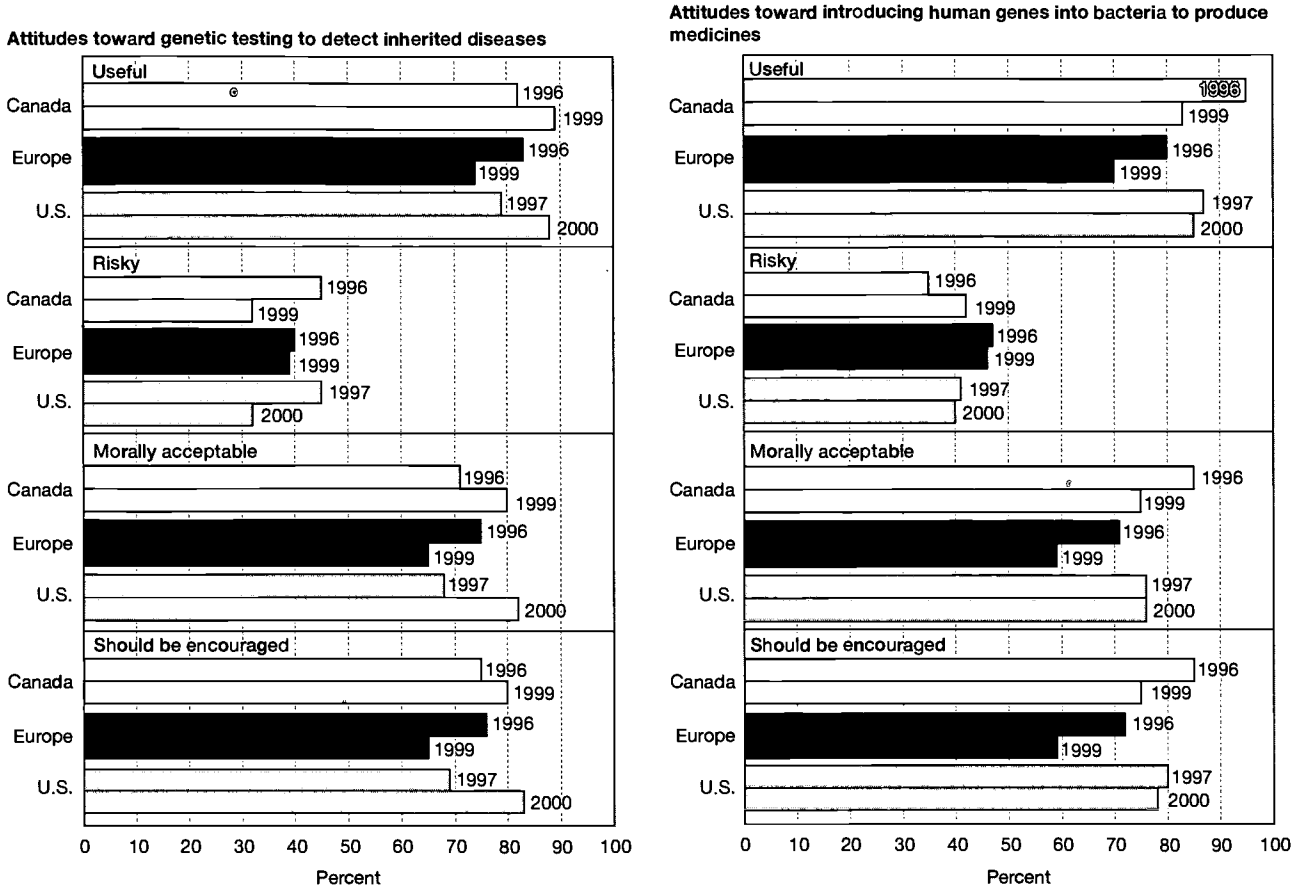
In response to a Gallup poll, 90 percent of those surveyed opposed human cloning and 64 percent opposed animal cloning (Carroll 2001). Support for animal cloning varied by education, income, sex, age, and religion. For example:

- A majority (56 percent) of those having postgraduate education and 52 percent of those having annual in-

*In response to the 2001 NSF survey, 89 percent said that they supported genetic testing to detect inherited diseases; 9 percent were opposed. (See appendix table 7-24.)

†In response to the 2001 NSF survey, 47 percent said that they supported cloning animals; 48 percent were opposed. (See appendix table 7-24.)

Figure 7-10.
Attitudes toward genetic testing and medicine production in Canada, Europe, and the United States



SOURCES: Gaskell, G., and Bauer, M.W. (editors) *Biotechnology 1996–2000*, National Museum of Science and Industry (U.K.) and Michigan State University Press. The 1999 and 2000 surveys were conducted by George Gaskell, Martin Bauer, and Nick Alum for the European Commission; Susanna Priest, Texas A&M University; and Edna Einsiedel, University of Calgary. The 1997 U.S. survey was conducted by Jon D. Miller, Chicago Academy of Sciences.

Science & Engineering Indicators – 2002

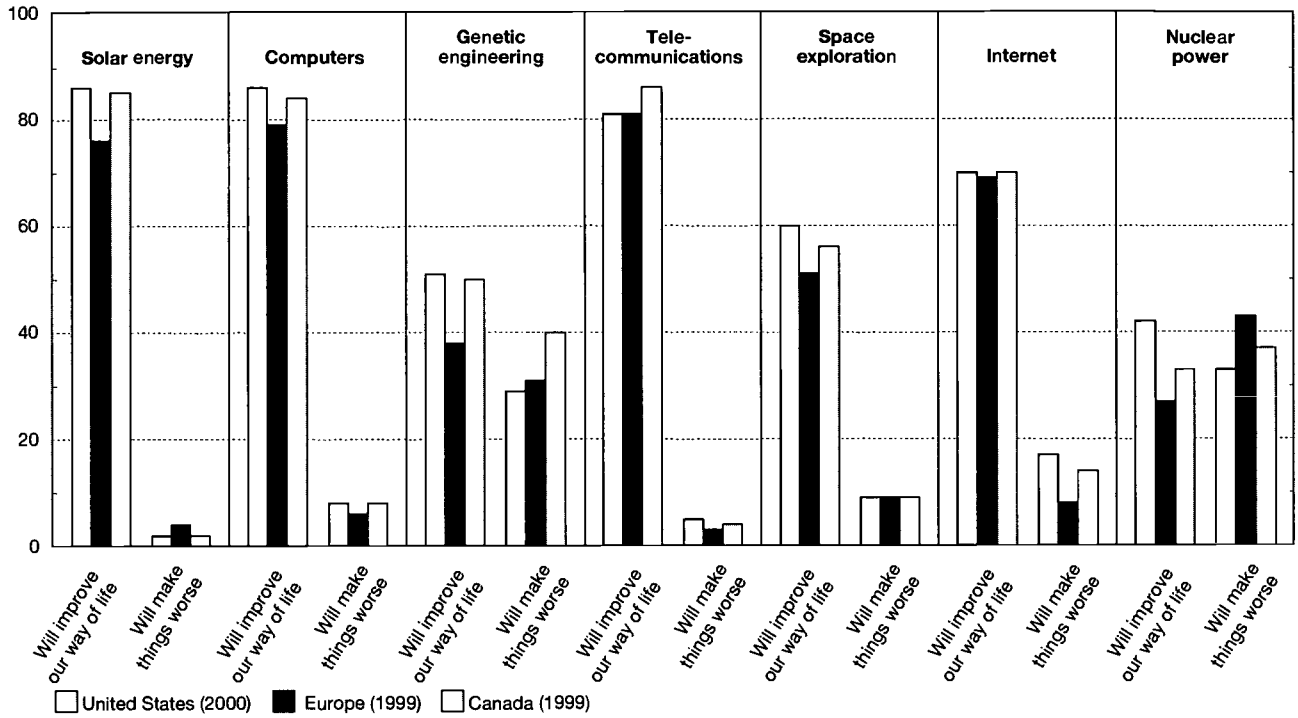
comes above $75,000 said that cloning animals should be allowed. Only 19 percent of those having a high school education or less and 14 percent of those earning less than $20,000 annually shared the same view.

- Seventy-four percent of women but only 53 percent of men opposed animal cloning.
- Seventy-eight percent of those over age 65 opposed animal cloning.
- Only 22 percent of those who said that religion was very important in their lives favored animal cloning compared to 40 percent of those who said that religion was "fairly" important. A majority of those who said that religion was not very important in their lives favored animal cloning.

In response to another poll conducted in early 2001, 90 percent of those surveyed said that it was a bad idea to clone human beings (the corresponding statistic for 1997 was 93 percent) (Time/CNN 2001). Survey respondents cited the following reasons for their opposition to cloning humans: cloning violates their religious beliefs (34 percent), cloning interferes with human distinctiveness and individuality (22 percent), cloning could be used for questionable purposes like breeding a superior race or cloning armies, and cloning is dangerous (14 percent).

The public is somewhat more accepting of human cloning to help infertile couples. In response to one poll, 71 percent said that cloning a human was unethical, but 40 percent thought it would be okay to use cloning to help infertile couples (*Popular Science* 2000). In response to another poll, 20 percent said that cloning would be okay to help infertile couples to have children without having to adopt (76 percent were opposed) (Time/CNN 2001).

Figure 7-11.
Public attitudes toward selected technologies in the United States, Europe, and Canada



SOURCES: Gaskell, G., and Bauer, M.W. (editors) *Biotechnology 1996–2000,* National Museum of Science and Industry (U.K.) and Michigan State University Press. The 1999 and 2000 surveys were conducted by George Gaskell, Martin Bauer, and Nick Alum for the European Commission; Susanna Priest, Texas A&M University; and Edna Einsiedel, University of Calgary.

Science & Engineering Indicators – 2002

Public Perceptions of Selected Technologies, Including Biotechnology

In response to the 1999/2000 surveys, 51 percent of Americans thought that genetic engineering would "improve our way of life in the next 20 years." The corresponding statistics for Europe and Canada were 38 and 50 percent, respectively. However, a sizable minority of Americans (29 percent) said the opposite, that genetic engineering would "make things worse" over the next 20 years compared with 31 percent of Europeans and 40 percent of Canadians. (See figure 7-11.)

How do these statistics compare with those for attitudes toward other technologies? In all three surveys, biotechnology ranked sixth among the technologies respondents were asked about. Only nuclear energy had a lower score, with less than half (42 percent of Americans, 33 percent of Canadians, and 27 percent of Europeans) saying that nuclear energy would improve our way of life in during the next two decades.

In other words, with respect to technologies that will "improve our way of life in the next 20 years," computers and information technology, solar energy, telecommunications, the Internet, and even space exploration received substantially higher numbers of positive responses than biotechnology did. More than 80 percent of Americans and Canadians said that solar energy, computers, and telecommunications would improve our way of life in the next 20 years. The corresponding European percentages were somewhat lower, but still greater than 70 percent. In addition, approximately 70 percent of Americans, Canadians, and Europeans each thought that the Internet would improve their lives during the next 20 years. The corresponding percentages for space exploration ranged from 51 percent (Europeans) to 60 percent (Americans).

Americans, Canadians, and Europeans Take a Pop Quiz on Biotechnology

Americans and Canadians may know more about the science of biotechnology than their European counterparts. On a 10-question quiz, Americans and Canadians averaged 6.2 and 6.1 correct responses, respectively, compared with the European average of 5.4.

One question on this quiz is mentioned just about every time this subject is discussed. Respondents were asked whether the following statement is true or false: "Ordinary tomatoes do not contain genes, while genetically modified tomatoes do."

Less than 50 percent of respondents in all three groups answered this question correctly. That is, 44 percent of

Americans and Canadians and 40 percent of Europeans gave the right answer, which is "false."*

In response to another question, 47 percent of Americans knew that more than half of human genetic makeup is identical to that of chimpanzees (actually it is closer to 98 percent).† Canadians and Europeans did somewhat better than Americans in answering this question correctly, with slight majorities, 52 and 51 percent, respectively, providing the correct answer.

The most difficult question on the quiz was: "Animal genes cannot be transferred into plants."

More Canadians (43 percent) answered correctly ("false") than Americans (36 percent) or Europeans (30 percent).

In the United States (and Canada) opposition to biotechnology does not seem to be related to science literacy or level of formal education. The opposite is true in Europe. That is, in Europe, better educated groups were markedly more positive about encouraging the use of biotechnology than less-educated groups (Priest 2000).

However, those in the United States with extensive university-level science training (those who remember having taken six or more courses in science) were more positive about all six biotechnology applications included in the survey. This difference in support between those with a lot of science education and those without can be seen most clearly in data for the two most controversial applications in the United States: cloning and organ transplants (Priest 2000).

Labeling Issue and Trust in Groups With a Stake in Biotechnology

In spring 2000, various environmental organizations such as the Sierra Club, Friends of the Earth, the Natural Resources Defense Council, Public Citizen, and the Humane Society put together a petition demanding that GM foods be taken off the shelf until they are tested for safety and labeled. Along with health and environmental concerns, labeling is another biotechnology issue that has received an increasing amount of attention in recent years. Data collected with the U.S. biotechnology survey revealed a substantial amount of concern about a lack of government regulation. In other words, the public is concerned about whether the regulatory system functions adequately in this new area (Priest 2000).

Although Americans have been eating food containing GM ingredients for many years, they have been unaware of that fact. Most Americans do not know that the government does not require labels on food to identify GM ingredients.‡ However, most think this type of labeling should be required. Around 85 percent of those surveyed in 1999 and 2000 agreed that the Food and Drug Administration (FDA) should require labeling on all fruits, vegetables, or foods that have been genetically altered (Shanahan, Scheufele, and Lee 2001). About the same percentage agreed that:

> Simply labeling products as containing biotech ingredients does not provide enough information for consumers. It would be better for food manufacturers, the government, health professionals, and others to provide more details through toll-free phone numbers, brochures, and websites.

In the United States, scientists are considered more competent and trustworthy than any other group involved in biotechnology. Scientists received more votes of confidence than the Department of Agriculture, farm groups, the FDA, or the U.S. Environmental Protection Agency. Environmental groups ranked next to last and major biotechnology companies ranked lowest in terms of competence and trustworthiness (Jenkins-Smith et al. 2001).

*In a more recent survey conducted in the United States, 58 percent of the participants provided the correct answer (Jenkins-Smith et al. 2001).

†In a more recent survey conducted in the United States, 55 percent of the participants provided the correct answer (Jenkins-Smith et al. 2001).

‡Approximately one-third (34 percent) of those surveyed answered "false" to the statement, "U.S. regulations require labels to identify any food that contains genetically modified ingredients" (Jenkins-Smith et al. 2001).

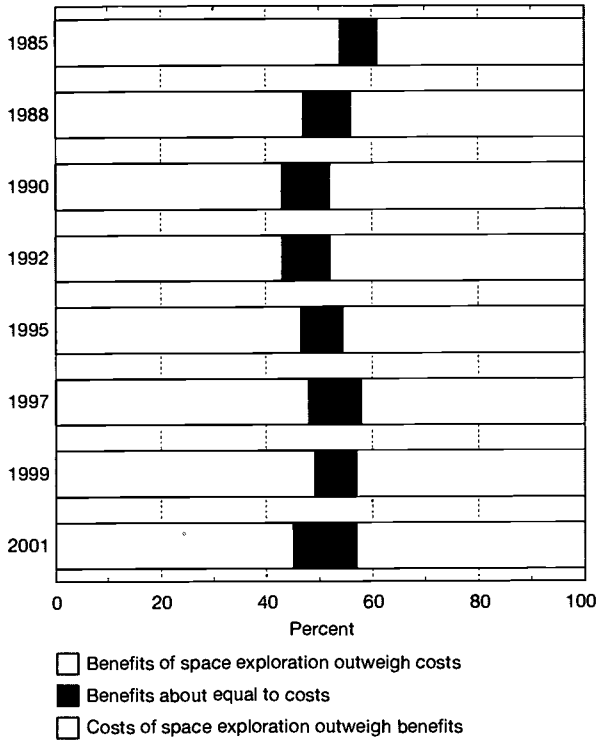
gram. The effects of the Challenger accident (and other mishaps, such as the loss of the billion-dollar Mars *Observer*) are still being felt, and even NASA's recent successes, such as Senator John Glenn's return to space on the space shuttle Discovery in late 1998, have not provided a lasting boost to public opinion. (See figure 7-12 and appendix table 7-25.)

Another survey series (Carlson 2001) has been tracking Americans' views of NASA. In late 1999, 53 percent of those surveyed described NASA's job performance as excellent or good; 43 percent gave the agency a fair or poor rating. In contrast, 76 percent rated NASA's performance as excellent or good following John Glenn's return to space in 1998. The lowest performance rating in this survey series was recorded in September 1993. At that time, only 43 percent thought that NASA's performance was excellent or good.

Like other issues, space exploration receives differing levels of support from men and women. Men are much more likely than women to champion the benefits of space exploration. In every year but two (1990 and 1992), a majority of men responding to the survey agreed that the benefits outweighed the costs, while 40 percent of women held this view. In contrast, during the late 1980s and early 1990s, 50 percent or more of women responding to the survey thought that the costs exceeded the benefits. This is no longer true; in 2001, 45 percent of women thought that the costs outweighed the benefits.

People who have more formal education are more likely than others to say that the benefits of space exploration exceed the costs. In 2001, only 33 percent of respondents lacking a high school education agreed that the benefits outweighed the costs compared with 44 percent of those who had graduated from high school and 55 percent of those who had a bachelor's or higher degree.

Figure 7-12.
Public assessment of space exploration: 1985–2001



See appendix table 7-25. *Science & Engineering Indicators – 2002*

Those identified as attentive to S&T or space exploration are more likely than the public at large to believe that the benefits exceed the costs. In 2001, at least 60 percent of each attentive group put the benefits ahead of the costs compared with less than 50 percent of the public at large.

Public Attitudes Toward Use of Animals in Scientific Research

Few issues in science are as divisive as the use of animals in scientific research. (See appendix tables 7-26 and 7-27.)[29]

Public attitudes toward research using animals are shaped by:

- **The purpose of the research.** Using animals in research to fight diseases such as cancer and AIDS draws less opposition than using animals to test cosmetics.
- **The type of animal.** The public tolerates the use of mice in scientific experiments to a greater degree than the use of dogs and chimpanzees.[30]
- **The existence of alternatives, such as computer simulations.** When researchers can meet their goals without using animals, the public opposes the use of animals (Kimmel 1997).

Data from the NSF surveys and those conducted by other organizations show the following:

- In 2001, 52 percent opposed research using dogs and chimpanzees.
- Compared with the citizens of other industrialized nations, Americans are more supportive of animal research (Kimmel 1997).

In addition, attitudes toward the use of animals in research continue to depend on the sex and age of the respondent. Women are far more likely than men to say they are opposed to the use of dogs and chimpanzees in scientific research. In 2001, 62 percent of women surveyed voiced opposition, but only 40 percent of men held the same view. (See appendix table 7-27.) This gender gap in opinion cannot be attributed to differences between the sexes in science and mathematics education or differences in science literacy (Kimmel 1997). In 2001, the majority of people 54 years of age and younger opposed the use of dogs and chimpanzees in scientific research, whereas a majority of those 65 and older were supportive. (See appendix table 7-27.)

Public Attitudes Toward Global Warming

Americans seem to be listening to what scientists and others have been saying about global climate change.[31] Data from the 2001 NSF survey show that 88 percent of the public had heard of global warming, and of those, 77 percent believed that "increased carbon dioxide and other gases released into the atmosphere will, if unchecked, lead to global warming and an increase in average temperatures." (See appendix table 7-28.) In addition, in assessing the severity of the problem, an overwhelming majority of those surveyed responded that the possibility of global warming should be treated as either a *very serious* (53 percent) or *somewhat serious* (33 percent) problem. (See appendix table 7-29.)

Gallup polls show an increasing number of Americans "worrying" about global warming between 1997 and 2000. In 2000, 40 percent of those polled reported that they worried *a great deal* about the "greenhouse effect," or global warming, up from 24 percent in 1997 and 34 percent in 1999. However, the percentage dropped to 33 percent in 2001. The most recent Gallup data show a decrease in the amount of public concern for all 13 environmental problems included in the survey between 2000 and 2001. (See sidebar "Gallup Polls on Environmental Issues" and text table 7-4.)

[29]In another survey, 71 percent of respondents answered "yes" to the question: "Do you believe the use of animals in medical research is necessary for progress in medicine?" (Research!America 2001).

[30]Fewer people oppose the use of mice in scientific research; 30 percent of those surveyed opposed research on mice compared with 52 percent who opposed research using dogs and chimpanzees. (See appendix tables 7-26 and 7-27.)

[31]The United Nations-sponsored Intergovernmental Panel on Climate Change recently issued a report warning of the catastrophic effects of global warming over the next century. The report represents a consensus of 700 scientists from more than 100 countries (Houghton et al. 2001).

Gallup Polls on Environmental Issues

The Gallup Organization has been tracking public attitudes toward environmental issues for more than a decade. The major findings include the following:

- Americans do not think environmental pollution is one of the most important problems facing the country today. According to a recent Gallup survey, the environment ranked 16th, well below education, the economy, crime, and health care, which top the list of problems identified as the most serious. However, the environment was considered to be the most important problem that will face the United States 25 years from now, more important than Medicare and Social Security and the lack of energy sources, which rank second and third on the list.*
- According to a poll taken in March 2001, 61 percent of respondents believed that global warming is occurring, up from 48 percent who responded the same way in November 1997 (Newport and Saad 2001). The same percentage also believes that human activities are more responsible for increases in the Earth's temperature over the last century than natural causes (one-third of those surveyed said the latter). In addition, 34 percent of those surveyed thought that news reports about the seriousness of global warming are accurate, and another 32 percent thought they were underestimating the problem, leaving only 30 percent who think the press is exaggerating the problem. Although Americans seem to be aware of the issue and believe press reports, they do not appear to be all that concerned. On a list of 13 types of environmental worries, the greenhouse effect, or global warming, ranked 12th. (See text table 7-4.)
- Given a choice of two statements, "protection of the environment should be given priority, even at the risk of curbing economic growth" or "economic growth should be given priority, even if the environment suffers to some extent," most respondents agreed with the first. However, the percentage agreeing with the first statement declined from 70 percent in January 2000 to 57 percent in March 2001, the lowest percentage recorded since this question was first asked (in September 1984).
- Most respondents (56 percent) opposed opening up the Alaskan Arctic Wildlife Refuge for oil exploration and 51 percent opposed expanding the use of nuclear energy. In addition, most (62 percent) opposed setting legal limits on the amount of energy an average consumer can use. But nearly 80 percent favored strengthening enforcement of Federal environmental regulations. Also, in March 2001, 52 percent (versus 36 percent) of those surveyed picked the statement "protection of the environment should be given priority, even at the risk of limiting the amount of energy supplies—such as oil, gas, and coal, which the United States produces" over the alternative statement "development of U.S. energy supplies, such as oil, gas and coal, should be given priority, even if the environment suffers to some extent."

*Another survey found scientists to be more concerned than those in other professions about the global environment. That is, they were more likely to agree that "improving the global environment" should be a top priority (they were also more concerned about population growth) (Pew Research Center for People and the Press 1997).

Public Attitudes Toward Science and Mathematics Education

Public discontent with the quality of science and mathematics education in the United States persists. As noted earlier in the chapter, surveys taken shortly before the 2000 presidential election revealed education to be at or near the top of lists of the most important problems facing the country.[32]

In response to the 2001 NSF survey, 68 percent of those queried agreed that "the quality of science and mathematics education in American schools is inadequate."[33] The percentage of survey respondents agreeing with this statement has ranged from 63 percent in 1985 and 1999 to 75 percent in 1992. Unlike other survey items, this question revealed no gender gap with respect to attitudes toward the quality of science and math education. (See appendix table 7-30.)

However, a strong positive correlation does exist between level of education and finding fault with the quality of science and math education. In 2001, 52 percent of respondents who had less than a high school education were dissatisfied with the quality of science and math education. In comparison, 68 percent of high-school-only graduates agreed with the statement, as did 76 percent of college graduates.

In another survey, more than 90 percent of those queried agreed that students in their states needed a stronger education in science and math "to be prepared for the new inventions, discoveries, and technologies that the increased investment in research and development will likely bring," and 85 percent agreed that "improving precollege science education should be one of [their] governor's top education priorities." Finally, 82 percent said they would be more likely

[32]However, according to another survey, 66 percent of the public thinks the public education system will improve in the next 50 years; 30 percent said it will get worse (Pew Research Center for People and the Press 1999a).

[33]According to another survey, conducted in August 2000, 61 percent of the public is either somewhat or completely dissatisfied with the quality of education in the United States, an increase over the percentage recorded the previous year (Gallup News Service 2001b).

Text table 7-4.
Environmental worries

Issue	Worry "a great deal" (percent) 1997	1999	2000	2001
Pollution of drinking water	NA	68	72	64
Pollution of rivers, lakes, and reservoirs	NA	61	66	58
Contamination of soil and water by toxic waste	NA	63	64	58
Contamination of soil and water by radioactivity from nuclear facilities	NA	48	52	49
Air pollution	42	52	59	48
Loss of natural habitat for wildlife	NA	51	51	48
Damage to Earth's ozone layer	33	44	49	47
Loss of tropical rain forests	NA	49	51	44
Ocean and beach pollution	NA	50	54	43
Extinction of plant and animal species	NA	NA	45	43
Urban sprawl and loss of open space	NA	NA	42	35
"Greenhouse effect" or global warming	24	34	40	33
Acid rain	NA	29	34	28

NA = not available

SOURCE: Gallup Organization, "Only One in Four Americans Are Anxious About the Environment," Poll Release (Princeton, NJ, 2001).

Science & Engineering Indicators – 2002

to vote for a presidential candidate in the November 2000 election if the candidate supported Federal efforts to strengthen U.S. science and math education (Bayer/NSF 2000).

Two NSF/Bayer surveys conducted in 2000 and 2001 included questions about public attitudes toward the results of the Third International Math and Science Study (TIMSS). One of the key findings of TIMSS, first conducted in 1995 and repeated in 1999 (see chapter 1, "Elementary and Secondary Education"), was that high school seniors in the United States performed poorly in tests of their knowledge of science and math. In fact, they ranked last or nearly last among the students who participated in TIMSS.

According to the 2000 NSF/Bayer survey, most people were unaware of the TIMSS results, although they received a considerable amount of coverage in the press. Only 7 percent of those queried knew that the scores of U.S. seniors were considerably lower than those of students in most other participating countries; nearly 50 percent thought that U.S. students scored average or higher. However, after being informed of the TIMSS results, almost everyone expressed concern, and 52 percent said that they were very concerned.

In 2001, two-thirds of NSB/Bayer survey respondents considered the TIMSS-R results a warning sign that "U.S. students may be inadequately prepared for the workplace when they enter it in several years."

Public Image of the Science Community

It is generally conceded that scientists and engineers have somewhat of an image problem (Congressional Commission on the Advancement of Women and Minorities in Science, Engineering and Technology Development 2000). Although their intelligence and work are highly respected (see "Public Confidence in Leadership of the Science Community"), that admiration does not seem to extend to other aspects of their lives. The charming and charismatic scientist is not an image that populates popular culture.[34] For example, the entertainment industry often portrays certain professions such as medicine, law, and journalism as exciting and glamorous, whereas scientists and engineers are almost always portrayed as unattractive, reclusive, socially inept white men or foreigners working in dull, unglamorous careers. (See sidebar "Few Scientists in Prime Time.")

Why does public image matter? What difference does it make if the public image of scientists and engineers is less than positive? Public image is important for at least two reasons:

- Scientists represent the first line of communication about science to the general public. That is, they are responsible for conveying information, often through the news media, about scientific issues. They can also help the public understand the importance of science and appreciate its benefits. Image has a lot to do with how effective that communication is in capturing the attention of the public. The more appealing the image, the more likely that people will listen to what is being said.

[34]See Goldman (1989). Theater also helps reinforce the stereotype, In the recent, Pulitzer prize and Tony-winning play *Proof*, mathematicians are portrayed as "a bunch of brilliant but crazy nerds who do things that are impossible to understand" (Davis 2001). Others, however, like author, screenwriter, and physician Michael Crichton defend Hollywood's depiction of science and technology. Movies such as *Jurassic Park* provide a needed balance to the "round-the-clock boosterism" science and technology usually receive in our society. According to Crichton (American Association for the Advancement of Science annual meeting in Anaheim California 1999), scientists are not the only professionals negatively portrayed on the big screen. Accountants, police officers, and politicians also frequently receive less than positive treatment.

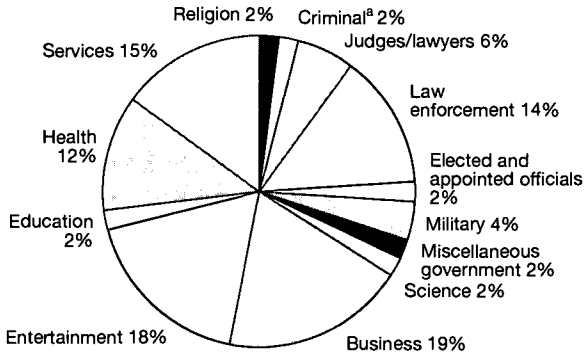
Few Scientists in Prime Time

Few characters on prime time television shows are scientists. According to a recent study, the percentage of scientists was typically less than 2 percent in the mid-1990s (Gerbner and Linson 1999). Figure 7-13 provides the breakdown for the professions of all characters in prime time between 1994 and 1997. In 1994, 2.3 percent of the characters on nighttime TV shows were scientists. Comparable figures for 1995, 1996, 1997, and 1998 were 1.6, 1.9, 1.8, and 1.0 percent, respectively.*

If scientists seldom show up on the small screen, the appearance of women and minorities as scientists is even more rare. During the period of the study, white men constituted 41 percent of the U.S. population, played 53 percent of all TV roles, and played 75 percent of the scientists. The corresponding statistics for white women were 42, 31, and 13 percent, respectively. Minorities were similarly underrepresented in the science profession on TV. However, the reverse was true for foreign nationals—only 3 percent of all characters on prime time shows were foreign nationals, but 9 percent of the scientists were members of this group. (See text table 7-5.)

*It should be noted that the 2 percent statistic for scientists in prime time probably does not differ that much from their total representation in the U.S. workforce. However, this issue can be looked at from the opposite perspective, that is, that members of other professions (e.g., doctors and lawyers) are probably overrepresented in prime time, which is not the case with respect to scientists.

Figure 7-13.
Occupations of characters in prime time dramatic entertainment: 1994–1997



[a]Although 4% (N = 245) of all characters committed crime during sample period, only 2% were identified with "criminal" as their main occupation.

NOTE: Occupations of 3,577 characters whose occupations are identified, from total sample of 6,882 speaking characters appearing in weekly samples of prime time dramatic entertainment programs (1994–97).

SOURCE: G. Gerbner and B. Linson, "Images of Scientists in Prime Time Television: A Report for the U.S. Department of Commerce From the Cultural Indicators Research Project" (Washington, DC: U.S. Department of Commerce, 1998). Unpublished report.

Science & Engineering Indicators – 2002

Text table 7-5.
Who plays scientists on television: 1994–97
(Percentages)

Characteristics	U.S. population	Television characters: Prime time characters	Television characters: Scientists in prime time
White			
Male	41.0	52.7	75.0
Female	42.1	30.7	13.2
Black			
Male	6.0	7.3	8.3
Female	6.6	4.9	1.4
Hispanic[a]	11.0	2.5	0.0
Asian	3.0	1.6	0.7
Foreign national origin	10.0	3.2	9.0
Disabled	19.0	0.7	0.7

[a]Hispanics may be of any race and are included in totals for each racial group as appropriate.

SOURCE: G. Gerbner and B. Linson. "Images of Scientists in Prime Time Television: A Report for the U.S. Department of Commerce From the Cultural Indicators Research Project" (Washington, DC, U.S. Department of Commerce, 1998), unpublished report.

Science & Engineering Indicators – 2002

♦ Children are strongly influenced by the images they see around them at home, at school, and in popular culture. Researchers in this field point out that television has a tremendous influence on children's attitudes and behaviors, and what they see on television can affect the choices they make in life, including the careers they choose.[35] If they harbor negative stereotypes of scientists and engineers as nerdy and weird-looking, then they could reject science and engineering as potential careers.[36]

Public Confidence in Leadership of the Science Community

Public confidence in the leadership of various professional communities has been tracked for more than a quarter of a century (Davis and Smith annual series). Participants in the General Social Survey were asked whether they had a "great deal of confidence, only some confidence, or hardly any confidence at all" in the leadership of various professional communities. In 2000, 41 percent reported that they had a great deal of confidence in the leadership of the science community. Only the medical community received a greater vote of

[35]According to one study of 1,500 television viewers, the more that people watch television, the more they think scientists are odd and peculiar (Gerbner and Linson 1999).

[36]According to one researcher, "ask any teenager, or even any preteen, what she or he thinks that students gifted in mathematics and science look like, and it is likely that the answer will include an image that looks like the 'nerdy' scientist from *Back to the Future*: male, with glasses, a pocket protector, and a very strange hairdo....It is nearly impossible to encourage students to do well in mathematics and science when they are faced with such ridiculous stereotypes everywhere they turn...We need more shows like *Apollo 13*, where scientists are shown as dedicated, intelligent professionals who lead exciting, fulfilling lives." (Sheffield 1997 pp. 377–78.)

confidence. Science has ranked second since 1978, when it displaced the education community for the first time. The military, Supreme Court, banks and financial institutions, major companies, organized religion, and education occupied the next six spots in 2000. The public had the least confidence in the press and television; in 2000, only 10 percent of respondents reported having a "great deal of confidence" in their leadership. (See figure 7-14 and appendix table 7-31.)

Although the vote of confidence for the science community has fluctuated somewhat since 1973, it has remained about 40 percent. In contrast, the vote of confidence for the medical profession, once as high as 60 percent in 1974, has been gradually declining during most of the past 25 years.

Public Perceptions of Scientists

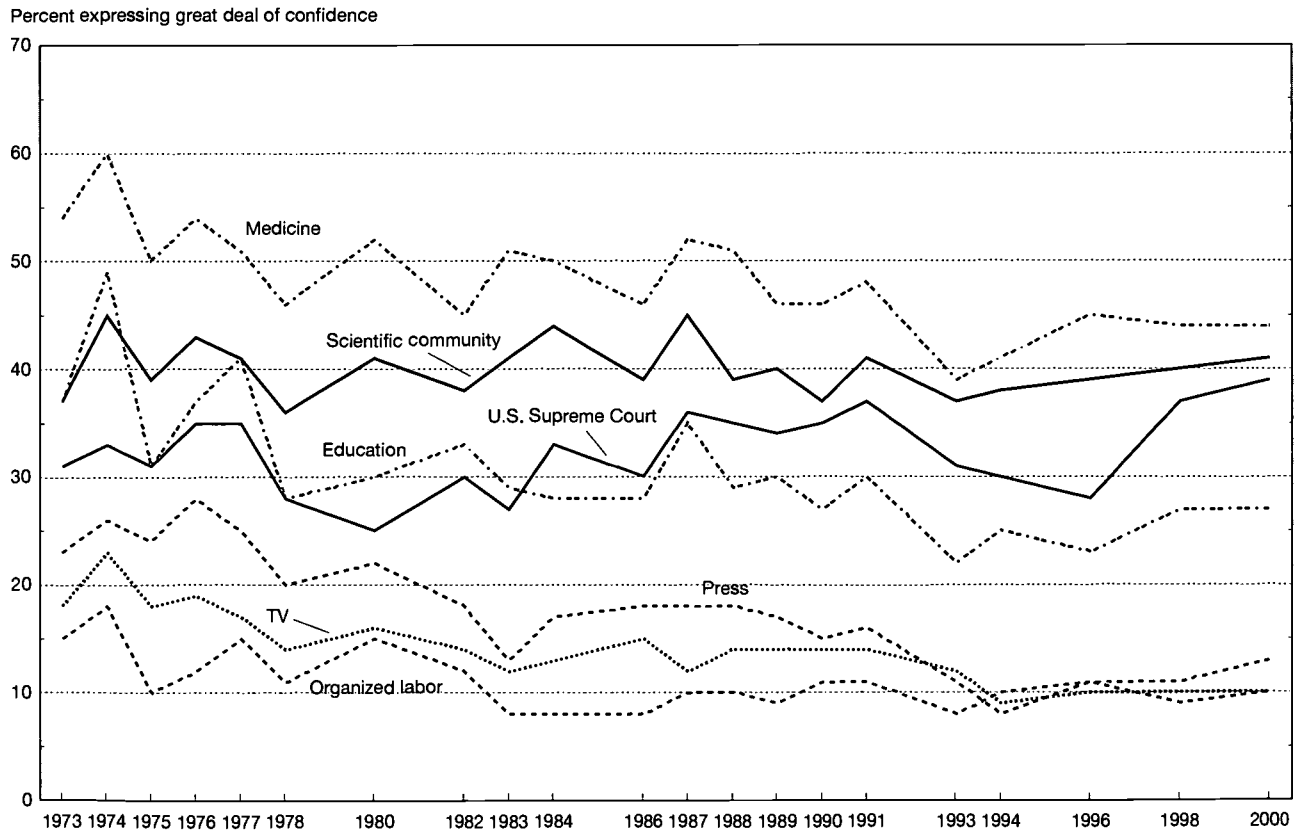
> The scientist is a man who wears a white coat and works in a laboratory. He is elderly or middle aged and wears glasses...He may wear a beard, may be...unkempt....He is surrounded by equipment...and spends his days doing experiments (Mead and Metraux 1957).

In the years since Margaret Mead first recorded her observations, several social scientists have administered the "Draw-a-Scientist" Test (DAST) to children. In this test, students are asked to draw pictures of scientists. Those pictures are then examined to see if they contain certain features normally associated with the stereotypical image of a scientist, including:

- a lab coat (usually white),
- eyeglasses,
- facial growth of hair (including beards, mustaches, or abnormally long sideburns),
- scientific instruments and laboratory equipment,
- books and filing cabinets,
- technology or the "products" of science, and
- captions, e.g., formulae, taxonomic classification, the "eureka!" syndrome.

Other features also are noted, such as the size of a scientific instrument in relation to the scientist; evidence of danger; the presence of light bulbs; the sex, race, or ethnicity of the scientist; and figures that resemble Einstein or "mad scientists" like Frankenstein (Chambers 1983). By counting the number of these indicators in the drawings, the researchers have been able to document the existence and prevalence of the stereotypical image of a scientist, one that contains at least several of the features cited above.

Figure 7-14.
Public confidence in leadership of selected institutions: 1973–2000



See appendix tables 7-31.

Science & Engineering Indicators – 2002

According to the DAST research, the stereotypical image of a scientist is alive and well in the minds of children. Moreover, children seem to form this image early in life, by the time they reach the second grade. It is even more ingrained and pronounced among older children. That is, the older the children, the more identified features their drawings contain. One study found little difference between the images held by college students and those of younger students, despite the fact that the former had probably had contact with actual scientists during their years at college (Barman 1997; Fort and Varney 1989; Barman 1999; Rahm and Charbonneau 1997).

In 2001, the NSF survey included questions intended to measure public perceptions of scientists. Respondents were asked whether they agreed or disagreed with certain statements. For example, almost everyone (96 percent) agreed that "scientists are helping to solve challenging problems," and 86 percent agreed that "scientific researchers are dedicated people who work for the good of humanity." (See appendix tables 7-32 and 7-33.) Less than 20 percent thought that "a scientist usually works alone" and "scientists do not get as much fun out of life as other people do." (See appendix tables 7-34 and 7-35.) Among these four statements, there was little, if any difference in perception between the sexes. However, the more formal education one had, the more positive the perception. This was true for two of the four items. For example, more than a third (37 percent) of those who had not graduated from high school thought that scientists did not get as much fun out of life as other people. This statistic dropped to 18 percent for high school graduates and to 11 percent for college graduates.

Four other statements included in the survey generated larger numbers of negative perceptions than the four items discussed above. However, fewer than half of those surveyed agreed that scientists:

- were apt to be odd and peculiar people (25 percent agreed),
- had few other interests but their work (29 percent), and
- were not likely to be very religious people (30 percent). (See appendix tables 7-36, 7-37, and 7-38.)

In contrast to the first group of questions, each of these statements produced a notable gender gap in perception, with more men than women having negative perceptions. For example:

- 28 percent of men agreed with the statement that scientists were odd and peculiar people compared with 22 percent of women,
- 33 percent of men but only 25 percent of women thought that scientists had few interests other than their work, and
- 34 percent of men versus 26 percent of women thought scientists were not likely to be very religious people.

Public Perceptions of Science Occupations

Despite the persistence of a stereotype that is difficult to dislodge, most people believe that scientists lead rewarding professional and personal lives. In fact, when asked how they would feel if their son or daughter wanted to become a scientist, 80 percent of respondents to the 2001 NSF survey said they would be happy with that decision (18 percent said they would not care and 2 percent reported they would be unhappy).[37] "Daughter" and "son" received equal percentages of positive responses, and men and women both "voted" the same way for *both* sons and daughters. (See appendix table 7-39.)

A Harris Poll Pilot Study conducted for the American Association of Engineering Societies in July 1998 produced what seems like an even higher level of enthusiasm for science as a career choice. This survey asked participants the following question:

> Using a scale of 1 to 10, with 1 being extremely displeased and 10 being extremely pleased, if your son or daughter or other family member said they wanted to be a scientist, technician, or an engineer, how pleased would you be?

"Scientist" received the highest level of endorsement, a perfect 10 for a median response, followed by engineer at 9, and technician at 8 (American Association of Engineering Societies 1998). One of the many scientific professional societies, the American Chemical Society, recently commissioned a survey of the public's attitudes toward its members and the work they do. Although the chemical industry did not receive high marks, its members did. (See sidebar "Public Perceptions of Chemistry, the Chemical Industry, and Chemists.")

Despite these positive perceptions of science occupations, 53 percent of respondents to the 2001 NSF survey agreed that "scientific work is dangerous." Equal percentages of men and women chose this response, but the level of agreement declined as the level of formal education rose. That is, 70 percent of those who had not completed high school agreed with the statement compared with 56 percent of high school graduates and 30 percent of college graduates. (See appendix table 7-40.)

Prestige of Science Occupations

Perceptions of science occupations can also be assessed by examining the prestige that the public associates with each. Respondents to the most recent Harris survey ranked "scientist" second among 17 occupations in terms of prestige; however, the engineering profession ranked eighth (Taylor 2000).[38] More than 50 percent of respondents chose "very great prestige" for three occupations: doctor (61 percent), scientist (56

[37]In a study conducted in the United Kingdom, 74 percent of those surveyed said that science and engineering represent good career choices, while only 4 percent had the opposite point of view. The adjectives used most often to describe scientists and engineers were "intelligent, enquiring, logical, methodical, rational, and ...responsible" (Office of Science and Technology and The Wellcome Trust 2000).

[38]The question asked in this survey was: "I am going to read off a number of different occupations. For each, would you tell me if you feel it is an occupation of very great prestige, considerable prestige, some prestige, or hardly any prestige at all?"

Public Perceptions of Chemistry, the Chemical Industry, and Chemists

The American Chemical Society (ACS) commissioned a survey of public attitudes towards chemistry and chemists. This survey, conducted in 2000 by The Wirthlin Group (The American Chemical Society 2000), had the following objectives:

- find out what the average person thinks about chemistry and chemists,
- assess public attitudes toward chemical companies and the chemical industry,
- measure public perceptions of chemists and chemistry as a career, and
- discover what factors influence perceptions of chemistry and the chemistry profession.

Perceptions of Chemistry

When asked to think about the word "science," 20 percent of respondents mentioned "medicine" or "biology"; 14 percent mentioned astronomy; 11 percent, chemistry; 7 percent, space; and 6 percent, physics. Those with higher levels of education and income were more likely than others to mention chemistry.

Perceptions of the Chemical Industry

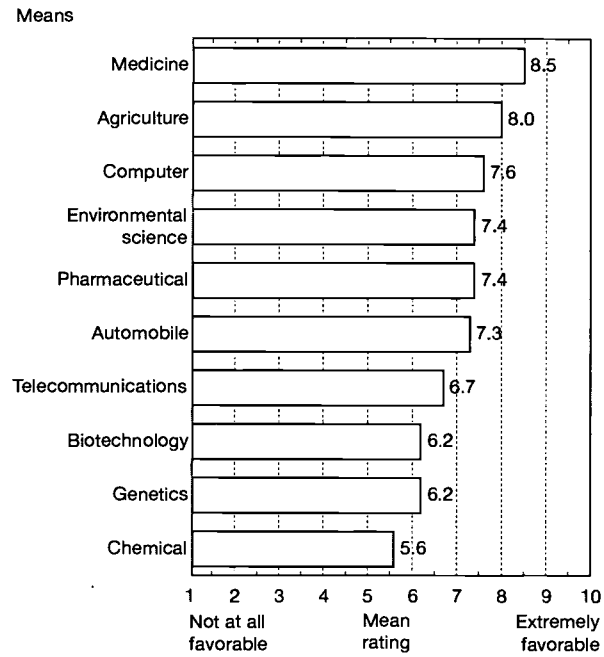
About one-third of those surveyed had an unfavorable opinion of chemical companies. Among the 10 industries included in the survey, the chemical industry ranked last. In contrast, medicine and agriculture had the most favorable ratings, followed by the computer, environmental science, pharmaceutical, automobile, telecommunications, biotechnology, and genetics industries. (See figure 7-15.)

Respondents expressing the least negative attitudes toward the chemical industry were those who had college degrees and/or household incomes exceeding $60,000, Caucasians, those not concerned about the effects of chemicals on human health and safety, and those who thought chemicals had made their lives better.

The survey participants who gave chemical companies a favorable rating (43 percent) were more likely than others to mention the positive social effects of chemicals and to express the belief that chemicals improve the quality of life. This group also cited the positive role of chemistry in research and development, cleaning uses, and pesticides.

Those with unfavorable opinions toward chemical companies (34 percent) cited the environmental impact of chemicals, harm to health, and the bad publicity the industry receives. According to this set of respondents, chemical companies harm the environment by disposing of waste irresponsibly and polluting in other ways. The Exxon Valdez and other oil spills were also mentioned. Bad publicity includes the perception that companies do not communicate with consumers.

Figure 7-15.
Industry favorability for selected industries



NOTE: Responses are to the following statement: "Next I would like to read you a list of industries. For each one I mention, please tell me how favorable you are toward that industry using a 1 to 10 scale where 1 means you are not at all favorable and 10 means extremely favorable. You may use any number between 1 and 10."

SOURCE: Figure reproduced from the American Chemical Society, National Benchmark Telephone survey, conducted by Wirthlin Worldwide, draft report, July 2000, Washington D.C.

Science & Engineering Indicators – 2002

A strong majority—three out of five of those surveyed—felt that chemicals make their everyday lives better. The remaining respondents were split evenly between those who were neutral (20 percent) and those who thought chemicals had made their lives worse (20 percent).

The positive aspects of chemistry mentioned fall into two categories: (1) health-related, e.g., medicine and finding cures for diseases, and (2) specific products, e.g., cleaning or agricultural, that make their lives easier. Those who feel chemicals have made their lives worse cited environmental and health concerns.

Public Perceptions of Chemists and Chemistry as a Career

Although the chemical industry suffers from an image problem, the public seems to have a positive attitude toward chemistry as a profession. ACS survey respondents ranked a career as a chemist higher than that as an environmentalist, physicist, mathematician, psychologist/psychiatrist, and astronomer. Only physicians and pharmacists ranked higher. In addition, the public recognizes chem-

ists' contributions to health maintenance. With respect to this criterion, chemists once again ranked second only to physicians and pharmacists, and about even with environmentalists.

Although only 8 percent of respondents had offered advice to a friend or family member about becoming a chemist, of those who had, an overwhelming majority (87 percent) gave positive advice. The reasons given for offering encouragement included supporting the individual's choice, considering chemistry a good field with a good future, and believing that chemistry would not only provide the opportunity to help people and benefit society but also pay well.

Other findings included the following:

- A majority of survey respondents (72 percent) considered a career in basic chemical research more appealing than a career in the chemical industry (14 percent chose the latter). The reasons cited for the former included having the opportunity to make new discoveries that will benefit mankind and help others. Those who chose the latter career option cited better opportunities for career advancement and better pay.
- The leadership traits most closely associated with chemists included being a visionary, being innovative, and being results oriented.

Other Survey Findings

- Respondents said that their views were influenced almost entirely by newspaper, magazine, and television coverage of science topics. For most of the public, the primary sources of information for new developments and innovations involving chemists, chemistry, and chemicals are newspapers (34 percent), national television reports (28 percent), magazines/periodicals (27 percent), and local television reports (24 percent). The role of the Internet is still quite small: only 5 percent named it as a primary information source. (See "Where Americans Get Information About S&T.")
- Nearly 60 percent of respondents thought that they were poorly informed about new chemical developments and innovations. Only 12 percent of the respondents reported feeling very well informed about the role of chemicals in improving human health; 60 percent considered themselves somewhat informed. The remaining respondents indicated that they were not at all informed. Despite the low levels of knowledge of the role of chemicals in improving human health, 52 percent were very concerned and 35 percent were somewhat concerned about the effects of chemicals on human health and safety.
- When a chemical substance had become a danger to consumer health and safety, most people (54 percent) said that government regulators were to blame; 39 percent thought that the companies that sold the substance were responsible. Only 14 percent thought that the chemists who had discovered the substance were the most culpable.

percent), and teacher (53 percent). Although these percentages changed little between 1998 and 2000, the prestige of teachers has risen dramatically, from 28 percent in 1982 to 53 percent in 1998. During the same period, there was a relatively small gain in prestige for doctors and a relatively small loss for scientists.

This survey shows that engineers are accorded not only less prestige than doctors, scientists, and teachers, but also less prestige than ministers, military officers, policemen, and members of Congress.[39] According to a recent study, "engineers have enjoyed a consistent but mediocre prestige for the past 20 years" (American Association of Engineering Studies 1998). However, engineers command more respect than architects, lawyers, athletes, and entertainers. The bottom tier includes journalists, union leaders, businessmen, bankers, and accountants.

Are Public Perceptions Based on Knowledge?

Although people perceive science and other occupations in terms of prestige or other value measures, on what do they base their perceptions? That is, how much do people actually know about science occupations and science professionals?

In response to the American Association of Engineering Societies survey in July 1998, sizable minorities of those surveyed did not consider themselves well informed about science and scientists (47 percent) or technology and technicians (41 percent). In addition, sizable percentages of survey respondents thought that the media did only a fair or poor job covering science (56 percent), technology (53 percent), and medical discoveries (44 percent).

The same survey produced telling statistics about the engineering profession. For example:

- 61 percent of respondents did not consider themselves well informed about engineering and engineers,[40] and
- 70 percent of respondents thought that the media did only a fair or poor job covering engineering.[41]

In addition, the public frequently underestimates the role engineers play in S&T advancement. For example, engineers

[39]In a study conducted in the United Kingdom, engineering was perceived as a mostly male profession. Although the respondents tended to view the personalities of engineers as "cold and detached," they also saw them as more "socially responsible" and "sympathetic" than scientists (The Office of Science and Technology and The Wellcome Trust 2000).

[40]The comparable figures for science and scientists and technology and technicians were 47 and 43 percent, respectively.

[41]The comparable figures for science, technology, and medical discoveries were 56, 53, and 44 percent, respectively.

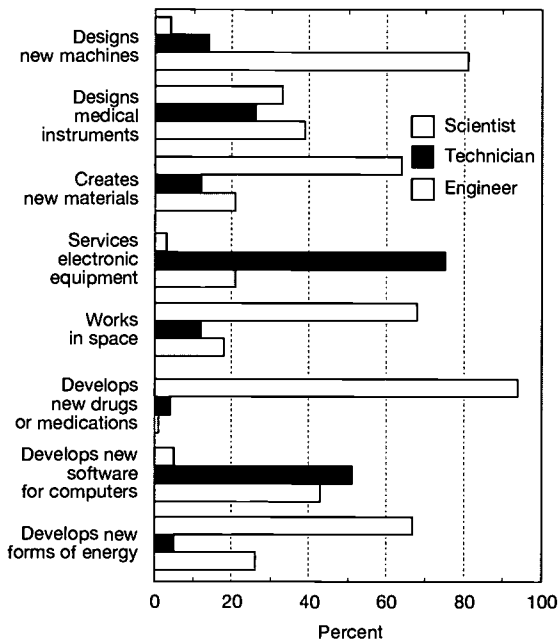
have a much larger role in conducting space research, developing new forms of energy, and creating new materials than the public gives them credit for. (See figure 7-16.) In addition, they are "perceived as pragmatic contributors to society—more so than are technicians—but are less attuned to societal issues than are scientists." (See figure 7-17.)

Where Americans Get Information About S&T

Science on the Internet

Has the Internet displaced television and the print media as Americans' primary source of news about current events or S&T? According to a 2000 Pew Research Center survey, the Internet is making inroads. Apparently, part of the time Americans used to spend watching the news broadcasts of ABC, CBS, NBC, and Fox is now being used to browse various news-oriented websites. (See sidebar "More Americans Are Turning to the Internet for News.") In addition, people who have access to the Internet at home seem to know more about science and the scientific process and have more positive attitudes toward S&T. (See sidebar "Internet Access Is an Indicator of Both Attitudes Toward and Knowledge of S&T.")

Figure 7-16.
Who does what—scientists, engineers, or technicians : 1998

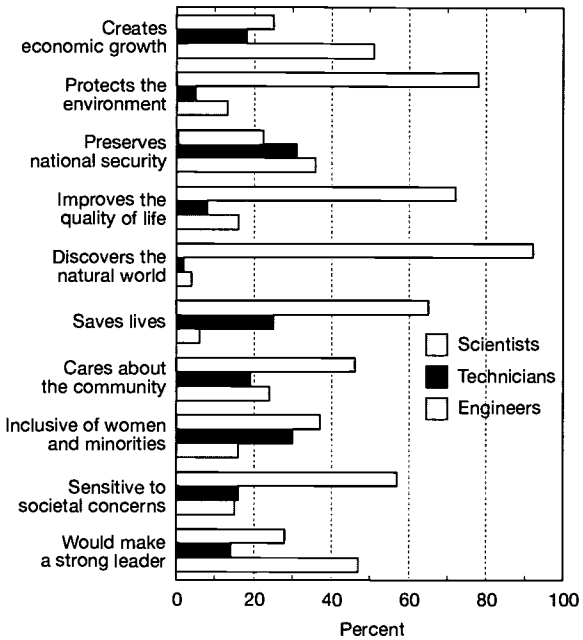


NOTE: Responses were to the question, "As I mention some activities, tell me who you *mostly* associate with that activity—a scientist, a technician, or an engineer?"

SOURCE: Louis Harris & Associates, Inc. "American Perspectives on Engineers & Engineering." A "Harris Poll" Pilot Study conducted for the American Association of Engineering Societies. July 1998.

Science & Engineering Indicators – 2002

Figure 7-17.
Public perception of scientists, engineers, and technicians: 1998



NOTE: Responses were to the question, "As I mention some characteristics, who first comes to mind—scientists, technicians, or engineers?"

SOURCE: Louis Harris & Associates, Inc. "American Perspectives on Engineers & Engineering." A "Harris Poll" Pilot Study conducted for the American Association of Engineering Societies. July 1998.

Science & Engineering Indicators – 2002

Despite its growing popularity, the Internet ranks a distant third as Americans' chief source of news in general. Only 7 percent of respondents to the NSF survey identified it as their main source of information about what is happening in the world around them. In contrast, 53 percent of those surveyed identified television, and 29 percent said that they got most of their information about current news events from newspapers. The corresponding statistics for radio and magazines are 5 and 3 percent, respectively. (See figure 7-19 and appendix table 7-42.)

Although 9 percent of respondents to the 2001 NSF survey said that the Internet was their main source of information about S&T, this percentage is still substantially below the percentage of respondents who identified television (44 percent), newspapers (16 percent), and magazines (16 percent) as their primary source of S&T news. (See figure 7-19 and appendix table 7-43.)

The Internet, however, is the preferred source when seeking information about specific scientific issues. The following question was asked in the 2001 NSF survey: "If you wanted to learn more about a scientific issue such as global warming or biotechnology, how would you get more information?"

The response to this question makes it clear that encyclopedias and every other information resource have lost a substantial number of customers to the Internet. A plurality (44

More Americans Turning to the Internet for News

Surveys conducted by the Pew Research Center (Pew Research Center for the People and the Press 2000b) show the Internet displacing network television as a source of news in some U.S. households.* (See figure 7-18.) The trend is most noticeable in the homes of younger, more affluent, and better educated survey participants. A majority of daily Internet news consumers (61 percent) are men, 75 percent are under 50, and 47 percent have a college education. Half have family incomes of $50,000 or more. This finding holds true only for news programs on the broadcast networks (ABC, CBS, NBC, and Fox). Cable news channels, daily newspapers, and radio news seem unaffected by Internet usage.

In 1998, 59 percent of two groups, those who regularly obtained news online (Internet users) and those who did not (nonusers), reported that they watched television news on a typical day. Two years later, the percentage of Internet users watching television news had dropped to 53 percent; the corresponding statistic for nonusers remained at 59 percent. Moreover, Internet users are spending less time watching news shows. That is, the percentage of Internet users reporting that they watched at least a half-hour of television news on a typical day fell from 48 percent in 1998 to 40 percent in 2000. In contrast, there was almost no change for the nonuser group: 49 percent in 1998 versus 47 percent in 2000. The data show that even when demographic variables such as sex, age, and level of education (factors associated with both watching the news and Internet access) are taken into account, Internet users are significantly less likely to watch network news than those not using the Internet.

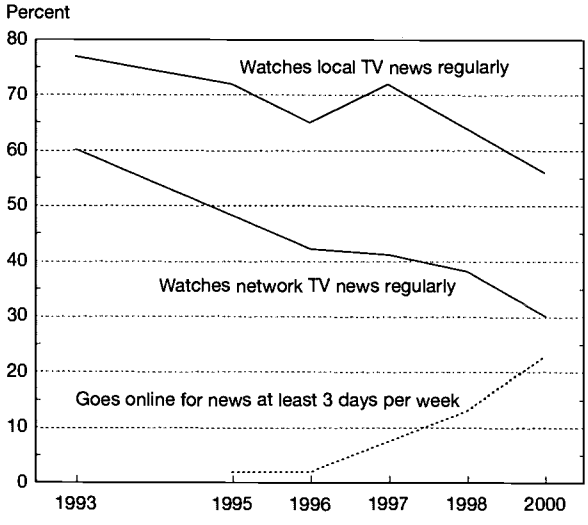
Internet users are also less likely than nonusers to watch other network news programs, including morning shows like *The Today Show* and evening news magazines like *60 Minutes*. For example, 28 percent of Internet users said that they regularly watched network news magazines compared with 34 percent of nonusers.

Text table 7-6 shows the most popular types of news sought online by Internet users. Weather, science/health, and technology are at the top of the list.

Americans who regularly get news online are more interested than non-Internet users in news about science and technology, business and finance, and sports. For example, 22 percent of those who got news online at least once a week said that they follow news about science and technology very closely compared with just 14 percent of those who did not go online. (See text table 7-1.)

*The percentage of Americans saying they enjoy keeping up with the news has declined steadily since the mid-1990s. The generational divide on these questions is striking (Pew Research Center for the People and the Press 2000c).

Figure 7-18.
U.S. public viewing broadcast news versus online news



SOURCE: Pew Research Center for the People and the Press, "Internet Sapping Broadcast News Audience: Investors Now Go Online for Quotes, Advice." Biennial Media Consumption Survey, June 11, 2000. http://www.people-press.org/media00rpt.htm.

Science & Engineering Indicators – 2002

Text table 7-6.
Online news topics for which people go online: 2000

News topic	Internet news consumers (percent) All	Men	Women
Weather	66	68	64
Science and health	63	60	67
Technology	59	72	45
Business	53	62	43
International	45	51	38
Entertainment	44	40	47
Sports	42	57	27
Political	39	44	34
Local	37	35	39

SOURCE: Pew Research Center for the People and the Press, "Internet Sapping Broadcast News Audience: Investors Now Go Online for Quotes, Advice," Biennial Media Consumption survey (Washington, DC, June 11, 2000). Available at <http://www.people-press.org/media00rpt.htm>.

Science & Engineering Indicators – 2002

Internet Access an Indicator of Both Attitudes Toward and Knowledge of S&T

People who have access to the Internet at home seem to harbor fewer reservations about S&T than those who do not have access at home. They may also have more knowledge of science and the scientific process than their no-access counterparts. Although the differences in attitudes and knowledge are the most striking among those whose highest level of formal education is a high school diploma, differences exist even among those having college degrees.

In 2001, 59 percent of those responding to the NSF survey said that they had access to the World Wide Web (WWW) at home. Given how much the so-called digital divide has been in the news, it is not surprising to see access strongly correlated with level of education, in terms of both formal education and number of math and science courses completed. In addition, this question produced a sizable gender gap; 63 percent of men said that they had home access, compared with 55 percent of women. (See appendix table 7-41.)

Those having access to the Internet at home harbor fewer reservations about science. For example:

- 43 percent of those having access to the WWW from home agreed with the statement "we depend too much on science and not enough on faith" compared with 60 percent of those without access;
- 30 percent of those having access agreed with the statement "science makes our way of life change too fast" compared with 50 percent of those without access; and
- 78 percent of those having access agreed that the benefits of scientific research outweigh the harmful results, compared with 63 percent of those without access.

In addition, 85 percent of those with access to the WWW from home, but only 75 percent without access, agreed with the statement: "Even if it brings no immediate benefits, scientific research that advances the frontiers of knowledge is necessary and should be supported by the Federal Government." However, this difference was entirely attributable to those without college degrees. Among college graduates, there are almost no differences in the percentages of respondents agreeing with the statement.

Responses to the knowledge questions on the survey reveal major differences between those who have access to the Internet and those who do not. For each of the knowledge questions, the percentage of correct responses given by respondents in the "access" group was higher—and for most questions, substantially higher—than the percentage of correct responses given by respondents in the "no access" group. For example:

- 56 percent of respondents in the access group knew that electrons are smaller than atoms compared with 36 percent of those in the no-access group;
- 61 percent knew that antibiotics do not kill viruses (compared with 36 percent);
- 52 percent knew that humans did not live at the same time as dinosaurs (compared with 41 percent);
- 83 percent knew that light travels faster than sound (compared with 67 percent); and
- 84 percent knew that Earth goes around the Sun and not vice versa (compared with 63 percent).

Even among college graduates responding to the survey, those with Internet access at home were more likely than those without access to respond correctly to most of the knowledge questions in the survey.

Among all survey respondents, 37 percent of those with access to the WWW at home were deemed to have an understanding of the scientific process, compared with 19 percent of the no-access group. For the access group, 48 percent of those with just a bachelor's degree and 56 percent of those with a graduate or professional degree met the criteria for understanding the scientific process. The comparable percentages for the no-acess group were 32 and 48 percent, respectively.

percent) of those surveyed chose the Internet as the resource they would use to look up information on the two scientific issues. About half as many (24 percent) chose books or other printed material. No other source, for example, magazines (8 percent), television (6 percent), or newspapers (4 percent), scored above 10 percent. (See figure 7-19 and appendix table 7-44.)

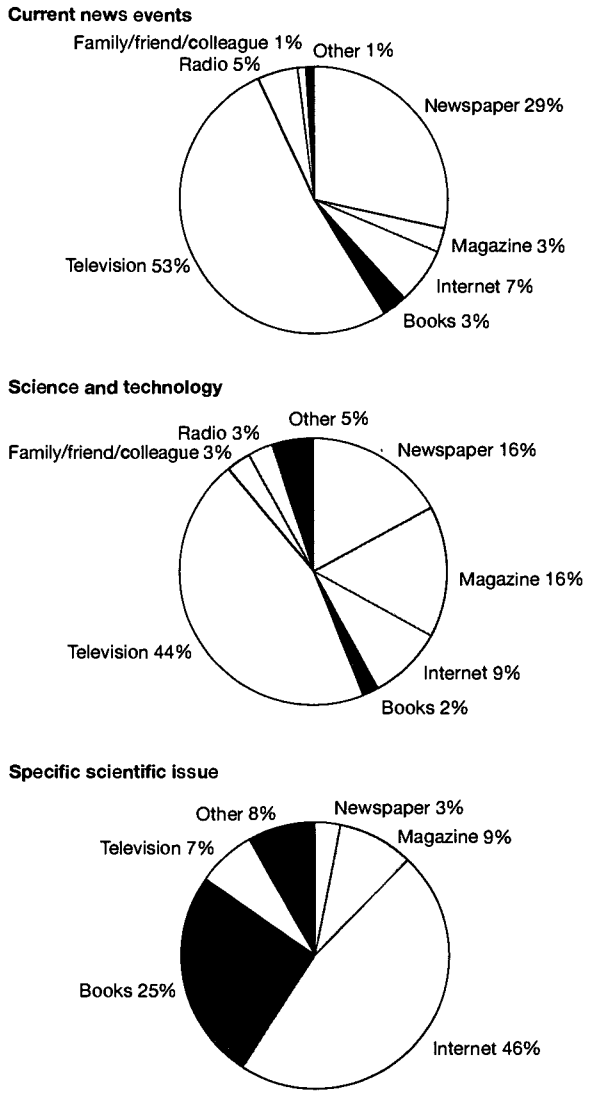
Although it is safe to conclude that the Internet is affecting what Americans know about S&T, it is also true that what most of them know about the latest developments in these subjects comes primarily from watching television.

Science on Television

When most people think about science on television, their first thoughts are probably about educational series, like *NOVA*, on Public Broadcasting Service (PBS) programming, or programs aimed at children, such as *Bill Nye the Science Guy*. In addition, most U.S. households now have access to cable television or satellite systems (see appendix table 7-45), so many Americans are also aware of the Discovery Channel and its mostly science-related offerings.[42] Although

[42] In March 2000, a two-hour special on the Discovery Channel, "Raising the Mammoth," drew 10.1 million viewers, the largest audience for a documentary in the history of basic cable television. Although a sequel, "Land of the Mammoth," attracted an audience only half the size of the original, that was still a laudable showing for a basic cable program (Carter 2001).

Figure 7-19.
Leading source of information: 2001



See appendix tables 7-42, 7-43, and 7-44.

Science & Engineering Indicators – 2002

programs and documentaries on PBS and the Discovery Channel are highly regarded, their audiences are relatively small. (See appendix table 7-46.) Other types of programming such as evening and morning news broadcasts and news magazines like *60 Minutes, 20/20*, and *Dateline* reach far more people. Therefore, most television viewers are exposed to information about S&T from news shows and news magazines that occasionally cover these subjects.[43]

In response to the 2001 NSF survey, 90 percent of adults said they watched television news reports or news shows every day (63 percent) or a few times a week (27 percent).[44] (See appendix table 7-47.) In addition, 31 percent said that they watched television news magazines like *60 Minutes, 20/20*, or *Dateline* regularly or most of the time, and 52 percent said that they watched those shows occasionally.[45] (See appendix table 7-46.) These television news magazines can be a leading source of news about science for the public, including members of Congress; for example, a *60 Minutes* segment on cloning humans was shown at the beginning of a March 28, 2001, hearing held by the Oversight and Investigations Subcommittee of the House Energy and Commerce Committee.

According to the 2001 NSF survey, 8 percent of Americans watch *NOVA* regularly or most of the time, and 29 percent watch the series occasionally. Twenty-two percent said they regularly watched public television programs other than *NOVA*, and 49 percent said they occasionally watched such programs.[46] Not surprisingly, a positive relationship exists between watching *NOVA* (as well as other PBS programs) and level of formal education. For example, 15 percent of those who had a graduate or professional degree said they watched *NOVA* regularly, compared with 11 percent of those who had only a bachelor's degree, 7 percent of those who had only a high school degree, and 4 percent of those who had not graduated from high school. Those who had a bachelor's or higher degree were also more likely than others to watch other PBS programs. (See appendix table 7-46). In response to a Pew Research Center survey, 37 percent said that they regularly watched documentaries on cable channels such as the History Channel or the Discovery Channel. More men (43 percent) than women (31 percent) said that they watched these shows.

[43]Science also shows up in entertainment programming, for example, children conducting science experiments on *Late Night with David Letterman*, or in an occasional storyline in a long-running show like *Friends* in which one of the characters is a research scientist. Also, each episode of *The West Wing* usually contains a science-related storyline. Because shows like these draw such large audiences, their conveying of information about science and science policy should not be discounted. They provide information and shape attitudes. A recent example of the influence of television on public opinion illustrates this point. During the 2000 presidential campaign, it was hard not to notice that a lot of voters were getting political news from entertainment talk shows, not just those on Sunday morning or the cable news networks or *Nightline*. Almost all major candidates felt compelled to do the talk show circuit, to appear on the *Late Show with David Letterman*, the *Tonight Show*, or the *Oprah Winfrey Show*, because of the growing recognition that their appearances on such shows proved to be an effective way of reaching Americans who do not watch the news or read a newspaper (Pfau et al. 2001).

[44]According to another survey (Pew Research Center for the People and the Press 2000b), the percentage of Americans who report watching a nightly network news program has been declining significantly for more than a decade, from 71 percent in 1987 to 65 percent in 1995, 59 percent in 1998, and 50 percent in 2000.

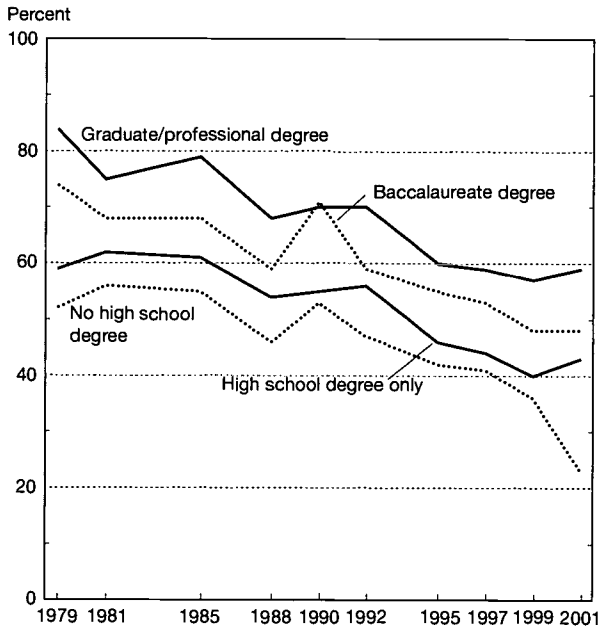
[45]According to the Pew Research Center survey, the percentage of Americans who say they regularly watch news magazines such as *20/20* and *Dateline* dropped from 37 percent in 1998 to 31 percent in 2000. Audiences for the three network morning shows also decreased, but by a smaller amount, during the past two years.

[46]According to the Pew Research Center survey, PBS viewership has remained stable.

Science in Newspapers and Museums

The decline in newspaper readership during the past decade has been well documented. According to the NSF survey, the percentage of all adults who read a newspaper every day dropped from 57 percent in 1990 to 41 percent in 1999. The decline is apparent at all education levels and continued for the less-than-high-school-education group through 2001. However, newspaper readership among the other three education groups either rose or stayed the same between 1999 and 2001, indicating that the overall decline in newspaper readership may have leveled off in recent years.[47] (See figure 7-20 and appendix table 7-48.)

Figure 7-20.
U.S. public reading a daily newspaper: 1979–2001



See appendix table 7-47. *Science & Engineering Indicators – 2002*

Sixty-six percent of those surveyed in 2001 reported that they had visited a science or technology museum at least once during the past year, the highest level of museum attendance ever recorded by the NSF survey. Museum attendance is positively related to formal education and attentiveness to S&T. (See appendix tables 7-45, 7-49, and 7-50.)

[47]Data from the Pew Research Center also show a recent leveling off in the decline in newspaper readership. Data from the center show 47 percent of whites reading a daily newspaper compared with 37 percent of blacks and 32 percent of Hispanics. However, blacks are somewhat more likely (60 percent) than whites (56 percent) to watch TV news. In addition, weekly news magazines, such as *Time* and *Newsweek*, have lost readers. In 2000, only 12 percent reported that they regularly read a news magazine; the corresponding statistics in 1996 and 1993 were 15 and 24 percent, respectively.

Science Fiction and Pseudoscience

Interest in Science Fiction

According to renowned physicist Stephen Hawking, "science fiction is useful both for stimulating the imagination and for diffusing fear of the future." Interest in science fiction may affect the way people think about or relate to science. For example:

- Interest in science fiction may be an important factor in leading men and women to become interested in science as a career. Although it is only anecdotal evidence, found on Internet discussion lists, for example, scientists often say they were inspired to become scientists by their keen interest in science fiction as children.

- It is useful to discover whether interest in science fiction is a possible indicator of positive attitudes toward S&T. For example, one study found a strong relationship between preference for science fiction novels and support for the space program.[48]

Thirty percent of those participating in the 2001 NSF survey said that they read science fiction books or magazines. (See appendix table 7-51.) The positive relationships that exist between reading science fiction and level of education, number of math and science courses completed, and attentiveness to science and technology are interesting, yet predictable. However, another finding is contrary to conventional wisdom. That is, there does not seem to be a gender gap: nearly equal percentages of men (31 percent) and women (28 percent) report that they read science fiction books or magazines. (See appendix table 7-51.)

However, a difference does exist with respect to watching science fiction television programs. For example, the Sci Fi channel is watched by more men (55 percent) than women (45 percent) (Brown 2000). In contrast, women make up the majority of the viewing audience of almost every other television network except the sports networks.

In response to the 2001 NSF survey, 35 percent of men reported that they watched any of the *Star Trek* series either regularly (12 percent) or occasionally (23 percent), compared with 28 percent of women who watched either regularly (10 percent) or occasionally (18 percent). There does not seem to be a relationship between level of education and watching *Star Trek*. (See appendix table 7-52.)

The *X-Files* is a show that focuses more on pseudoscience than science fiction. About 15 percent of those surveyed said they watch the show regularly, and another 28 percent said that they watch it occasionally. Those with more formal education are less likely than others to watch the show. (See appendix table 7-52.)

[48]The same study also found that students who read science fiction are much more likely than other students to believe that contacting extraterrestrial civilizations is both possible and desirable (Bainbridge 1982).

Relationships Between Science and Pseudoscience

What Is Pseudoscience?

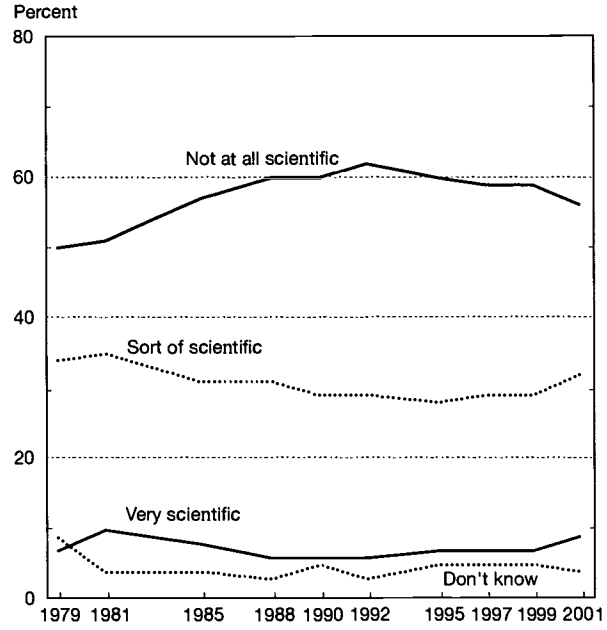
Pseudoscience is defined here as "claims presented so that they appear [to be] scientific even though they lack supporting evidence and plausibility" (Shermer 1997, p. 33). In contrast, science is "a set of methods designed to describe and interpret observed and inferred phenomena, past or present, and aimed at building a testable body of knowledge open to rejection or confirmation" (Shermer 1997, p. 17). According to one group studying such phenomena, pseudoscience topics include yogi flying, therapeutic touch, astrology, fire walking, voodoo magical thinking, Uri Gellar, alternative medicine, channeling, Carlos hoax, psychic hotlines and detectives, near-death experiences, Unidentified Flying Objects (UFOs), the Bermuda Triangle, homeopathy, faith healing, and reincarnation (Committee for the Scientific Investigation of Claims of the Paranormal <http://www.csicop.org>).

How Widespread Is Belief in Pseudoscience?

Belief in pseudoscience is relatively widespread. Various polls show the following:

- More than 25 percent of the public believes in astrology, that is, that the position of the stars and planets can affect people's lives. In one recent poll, 28 percent of respondents said that they believed in astrology; 52 percent said that they did not believe in it; and 18 percent said that they were not sure (Newport and Strausberg 2001). Nine percent of those queried in the 2001 NSF survey said that astrology was "very scientific" and 32 percent answered "sort of scientific"; 56 percent said that it was not at all scientific. (See appendix table 7-53 and figure 7-21.) A minority of respondents (15 percent) said that they read their horoscope every day or "quite often"; 30 percent answered "just occasionally." (See appendix table 7-54.)
- At least half of the public believes in the existence of extrasensory perception (ESP). The statistic was 50 percent in the latest Gallup poll and higher in the 2001 NSF survey, in which 60 percent of respondents agreed that "some people possess psychic powers or ESP."[49] (See appendix table 7-55.)
- A sizable minority of the public believes in UFOs and that aliens have landed on Earth.[50] In 2001, 30 percent of NSF survey respondents agreed that "some of the unidentified flying objects that have been reported are really space vehicles from other civilizations" (see appendix table 7-56), and one-third of respondents to the Gallup poll reported that they believed that "extraterrestrial beings have visited earth at some time in the past."

Figure 7-21.
Public perception of whether astrology is scientific: 1979–2001



See appendix table 7-53. *Science & Engineering Indicators – 2002*

- Polls also show that one quarter to more than half of the public believes in haunted houses and ghosts, faith healing, communication with the dead (see figure 7-22), and lucky numbers (see appendix table 7-57).

Surveys administered periodically even show increasing belief in pseudoscience. Of the 13 phenomena included in the 2001 Gallup survey, belief in 8 of them increased significantly during the past decade, and belief in only 1 (devil possession) declined. Belief in four of the phenomena, haunted houses, ghosts, communication with the dead, and witches, had double-digit percentage point increases. Movies like *The Sixth Sense* and *The Blair Witch Project* as well as the plethora of mediums on the small screen may have been fueling such beliefs.

In most cases, more women than men believe in these types of pseudoscience. In response to the 2001 NSF survey, women were more likely than men to believe in ESP.[51] The percentages of men and women who said that they believed in UFOs were about equal, which contrasts with the findings of other surveys. In fact, in most other surveys of this type, aliens-from-outer-space-type questions are the only ones that show higher levels of belief among men than women (Irwin 1993).

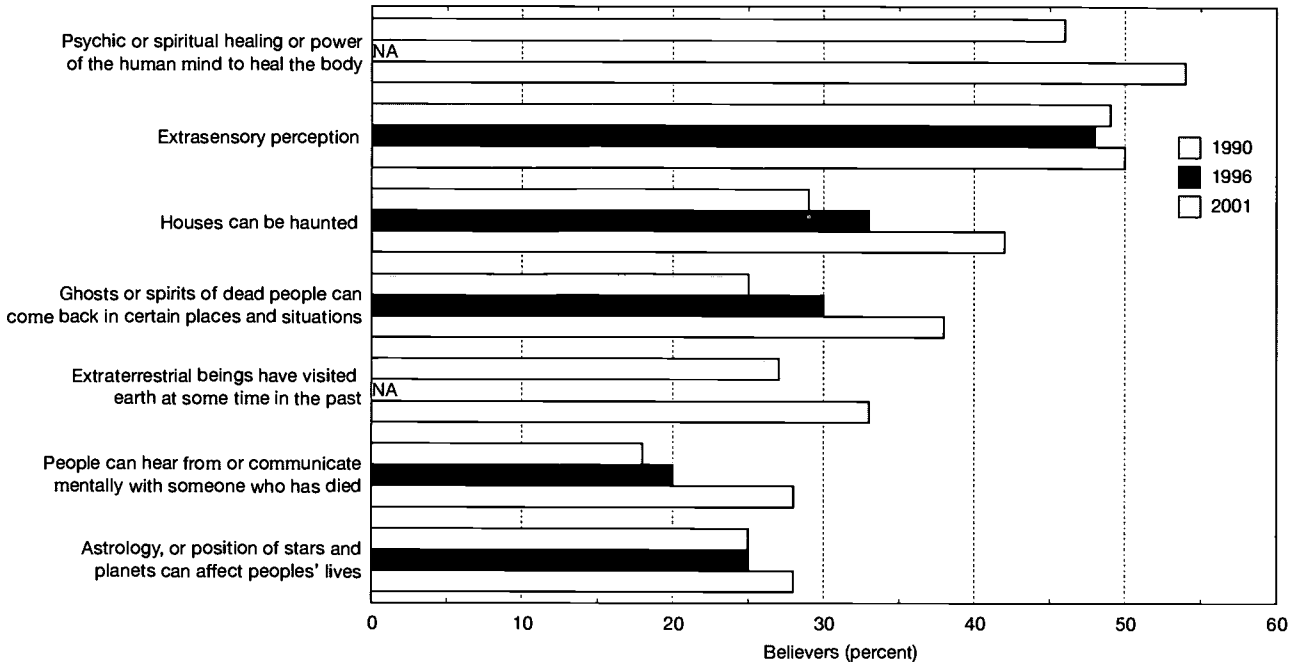
The relationship between level of education and belief in pseudoscience is not as straightforward, although for some topics such as astrology, a strong negative relationship exists. In response to the 2001 NSF survey, only 45 percent of those with less than a high school education and 52 percent of those who

[49]Between 1972 and 1995, the Central Intelligence Agency and the Department of Defense spent $20 million on "psychic" research (Barrett 2001).

[50]In a poll commissioned by *Popular Science* magazine, 45 percent thought that intelligent aliens had visited Earth (Popular Science 2000).

[51]Although women account for only 45 percent of the Sci Fi Channel's viewing audience, one show on that network, *Crossing Over*, which features a medium, has a largely female audience (Brown 2000).

Figure 7-22.
Belief in paranormal phenomena



NA = not available

SOURCE: Gallup Organization, "Americans' Belief in Psychic Paranomal Phenomena is up Over Last Decade," (Princeton, NJ, 2001).

Science & Engineering Indicators – 2002

had completed high school but not college said that astrology "is not at all scientific" compared with 74 percent of those who had at least a bachelor's degree. (See appendix table 7-53.)

Is Belief in Pseudoscience Harmful?

Concerns have been raised, especially in the science community, about widespread belief in pseudoscientific phenomena.[52] Scientists and others believe that the media, and in particular, the entertainment industry, may be at least partially responsible for the large numbers of people who believe in astrology, ESP, alien abductions, and other forms of pseudoscience.[53] Because not everyone who watches shows with pseudoscientific themes perceives such fare as merely entertaining fiction, there is concern that the unchallenged manner in which some mainstream media portray pseudoscientific phenomena is exacerbating the problem and contributing to the public's scientific illiteracy.[54] Belief in pseudoscience may indicate a lack of critical thinking skills (Maienschein et al., 1999).

Although scientists are concerned about scientific illiteracy, including the public's gullibility regarding pseudoscience, few choose to say much about it. According to physicist Robert L. Park, most scientists would rather talk about their latest cutting-edge research, not the basic laws of thermodynamics.[55] Park has been speaking out for many years. In explaining why, he recently said:

> [P]eople drawn to [pseudoscience long] for a world that is some other way than the way it is. They pose no great threat to science. [Pseudoscience] is a sort of background noise, annoying, but rarely rising to a level that seriously interferes with genuine scientific discourse. The more serious threat is to the public, which is not often in a position to judge which claims are real and which are [not]. Those who are fortunate

[52]The rise of pseudoscience in China has become a growing concern for scientists in that country. According to one scientist, "the number of high-profile attempts to pass off superstition and money-making scams under the respectable cloak of science is one of the most disturbing features of Chinese science and society" (Tsou 1998).

[53]Groups like the Committee for the Scientific Investigation of Claims of the Paranormal <http://www.csicop.org> contend that shows like *The X-Files* fuel belief in misinformation about science and conspiracy theories, and several studies of this subject also support this contention (Sparks, Nelson, and Campbell 1997). Others have spoken out similarly: "[t]he UFO conspiracy theory has been fed and watered by *The X-Files* series on television" (Borger 2001). According to Richard Dawkins, in his 1998 treatise *Unweaving the Rainbow: Science, Delusion, and the Appetite for Wonder,* the show "systematically purveys an anti-rational view of the world which, by virtue of its recurrent persistence, is insidious."

[54]Another recent example of the media covering, and thus giving credence to, pseudoscience was a story posted on the Fox News website (Patrick Riley, "After 25 Years, Martian 'Face' Still Raises Questions") on September 8, 2000, about whether or not there's a "face" on Mars, two years after the Mars *Global Surveyor* sent back data providing conclusive evidence that the object was a natural geographical formation. An online poll on the website produced the following results: 37 percent said it was made by aliens, 31 percent thought it was a natural geographical feature, and 32 percent answered that they thought there was not enough data to decide either way.

[55]Robert Park, speech at the National Press Club, July 13, 2000.

enough to have chosen science as a career have an obligation to help the public make that distinction (Park 2000).

How Are Policymakers and Scientists Confronting Public Belief in Pseudoscience?

Members of the science policymaking community concerned about scientific literacy among the general public tend to focus on improving the quality of formal science and mathematics education, usually at the precollege level, and the communication of science-related information to adults, for example, media coverage of topical issues such as biotechnology and global warming. Special committees at both the NSF and the National Academy of Sciences have been studying how to improve the latter. Several reports have been issued (National Science Board 2000). All of these endeavors seem to be directed at how to increase media coverage of science. However, none of the reports addresses the subject of *miscommunication* of science by the media. Most of this miscommunication involved the promotion of pseudoscience and the inaccurate portrayal of the scientific process.

A recent example of this miscommunication was the purported documentary, shown on the Fox Network, "Conspiracy Theory: Did We Land on the Moon?"[56] Astronomers and other members of the scientific community were highly critical of the way science (and everything else) was portrayed on the show.[57] However, the program was so popular with the public it was repeated twice within a six-month period.[58]

Belief in Alternative Medicine

Alternative medicine is another concern. As used here, alternative medicine refers to all treatments that have not been proven effective using scientific methods. A scientist's view of the situation appeared in a recent book (Park 2000):

> Between homeopathy and herbal therapy lies a bewildering array of untested and unregulated treatments, all labeled *alternative* by their proponents. Alternative seems to define a culture rather than a field of medicine—a culture that is not scientifically demanding. It is a culture in which ancient traditions are given more weight than biological science, and anecdotes are preferred over clinical trials. Alternative therapies steadfastly resist change, often for centuries or even millennia, unaffected by scientific advances in the understanding of physiology or disease. Incredible explanations invoking modern physics are sometimes offered for how alternative therapies might work, but there seems to be little interest in testing these speculations scientifically.[59]

In response to the 2001 NSF survey, an overwhelming majority (88 percent) agreed that "there are some good ways of treating sickness that medical science does not recognize." (See appendix table 7-58.) The American Medical Association defines alternative medicine as any diagnostic method, treatment, or therapy that is "neither taught widely in U.S. medical schools nor generally available in U.S. hospitals." However, at least 60 percent of U.S. medical schools devote classroom time to the teaching of alternative therapies, generating controversy within the scientific community. Critics have also been quick to note that one of these therapies, "therapeutic touch," was taught at more than 100 colleges and universities in 75 countries before the practice was debunked by a nine-year-old child for a school science project (Rosa 1998).

Nevertheless, the popularity of alternative medicine appears to be increasing. A recent study documented a 50 percent increase in expenditures and a 25 percent increase in the use of alternative therapies between 1990 and 1997 (Eisenberg et al. 1998) A large minority of Americans (42 percent) used alternative therapies in 1997 and spent a total of at least $27 billion on them. In addition, the authors of the study reported that the use of alternative therapies was:

- at least as popular in other industrialized nations as it was in the United States;
- more popular among women (49 percent) than among men (38 percent) and less popular among African Americans (33 percent) than among members of other racial groups (44.5 percent); and
- higher among those who had attended college, among those who had incomes above $50,000, and among those who lived in the western United States.

Furthermore, among the 16 therapies included in the study, the largest increases between 1990 and 1997 were in the use of herbal medicine (a 380 percent increase), massage, megavitamins, self-help groups, folk remedies, energy healing, and homeopathy. [60]

Among those who reported using energy healing, the most frequently cited technique involved the use of magnets. In 2001, NSF survey respondents were asked whether or not they had heard of magnetic therapy, and if they had, whether they thought that it was *very scientific, sort of scientific,* or *not all scientific*. A substantial majority of survey respondents (77 percent) had heard of magnetic therapy. Among all who had heard of this treatment, 14 percent said it was *very scientific* and another 54 percent said it was *sort of scientific*. Only 25 percent of those surveyed answered correctly, that is, that it is *not at all scientific*.[61] These percentages vary by level of formal education. That is, among those who had not completed high school, only 18 percent chose the *not-at-all-sci-*

[56]The program first aired on February 15, 2001, and was repeated on March 21, 2001.

[57]A comprehensive critique of this program can be found at <http://www.badastronomy.com>.

[58]A 1999 Gallup poll showed that about 6 percent of Americans have doubts about the moon landing; the Fox show claimed the number is 20 percent.

[59]In 1992, Congress created the National Center for Complementary and Alternative Medicine within the National Institutes of Health. With an annual budget of around $100 million, the Center funds research on alternative therapies to find out if they really do work. In addition, a White House Commission on Complementary and Alternative Medicine Policy is currently studying and will be making recommendations to Congress on how to promote research and training in alternative medicine.

[60]The massive increase in herbal medicine is probably attributable to passage of the Dietary Supplement and Health Education Act of 1994, which allows manufacturers to market and sell herbal remedies without having to prove that they are effective.

[61]Researchers have yet to demonstrate that magnetic therapy is effective in treating pain or any other ailment (Park 2000).

entific response, as did 22 percent of the high school graduates, compared with 35 percent of the college graduates. Among those classified as attentive to S&T, 34 percent answered correctly. (See appendix table 7-59.)

Conclusion

Although Americans express a high level of interest in S&T, they lack confidence in their knowledge of these subjects. In 2001, less than 15 percent thought that they were well informed about S&T. In addition, few Americans follow news stories about scientific breakthroughs, research, and exploration. Those with more years of formal education and those who have taken more courses in science and mathematics are more likely than others to express a high level of interest in S&T and to believe that they are well informed.

Data on science literacy in the United States indicate that most Americans do not know a lot about S&T. The percentage of correct responses to a battery of questions designed to assess the level of knowledge and understanding of science terms and concepts has not changed appreciably in the past few years. In addition, approximately 70 percent of Americans do not understand the scientific process. Individuals with more years of formal schooling and who have completed more courses in science and mathematics were more likely than others to provide correct responses to the science literacy questions.

Americans have highly positive attitudes toward S&T, strongly support the Federal Government's investment in basic research, and have high regard for the science community. In addition, most people believe that scientists and engineers lead rewarding professional and personal lives, although a stereotypical image of these professions, rooted in popular culture, does exist and has been difficult to dislodge.

Some individuals harbor reservations about science and technology, especially about technology and its effect on society. Although anti-biotechnology sentiments are much more common in Europe, U.S. support for genetic engineering has declined during the past 15 years.

The vast majority of the public believes that global warming exists and that it should be treated as a serious problem. However, Americans think that environmental pollution is not one of the most important problems facing the country today. They are more concerned about economic and especially education issues—more than two-thirds believe that the quality of science and mathematics education in American schools is inadequate.

Belief in pseudoscience is relatively widespread and growing. In addition, the media have come under criticism, especially by scientists, for sometimes providing a distorted view of science and the scientific process and thus contributing to scientific illiteracy.

Americans get most of their information about the latest developments in S&T from watching television, although the Internet is beginning to make inroads. It is now the leading source of information on specific scientific issues. The rapid growth of information technologies, including the Internet, is thoroughly explored in chapter 8, "Significance of Information Technologies."

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Chapter 8
Significance of Information Technology

Highlights

Trends in IT

- **Information technology (IT) continues to develop and diffuse at a rapid rate.** Exponential quality improvements and cost reductions in microprocessors, storage, and networking are enabling new applications and the expanded use of IT.
- **The number of Internet hosts and servers continues to expand domestically and internationally.** In January 2001, more than 100 million computers were connected to the Internet.
- **The United States continues to be a leader in Internet access and use.** Internet use throughout the world is strongly dependent on telecommunication access charges.
- **Mobile phones are expected to be a major means of accessing the Internet in many countries.** The United States lags behind many other countries in mobile phone penetration. In June 1999, there were 28 mobile phones per 100 inhabitants in the United States compared with more than 60 per 100 inhabitants in Finland and Norway and 27 per 100 inhabitants in all Organisation for Economic Co-operation and Development (OECD) countries.

Societal Implications of IT

- **Businesses have invested heavily in IT.** Industry spending on IT equipment and software rose from less than $200 billion in 1993 to more than $600 billion in 2000.
- **Electronic commerce is having a major impact in traditional businesses.** Approximately 90 percent of electronic commerce (e-commerce) transactions are business to business rather than business to consumer. E-commerce is especially important in manufacturing, which has a history of pre-Internet e-commerce. E-commerce shipments accounted for 12 percent of the total value of manufacturing shipments, or $485 billion.
- **Retail e-commerce sales are still relatively modest.** The Census Bureau estimates 2000 retail e-commerce sales to be $27.3 billion.
- **Increasingly strong evidence suggests that IT is contributing to productivity and economic growth in the overall economy.** Productivity growth is especially evident in IT-producing sectors of the economy, but evidence of positive effects in IT-using sectors exists as well.
- **The Internet access gap between the richest and poorest areas of the world is large and, by some measures, still growing.** In 1997, Internet host penetration rates in North America were 267 times greater than rates in Africa; by October 2000, the gap had grown to a multiple of 540.
- **In the United States, Internet access is increasing for virtually all demographic groups.** The share of households with Internet access increased from 26.2 percent in December 1998 to 41.5 percent in August 2000.
- **Internet access remains greatest among people with the most income and education and is more common among Asian Americans and whites than blacks and Hispanics.** The share of black and Hispanic households with Internet access was about 18 percent lower than the national average. The growth rate in Internet access, however, was highest among these groups.
- **People with disabilities are only half as likely to have access to the Internet as people without disabilities.** IT may greatly aid people with disabilities by making work from home more viable and by providing aids to people with visual and hearing impairments.
- **Government is making increasing use of the Internet to provide constituent information and services and to conduct procurement and payment transactions.** Internet use is increasing at all levels of government. Interagency websites make it possible for government to organize services around segments of the population. State and local governments use the Web for a variety of services, such as issuing licenses, filing taxes, and applying for jobs.

Implications of IT for Science and Engineering

- **Modeling and simulation are becoming increasingly powerful complements to theory and experimentation in many areas of science and engineering.** The fastest supercomputers now run at more than 10 trillion operations per second. Modeling and simulation are increasingly used in a wide range of applications, including climate modeling, engineering design, and genomics.
- **Large, shared scientific databases have become key resources in many areas of science and social science.** Examples include gene and protein databanks, collections of satellite sensing data, and social science databases.
- **Electronic versions of journals, preprint servers, and other electronic resources are changing how researchers receive and disseminate technical information.** Research libraries are faced with competing demands for electronic and paper journals. Academic journals are facing challenges to their business models.

- **IT supports increased and larger scale research and development collaborations.** Many multi-institution projects now use advanced collaborative tools, Internet videoconferencing, remote access to scientific instruments, and shared databases.
- **IT has contributed to a market environment characterized by rapid innovation.** In most industries, companies know they must constantly innovate if they are to succeed in a market influenced by continuing improvements in IT.
- **IT affects the organization of innovation, within and among organizations.** IT can speed the flow of technical information within firms. It can also support innovation-related activities that are increasingly performed outside large firms by large and small companies that collaborate with each other and with academic institutions and government agencies.
- **Innovation in IT is accelerating and is different in some respects from innovation in other areas of technology.** IT patents' share of all U.S. patents increased from 9 percent in 1980 to 25 percent in 1999. IT patents cite other technology patents more extensively than scientific papers.
- **IT certificate courses are changing the way IT workers are trained.** Companies and associations have created more than 300 new certifications since 1989. Approximately 1.6 million individuals had earned about 2.4 million IT certificates by early 2000; half were earned by students outside the United States.
- **Use of IT in both traditional university courses and distance education continues to expand.** Many questions remain about the extent to which IT will change higher education.

Introduction

Information technology (IT) is a manifestation of public and private investment in science and engineering (S&E) that is enabling broad and significant changes in society. Many observers (Drucker 1999; Alberts and Papp 1997; Castells 1996; Freeman, Soete, and Efendioglu 1995; Kranzberg 1989) compare the rapid development and expansion of IT to the industrial revolution in terms of its potential scope and impact on society. Few other modern advances in technology have had the capacity to affect so fundamentally the way people work, live, learn, and govern themselves. As with the industrial revolution, both the time and direction of many of the changes are difficult to predict.

The relationship between IT and S&E has two aspects. In addition to being a product of S&E, IT is enabling changes in S&E. IT has become an important part of the overall U.S. investment in research and development (R&D) and affects how R&D is conducted in all disciplines. For example, scientists and engineers make extensive use of computer modeling and simulation and large shared databases; advances in networking facilitate global collaboration in research and product development; and IT producers employ scientists and engineers, implement the results of academic research, and conduct significant amounts of applied R&D. IT also influences the pipeline for S&E through its effects on the demand for people with technical skills and through its use in education at all levels.

This chapter addresses IT as a leading example of the effects of investment in S&E on society and focuses on IT as a major force underlying changes in the S&E enterprise.

A complete discussion of the impact of IT on society and the economy is beyond the scope of this chapter because IT has become integrated into nearly all aspects of society, from entertainment to national security. Moreover, in recent years, other government publications (Council of Economic Advisers 2001; U.S. Department of Commerce (DOC) 2000a,b) have begun to cover important aspects of the digital economy. References and notes in this chapter direct the reader to some of these other more detailed sources.

The chapter begins with a description of trends in IT and then discusses some major implications of IT, including effects on the economy and the general public. Finally, it discusses the effects of IT on elements of the S&E system, including R&D, innovation processes, higher education, and the IT workforce.

Trends in IT

IT, as defined in this chapter, reflects the combination of three key technologies: digital computing, data storage, and the ability to transmit digital signals through telecommunications networks. Rapid changes in semiconductor technology, information storage, and networking, combined with advances in software, have enabled new applications, cost reductions, and the widespread diffusion of IT. The expanding array of applications makes IT more useful and further fuels the expansion of IT.

Semiconductor Technology

Enormous improvements in the performance of integrated circuits and cost reductions brought about by rapid miniaturization have driven much of the advances in IT. See sidebar, "Moore's Law."

A related trend is the migration of computing into other devices and equipment. This is not a new trend—automobiles have been major users of microprocessors since the late 1970s—but as semiconductor chips become more powerful and less expensive, they are becoming increasingly ubiquitous. Also, new capabilities are being added to chips. These include microelectromechanical systems (MEMs), such as sensors and actuators, and digital signal processors that enable cost reductions and extend IT into new types of devices.[1] Examples of MEM devices include ink-jet printer cartridges, hard disk drive heads, accelerometers that deploy car airbags, and chemical and environmental sensors (Gulliksen 2000). Trends toward improvements in microelectronics and MEMs are expected to continue. See sidebar, "Nanoscale Electronics."

Information Storage

Disk drives and other forms of information storage reflect similar improvements in cost and performance. (See figure 8-2.) As a consequence, the amount of information in digital form has expanded greatly. Estimates of the amount of original information (excluding copies and reproductions) suggest that information on disk drives now constitutes the majority of information (Lyman and Varian 2000). (See appendix table 8-2.) Increasingly, much of this information is available on-line.

Computers, reflecting the improvements in their components, have shown similar dramatic improvements in performance. Due to improvements in semiconductors, storage, and other components, price declines in computers (adjusted for quality) have actually accelerated since 1995. (See figure 8-3.)

Networking

The third trend is the growth of networks. Computers are increasingly connected in networks, including local area networks and wide area networks. Many early commercial computer networks, such as those used by automated teller machines and airline reservation systems, used proprietary systems that required specialized software or hardware (or both). Increasingly, organizations are using open-standard, Internet-based systems for networks.[2] As people have been

[1]Related terms are microstructure technologies or microsystem technologies (MSTs). To some, MSTs include all chips that have noncomputing functions (such as sensors or actuators), whereas MEMs are the subset of MSTs that have moving parts (Gulliksen 2000).

[2]The Internet, as defined by the Federal Networking Council, refers to the global information system that "(i) is logically linked together by a globally unique address space based on the Internet Protocol (IP) or its subsequent extensions/follow-ons; (ii) is able to support communications using the Transmission Control Protocol/Internet Protocol (TCP/IP) suite or its subsequent extensions/follow-ons and/or other IP-compatible protocols; and (iii) provides, uses, or makes accessible—either publicly or privately—high level services layered on the communications and related infrastructure described herein" (Kahn and Cerf 1999).

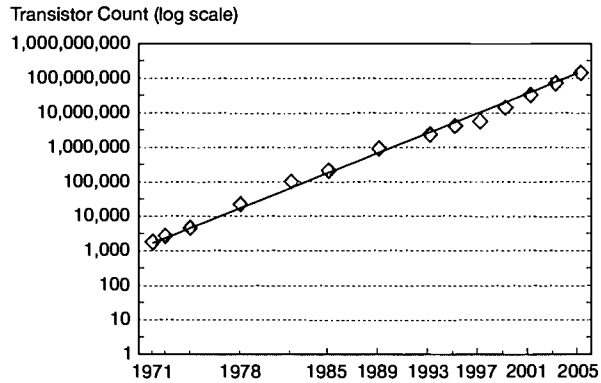
Moore's Law

The number of transistors on a chip has doubled approximately every 12 to 18 months for the past 30 years—a trend known as Moore's Law. (See figure 8-1 and appendix table 8-1.) This trend is named for Gordon Moore of Intel, who first observed it. Performance has increased along with the number of transistors per chip, while the cost of chips has remained generally stable. These factors have driven enormous improvements in the performance/cost ratio.

Moore's Law has become the basis for planning in the semiconductor industry. The International Technology Roadmap for Semiconductors (2000), a plan for semiconductor development prepared collaboratively by semiconductor industries around the world, is geared toward continuing improvements at approximately the rate predicted by Moore's Law.

Kurzweil (2001) suggests that this trend is not limited to semiconductors in the last few decades but that calculations per second per dollar have been increasing exponentially since electromechanical calculators were introduced in the early 1900s.

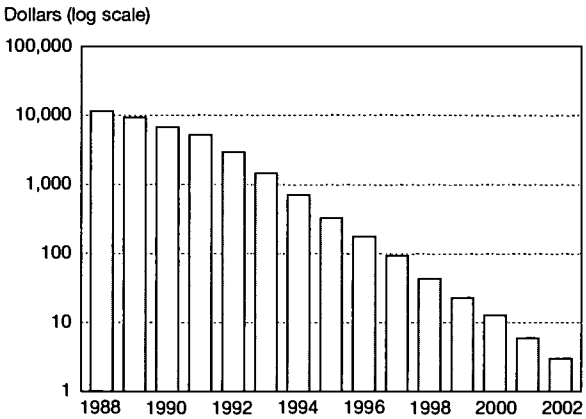
Figure 8-1.
Moore's Law: 1971–2005



NOTES: The line on the graph represents the trend that defines Moore's Law. The data points reflect actual (1971–2001) and projected (2003–2005) data.

See appendix table 8-1. *Science & Engineering Indicators – 2002*

Figure 8-2.
Cost per gigabyte of stored information: 1988–2002



NOTES: 2001 and 2002 data are projected.

SOURCE: P. Lyman and H. R. Varian. 2000. "How Much Information?" Available at <http://www.sims.berkeley.edu/how-much-info/>. Accessed July 2, 2001.

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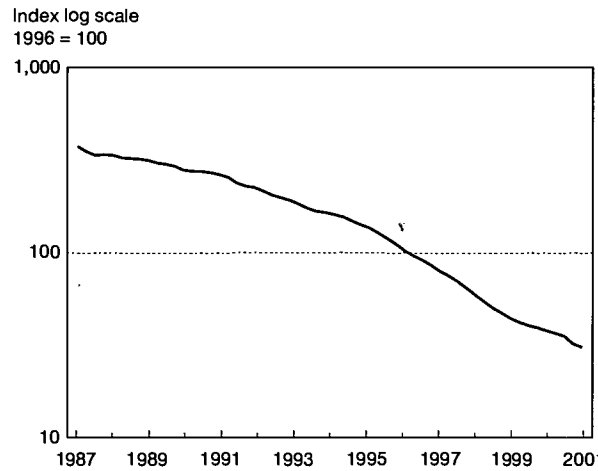
Figure 8-3.
Computer price declines



SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis, National Accounts Data.
Available at <http://www.bea.doc.gov/bea/dn1.htm>.

Science & Engineering Indicators – 2002

able to interconnect and share information with each other, the value of IT has increased. See sidebar, "Metcalfe's Law."

The growth in networking has been enabled by rapid advances in optical networking. In 1990, a single optical fiber could transmit about 1 billion bits per second; by 2000, a single fiber could transmit nearly 1 trillion bits per second (Optoelectronics Industry Development Association 2001).

The growth in networking is best illustrated by the rapid growth of the Internet. Worldwide, there were nearly 100 million Internet hosts—computers connected to the Internet—in July 2000, up from about 30 million at the beginning of 1998. (See figure 8-4.) Networking is evolving in several ways: more people and devices are becoming connected to the network,

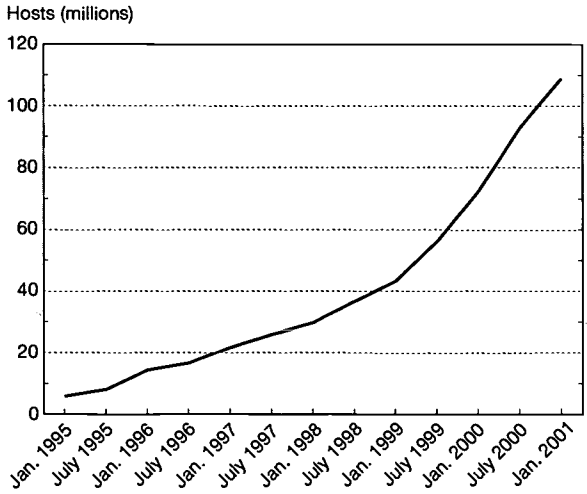
Nanoscale Electronics

As miniaturization proceeds, it may lead to the emergence of nanoscale devices (devices with structural features in the range of 1 to 100 nanometers). The International Technology Roadmap for Semiconductors (2000) projects semiconductor manufacturing to approximately 2010, at which time semiconductors are expected to have 0.1-micron (100-nanometer) structures. Beyond this, the principles, fabrication methods, and ways of integrating devices into systems are generally unknown. Potential applications of nanoscale electronics 10–15 years in the future include (National Science and Technology Council 2000):

- microprocessor devices that continue the trend toward lower energy use and cost per gate, thereby improving the efficacy of computers by a factor of millions;
- communications systems with higher transmission frequencies and more efficient use of the optical spectrum to provide at least 10 times more bandwidth, with consequences for business, education, entertainment, and defense;
- small mass storage devices with capacities at multiterabit levels, 1,000 times better than today; and
- integrated nanosensor systems capable of collecting, processing, and communicating massive amounts of data with minimal size, weight, and power consumption.

Such advances would continue to expand the cost effectiveness and utility of IT in new applications.

Figure 8-4.
Internet domain survey host count worldwide



SOURCE: Internet Software Consortium (<http://www.isc.org>).

Science & Engineering Indicators – 2002

the speed and capacity of connections are increasing, and more people are obtaining wireless connections. See sidebar, "Wireless Networking."

Applications of IT

A fourth trend is the ever-increasing array of applications that make IT more useful. Computers were originally used primarily for data processing. As they became more powerful and convenient, applications expanded. Word processing, spreadsheets, and database programs were among the early minicomputer and PC applications. Over the past two decades, innovations in software have enabled applications to expand to include educational software, desktop publishing, computer-aided design and manufacturing, games, modeling and simulation, networking and communications software, electronic mail, the World Wide Web, digital imaging and photography, audio and video applications, electronic commerce applications, groupware, file sharing, search engines, and many others. The growth and diversity of applications greatly increase the utility of IT, leading to its further expansion.

In the 1960s, computers were used primarily in the R&D community and in the offices of large companies and agencies. Over the past few decades, the expansion of applications has contributed to the rapid diffusion of IT to affect nearly everyone, not just the relatively few people in computer-intensive jobs. IT has become common in schools, libraries, homes, offices, and businesses. For example, corner grocery stores use IT for a variety of electronic transactions such as debit and credit payments, and automobile repair shops use IT to diagnose problems and search for parts from dealers. New IT applications are still developing rapidly; for example, instant messaging and peer-to-peer communication systems such as Napster are examples that have become popular in the past 2 years. See sidebar, "Peer-to-Peer Applications."

Societal Implications

In contrast to the steady and rapid advances in semiconductor technology, information storage, networking, and applications, the interaction of IT with various elements of society is more complex. Although IT performance in many cases improves exponentially, the utility to users in many cases improves more slowly (Chandra et al. 2000). For example, a doubling of computer processing speeds may bring only small improvements in the most widely used applications, such as word processing or spreadsheets. Furthermore, although it is common to talk about the "impact" or "effect" of IT or the Internet—implying a one-way influence—the interaction of IT with society is multidirectional and multidimensional. Over the past two decades, many studies have explored how organizations use IT. Cumulatively, these studies have found that a simple model of IT leading to social and organizational effects does not hold (Kling 2000). Instead, IT is developed and used in a social context in which organizations and individuals shape the technology and the way it is used. The implementation of IT is an ongoing social process that involves

Metcalfe's Law

Metcalfe's Law states that the value of a network grows in proportion to the square of the number of users (Metcalfe 1996; and Downes, Mui, and Negroponte 1998). Just as the value of a telephone to a user depends on the number of other people who also have a telephone, the value of being on a computer network depends on how many other people are also on the network. As a network grows, its value to each individual user increases, and the total value of the network increases much faster than the number of users. This is also referred to as "network effects."

Technologies other than telecommunications also exhibit network effects. The value of owning a certain type of word processing software, for example, depends on how many other people use the same (or at least compatible) software to share files. A more widely used technology also becomes more valuable because more people are trained to use or service it. The more valuable a technology becomes, the more new users it will attract, increasing both its utility and the speed of its adoption by still more users.

Metcalfe's Law explains why the adoption of a technology often increases rapidly once a critical mass of users is reached and the technology becomes increasingly valuable. Because many technology developers are now aware of this phenomenon, initially they often heavily subsidize technologies that exhibit network potential to attain a critical mass of users. The Internet has been the most dramatic demonstration of Metcalfe's Law. Many Internet-related services also exhibit network effects, and many companies have heavily discounted their services in hopes of later being able to capitalize on the value of the network they have created.

The presence of network effects has implications for antitrust law. It implies that markets with strong network effects may tend toward monopoly, as the dominant technology becomes more valuable and the less widely used technology becomes less valuable (even if it is technically superior). It also may become more difficult for new entrants to become established if they need to compete with an established network.

changes in people's roles and in organizational procedures. Incentives and trust are important factors in the success of IT implementation. The following sections examine the effects of IT on the economy and the general public.

Economic Implications

Over the past two decades, there has been considerable debate over the extent to which IT is transforming the economy. Businesses have invested heavily in IT in anticipation of large productivity increases and economic transformations. Only recently, however, have economists found evidence of sector- or economywide IT-related productivity increases, and the question of whether the productivity gains are distributed across the economy or concentrated in the IT sector is still under debate (U.S. DOC 2000a; Council of Economic Advisers 2001).

Although topics such as the expansion of e-commerce and the stock market valuation of Internet companies have received much recent attention, these are only surface manifestations of the role of IT in the economy. This role is both broad and deep and involves changing the composition of the economy, changing productivity (primarily in traditional businesses), and changing both the nature of work and the needs of the workforce. This section outlines these changes.[3]

IT Applications in Business

Businesses have invested heavily in IT. The purchase of IT equipment continues to be the largest category of industry spending for all types of capital equipment (including industrial, transportation, and others). In current dollars, industry spending on IT equipment and software rose from less than $200 billion in 1993 to more than $600 billion in 2000. (See figure 8-7.)

Businesses use IT in many different ways. Some IT applications automate a variety of basic business activities, from production control systems in manufacturing to word processing and financial calculations in office work. Other applications involve databases and information retrieval that support management, customer service, logistics, product design, marketing, and competitive analysis. Through IT, companies can combine computing and communications to facilitate ordering and product tracking. IT functions often are implemented as mechanizations of older, manual processes; ideally, however, they involve fundamental redesign of processes. The use of IT by business began with and in many instances continues to rely on mainframe computers, minicomputers, and microcomputers, as well as telephone networks including the public switched network and leased-line private networks.[4]

More recently, the business community has begun to broaden integration of IT-based systems and, through them, integration of enterprises. The spread of Internet technology and the proliferation of portable computing and communications devices have accelerated trends that began in the past two decades and now are viewed as "electronic commerce" or e-commerce. Companies now use the World Wide Web to communicate with the general public and also use similar but more secure intranets and extranets to communicate with employees, suppliers, and distribution partners.

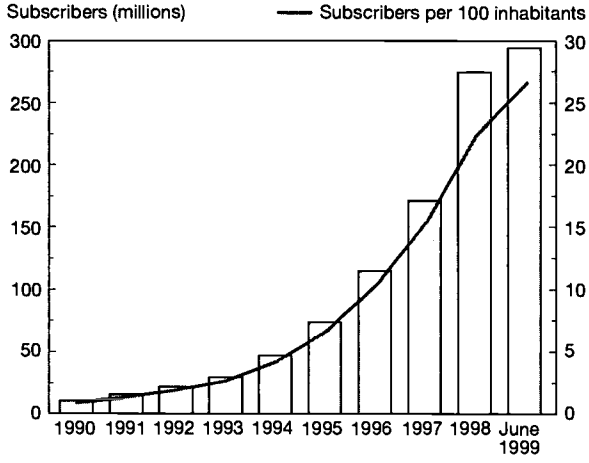
[3]A major U.S. Government source of information on IT and the economy is the *Digital Economy*, a series of reports published by the U.S. DOC's Economics and Statistics Administration. The 2001 edition of the *Economic Report of the President* (Council of Economic Advisers 2001) also focuses extensively on the role of IT in the economy.

[4]Businesses now also rely on virtual private networks, which use the open, distributed infrastructure of the Internet to transmit data between corporate sites, with encryption and other security measures to protect the data against eavesdropping and tampering by unauthorized parties.

Wireless Networking

At present, most people in the United States connect to the Internet through wires. Much of the growth in Internet connections, however, is expected to be through wireless connections. Currently, more people around the world have mobile phones than Internet access. Figure 8-5 shows the growth in mobile phone subscribers in Organisation for Economic Co-operation and Development (OECD) countries; figure 8-6 shows mobile phone penetration in individual OECD countries.

Figure 8-5.
Mobile phone subscriber growth in OECD countries: 1990–99



OECD = Organisation for Economic Co-operation and Development

See appendix table 8-3.

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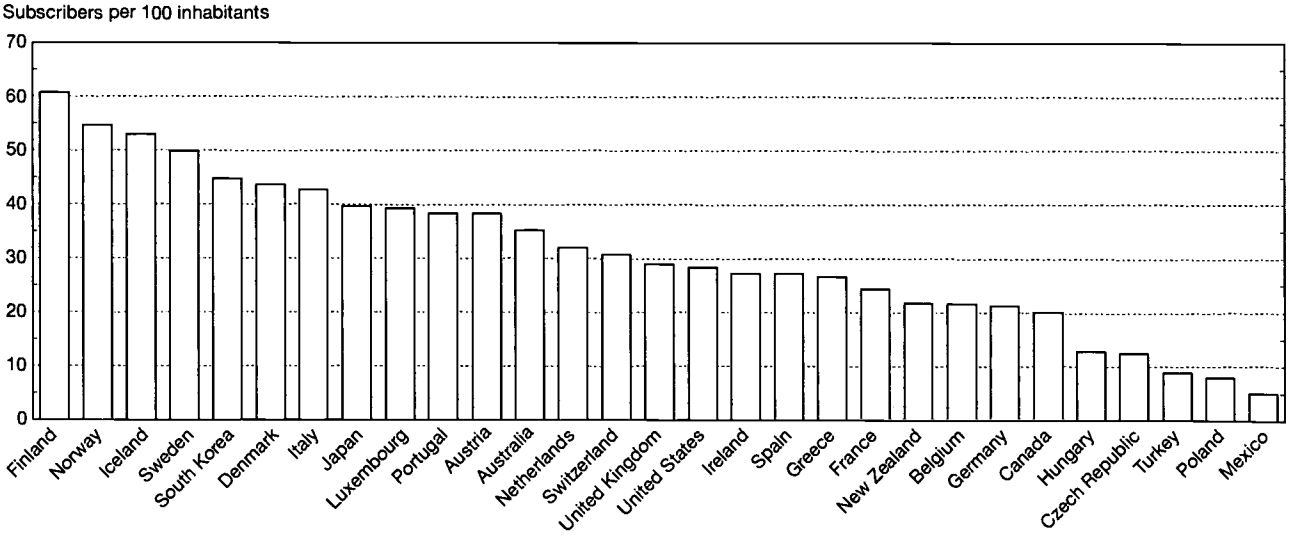
Over the next few years, most mobile phones will obtain Internet access (Wong and Jesty 2001). By 2005, the penetration level of mobile devices (including phones) with data capabilities is expected to approach mobile phone user penetration levels in the United States, Western Europe, and Japan. It is expected that, by then, all mobile terminals will be data enabled and subscribers will be able to access data and Internet services via mobile phones. As a result, it is likely that in many areas of the world where there are more mobile phone users than personal computer users, more people will have access to the Internet through mobile phones than through computers. International Data Corporation estimates that the number of wireless Internet subscribers in the United States, Western Europe, Asia/Pacific, and Japan will increase from 5 million in 1999 to more than 329 million by 2003 (Wrolstad 2001). Mobile Internet usage is growing particularly fast in Japan, primarily because of the popularity of the relatively low-cost NTT DoCoMo "I-mode" phones, which are being widely used for e-mail and games.

Because of the relatively small screen size, limited memory, and weak data entry capabilities of mobile phones, Internet access through mobile phones is qualitatively different from access through computers. Efforts are under way to determine what applications will work effectively over mobile phones. Successful mobile applications are likely to differ from typical computer-based applications. In addition to limited e-mail and Web browsing capabilities, mobile phones may also offer various location-based services, such as information on restaurants, shops, and services in the vicinity of the phone's current location.

Figure 8-6.
Mobile phone penetration in OECD countries: June 1999

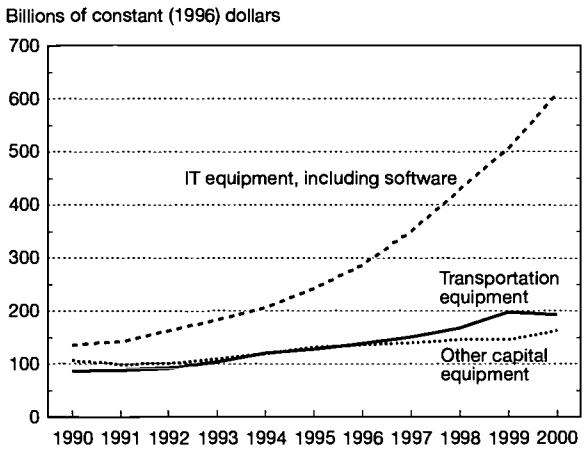


OECD = Organisation for Economic Co-operation and Development

See appendix table 8-3.

Science & Engineering Indicators – 2002

Figure 8-7.
Industry spending on capital equipment



SOURCE: Bureau of Economic Analysis. Available at http://www.bea.doc.gov/bea/dn/nipaweb/

Science & Engineering Indicators – 2002

Growth of e-Commerce

The growth of e-commerce has changed the focus of the discussion of IT's role in the economy. Previously, the focus had been on how IT applications within companies could improve internal operations. With the growth of e-commerce, the focus has shifted to how businesses are using IT to communicate with customers and suppliers and develop new distribution chains and new methods of marketing and selling.

Definitions of e-commerce vary. The U.S. Census Bureau (Mesenbourg 2001) defines e-commerce as the value of goods and services sold on-line, with "on-line" including the use of the Internet, intranets, extranets, and proprietary networks that run systems such as electronic data interchange (EDI). Other definitions include only transactions that use open (generally Internet-based) systems rather than proprietary electronic systems.

E-commerce includes both business-to-business transactions and business-to-consumer transactions. The following sections summarize developments in these two areas.

Business-to-Business e-Commerce. Although business-to-consumer e-commerce has attracted more public attention, electronic transactions between businesses are much larger in volume. Because business-to-business e-commerce is built on the history of pre-Internet electronic transactions, many companies have substantial relevant expertise already in place. As a result, business-to-business e-commerce has expanded rapidly.

The U.S. Census Bureau (2001b) has produced estimates of 1999 e-commerce activity for several sectors of the economy. In manufacturing, e-commerce shipments accounted for 12.0 percent of the total value of shipments or $485 billion. For merchant wholesalers, e-commerce sales represented 5.3 percent of total sales or $134 billion. The Census Bureau estimates that approximately 90 percent of e-commerce transactions are business to business rather than business to consumer. The U.S. Census Bureau (2001b) also suggests that the manufacturing sector has a higher rate of e-commerce than other sectors because manufacturing firms (especially large ones) have been using private data networks for business-to-business transactions for many years.

Private estimates of business-to-business e-commerce in 2000 and 2004 are shown in text table 8-1. The private estimates vary in part because each firm uses somewhat different definitions. Despite the slowdown in the economy in 2001, many analysts still forecast continued growth for business-to-business e-commerce (Thompson 2001).

Business-to-business e-commerce enables businesses to offer their customers additional services and the means to improve communication. By improving communication, business-to-business e-commerce makes it possible for businesses to outsource more easily and to streamline and augment supply chain processes. It also allows businesses to eliminate

Peer-to-Peer Applications

A new class of applications known as peer-to-peer (P2P) services have become widely used. These applications take advantage of computing resources, such as storage, processing cycles, and content, available at the "edge" of the Internet, and include computers that are only temporarily connected to the Internet (Shirky 2000). In its early days, the Internet primarily connected computers at research institutions, and these computers shared resources on a fairly equal basis. Since the advent of the World Wide Web, the Internet has evolved into a client-server architecture, in which client computers connect to the Web primarily to download information. Many client computers are not permanently connected to the Web, do not have permanent Internet Protocol (IP) addresses, and thus are not available for other computers to access. P2P services provide a way for these computers to be available to others on the Internet.

The most widely known of the P2P services is Napster. Founded in 1999 by Shawn Fanning, then an 18-year-old college freshman, Napster enables users to find and access music files that are available on other users' computers. By March 2001, the Napster service had grown to the point where it was accessed by more than 4 million individual users each day (defined by unique IP addresses) and consistently had up to 500,000 concurrently active users (Napster 2001). Because Napster made it possible for people to share and copy copyrighted information, it has also raised some substantial intellectual property concerns. As a result of litigation, Napster has been required to remove copyrighted material from its network.

Many other less visible and less controversial P2P applications have been developed, including applications that let people access computer-based information across companies or government agencies, and applications that use idle computers to carry out complex scientific calculations (Ante, Borrus, and Hof 2001).

Text table 8-1.
U.S. business-to-business e-commerce estimates and forecasts: 2000 and 2004
(Billions of dollars)

Firm	Study date	2000	2004
Boston Consulting Group	September 2000	1,200	4,800
Forrester Research	February 2000	406	2,696
Gartner Group	March 2001	255	3,600
Giga Information	December 2000	957	3,804
International Data Corporation (IDC)	April 2001	117	1,000
Jupiter Research	September 2000	336	4,592
Yankee Group	April 2000	740	2,780

NOTE: Each firm listed defines business-to-business e-commerce differently.

SOURCE: *The Industry Standard*. Available at <http://www.thestandard.com/article/image/popup/0,1942,15847-15845-15846-15848,00.html>. Accessed August 19, 2001.

Science & Engineering Indicators – 2002

some intermediary organizations between customers and suppliers but has also has given rise to new classes of business intermediaries, such as on-line auctions.

These new intermediaries can provide new places for buyers and sellers to meet, allow a variety of pricing schemes to flourish, alter the roles of traditional intermediaries, facilitate complex transactions, and shift the balance of power among market participants by making vast amounts of information available at very low costs (U.S. DOC 2000a). These on-line marketplaces enable buyers to solicit bids from a broader range of suppliers and allow suppliers to develop relationships with more buyers. In many cases, however, it is not yet clear how well these new intermediaries will work, in part because they do not replace certain functions such as the establishment of personal relationships based on trust found in traditional forms of business interaction.

The on-line marketplaces under development in the automotive industry exemplify this emerging form of business-to-business e-commerce. In February 2000, General Motors Corporation, Ford Motor Company, and Daimler Chrysler launched the e-business exchange Covisint in an attempt to consolidate their $600 billion in purchasing power, gain efficiencies, and lower costs (U.S. DOC 2000a). The Federal Trade Commission investigated the exchange because of antitrust concerns, and growth has been slower than expected (Welch 2001). The automobile industry has launched other exchanges similar to Covisint. In other examples, Sears, Roebuck and Company is joining with Carrefour SA, a Paris-based retailer, to create GlobalNetXchange, an on-line marketplace for the retail industry, and Boeing, Lockheed Martin, BAE Systems, and Raytheon Company plan to develop an Internet trading exchange for the global aerospace and defense industry (U.S. DOC 2000a).

Business-to-Consumer e-Commerce. Business-to-consumer (or retail) e-commerce has spawned many new businesses that have no physical stores but can deliver a wide variety of goods on request. In response, many traditional retail stores have launched their own e-commerce strategies.

Retail e-commerce sales are still modest. The U.S. Census Bureau (2001a) reported 2000 retail e-commerce sales to be $27.3 billion. In 1999, (the latest year for which detailed information is available) 76 percent of e-commerce sales were in North American Industry Classification System (NAICS) code 454110—Electronic Shopping and Mail-Order Houses. Text table 8-2 shows NAICS 454110 sales data by merchandise category. The two leading categories, computer hardware and books and magazines, account for approximately 50 percent of the NAICS 454110 total e-commerce sales.

The Census Bureau quarterly estimates of retail e-commerce sales are shown in figure 8-8. These estimates encompass sales of goods and services over the Internet, extranets, EDI networks, and other on-line systems. In these transactions, payment may or may not be made on-line. The figures include only retail firms and do not include on-line travel services, financial brokers and dealers, or ticket sales agencies, all of which are not classified as retail.

One mode of retail e-commerce that has expanded rapidly is the on-line auction, which puts buyers and sellers directly in touch with each other to negotiate a price. As of April 2001, eBay (one of the first and largest on-line auction enterprises) offered more than 5 million items for sale. During 2000, the value of goods traded on the eBay site was more than $5 billion (eBay 2001).[5] Hundreds of other on-line auction enterprises have been established, and many early e-commerce retailers such as Amazon.com and Dell Computer have added auctions as additional features of their websites.

IT Effects on Productivity and Economic Growth

As the IT sector has grown faster than the economy as a whole, its share of the economy has increased. (See figure 8-9.) IT also is commonly credited as being a key factor in the economy's structural shift from manufacturing to services. The widespread diffusion of IT is largely responsible for the growth in existing services (such as banking) and the creation of new service industries (such as software engineering) (Computer Science and Telecommunications Board (CSTB) 1994a; Link

[5]These sales are not captured in the Census Bureau figures, which only include sales from e-marketplaces that take title to the goods they sell. Generally, most e-marketplaces arrange for the purchase or sale of goods owned by others and do not take title to the goods they sell (U.S. Census Bureau 2001c).

Text table 8-2.
Electronic shopping and mail-order house total (NAICS 454110) and e-commerce sales by merchandise line: 1999

Merchandise Items	Sales (millions of dollars) Total	Sales (millions of dollars) E-commerce	E-commerce percentage of total sales	Percent distribution E-commerce	Percent distribution Total
Total sales	93,149	11,733	12.6	100.0	100.0
Books and magazines	3,611	1,631	45.2	13.9	3.9
Clothing and clothing accessories (including footwear)	12,363	757	6.1	6.5	13.3
Computer hardware	25,098	4,336	17.3	37.0	26.9
Computer software	2,484	760	30.6	6.5	2.7
Drugs, health aids, and beauty aids	10,362	258	2.5	2.2	11.1
Electronics and appliances	2,258	399	17.7	3.4	2.4
Food, beer, and wine	1,540	230	14.9	2.0	1.7
Furniture and home furnishings	5,494	240	4.4	2.0	5.9
Music and videos	4,490	809	18.0	6.9	4.8
Office equipment and supplies	7,502	600	8.0	5.1	8.1
Toys, hobby goods, and games	2,052	391	19.1	3.3	2.2
Other merchandise[a]	14,723	966	6.6	8.2	15.8
Nonmerchandise receipts[b]	1,173	356	30.3	3.0	1.3

[a]Merchandise such as jewelry, sporting goods, collectibles, souvenirs, auto parts and accessories, hardware, and lawn and garden supplies.

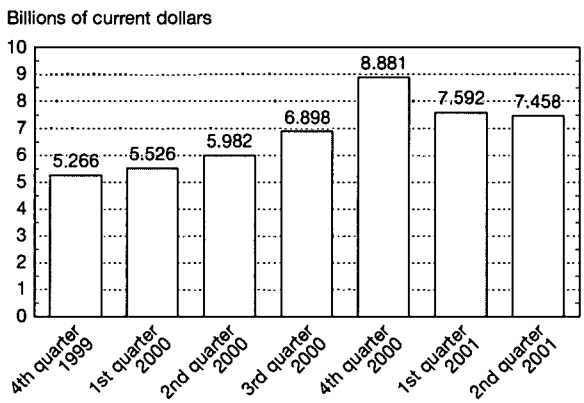
[b]For example, auction commissions, shipping and handling, customer support, and online advertising.

NOTES: Details may not add to totals because of rounding. Data are grouped according to merchandise categories used in the *Annual Retail Trade Survey*. North American Industrial Classification System (NAICS) 454110, "Electronic shopping and mail-order houses" comprises businesses primarily engaged in retailing all types of merchandise through catalogs, television, and the Internet. Data are preliminary and subject to revision.

SOURCE: U.S. Bureau of the Census. *1999 Annual Retail Trade Survey.*

Science & Engineering Indicators – 2002

Figure 8-8.
Estimated quarterly U.S. retail e-commerce sales: 4th quarter 1999–2nd quarter 2001

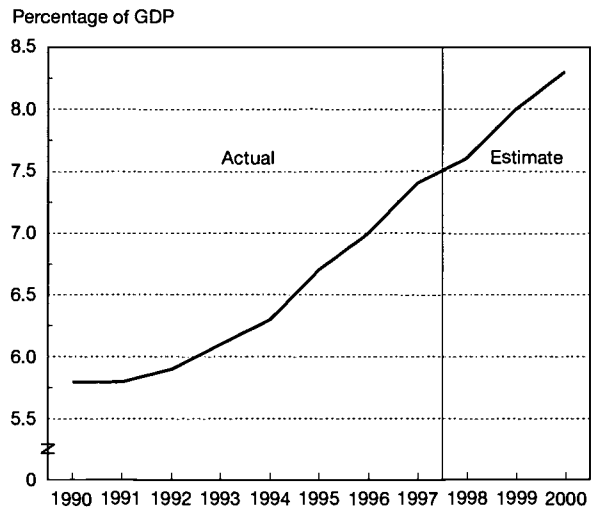


NOTE: Data are not adjusted for seasonal, holiday, or trading day differences.

SOURCE: U.S. Department of Commerce. Available at <http://www.census.gov/mrts/www/current.html>

Science & Engineering Indicators – 2002

Figure 8-9.
Economy share of IT-producing industries



GDP = gross domestic product

SOURCE: U.S. Department of Commerce, Economics and Statistics Administration, 2000. *Digital Economy 2000*. Washington, DC.

Science & Engineering Indicators – 2002

and Scott 1998). In addition to its role in changing the structure of the economy, IT affects productivity and economic growth overall, as discussed in the following sections.

The Productivity Paradox: Recent Studies. For a long time, little evidence showed that IT had improved productivity in the aggregate. Solow (1987) noted that "we see computers everywhere but in the productivity statistics," an observation that became referred to as the "productivity paradox." Many econometric analyses failed to find any sector- or economywide productivity benefits for IT (for reviews of this literature, see Brynjolfsson and Yang 1996 and CSTB 1994a).

Several explanations have been put forward for the productivity paradox. One explanation involves measurement difficulties. Much of the expected effect of IT would occur in the service industries, where productivity is always difficult to measure. IT may lead to improvements in services that do not readily show up as productivity improvements. Another possibility is that productivity has not increased in the aggregate because it takes time and investment in training for organizations to learn to use IT effectively. Using IT is expensive not only in terms of initial costs but also in terms of the cost to maintain and upgrade systems, train people, and make the organizational changes required for a company to benefit from IT. Such costs may greatly exceed the original investment in IT equipment. Although some companies have successfully made these investments and have greatly benefited, many have not. Another possible explanation is that until the 1990s, business investment in IT was small enough that one would not expect to see a large productivity increase in the overall economy.

In the past few years, however, several studies that have used a variety of approaches have concluded that IT is having a positive effect on productivity (U.S. DOC 2000a; Council of Economic Advisers 2001). Economists who were skeptical about the impact of computers on U.S. productivity have begun to credit IT for increases in the growth rates of output and productivity since 1995. Several studies found that the acceleration in productivity growth during the mid-1990s was attributable largely to increased computer use (capital deepening) among IT users and also to technical advances and innovations by IT producers (U.S. DOC 2000a).

Sector-level studies also suggest that IT investments contribute to productivity growth. U.S. DOC (2000a) found that IT-intensive goods-producing industries have achieved higher productivity gains than their non-IT-intensive counterparts but that the effect of IT on service industry productivity will remain clouded until better output measures are developed.

Recent firm-level analyses also have shown that IT contributes substantially to productivity growth. Brynjolfsson and Hitt (2000, 1998, 1996, 1995) have explored the relationship between computers and productivity growth at the firm level and have found positive correlations between IT and productivity. They also have found that investments in organizational change greatly increase IT's contribution to productivity. Brynjolfsson and Hitt (1998) conclude that although computerization does not automatically increase productivity, it is an essential component of a broader system of organizational change that does.

Inflation and Overall Economic Growth. IT appears to be having positive effects on inflation and growth. These effects derive primarily from price and growth trends in the IT sector rather than from IT applications in other sectors. U.S. DOC (1999a, 2000a) found that declining prices in IT-producing industries have helped to reduce inflation in the economy as a whole. Declining IT costs may also have helped other industries to control their costs. DOC also found that IT-producing industries have contributed substantially to overall economic growth, accounting for more than one-third of the growth in real output between 1995 and 1999.

Outlook for Continued Productivity Growth. Litan and Rivlin (2001) estimated how much the Internet might contribute to productivity increases in the future. In their study, experts in particular sectors of the economy examined how the Internet was being used in leading firms or institutions in these sectors; what the impact on cost, prices, and productivity appeared to be; and how rapidly the Internet's impact might spread to other parts of the sector. See sidebars, "The Internet and Productivity in the Automobile Industry" and "The Internet and Productivity in the Personal Computer Industry." Based on these sector analyses, Litan and Rivlin concluded that the Internet has the potential to add as much as 0.2–0.4 percent a year to productivity. The improvements result from the application of networked computing via the

The Internet and Productivity in the Automobile Industry

The Internet can potentially lead to cost reductions and productivity improvements in the automobile industry in a variety of ways (Fine and Raff 2001). Potential savings can occur in:

- product development (improved ease of making engineering changes, reduced cost of making changes, lower direct cost of communication and coordination, faster product development cycle speed);
- procurement and supply (reduced transaction costs in purchasing, more bulk buying and shipping, more price competition among suppliers, improved logistics and reduced "rush" orders as a result of better information);
- manufacturing system (improved design for ease of manufacture, faster setups, smaller lot sizes, reduced inventory, higher capacity utilization, more outsourcing); and
- vehicle order-to-delivery management (reduced order-to-delivery cycle times, lower inventory levels in pipeline, better matching of supply to demand, less discounting of undesired stock, lower sales commissions, fewer dealers and lower total overhead, fewer distribution centers, and lower shipping costs).

The estimated combined potential for cost reductions in these areas is equivalent to 13 percent of the cost of automobiles. Achieving these savings, however, would require changes in the manufacturing system and supply chain that would be difficult to bring about, and actual cost saving may be much lower. Nevertheless, because the automobile industry is large, achieving only part of these savings could result in measurable productivity changes in the overall economy.

The Internet and Productivity in the Personal Computer Industry*

The personal computer (PC) industry has been closely linked to development of the Internet. The availability of inexpensive PCs has fueled expansion of the Internet, and the Internet, in turn, has driven much of the demand for PCs. It is not surprising that the PC industry has been an early adopter of the Internet as a business tool.

Cutthroat pricing, rapid technological change, global supply and distribution chains, and changing consumer tastes have characterized the PC industry. The modularity of PCs and the availability of components on the open market have led to intense competition at many levels in the industry. No single business and distribution model has dominated the industry, which includes large global players such as Compaq, Hewlett-Packard, and IBM that sell through traditional distribution channels, direct-order marketers such as Dell, and many small companies.

As a strategy for meeting the intense price competition in the PC industry, some manufacturers began to use foreign sources for components and even for finished PCs. However, this tended to lead to having more components tied up in the supply and distribution chain for a longer time. Constant improvements in the cost and performance of semiconductors and disk drives (see figures 8-1 and 8-2) have led to continued and even accelerating improvements in the cost and performance of computers (see figure 8-3). The effect of the price declines of PCs has meant that components and computers depreciate very quickly. In this environment, improving efficiency throughout the supply chain—from component producer to consumer—is extremely important.

The direct-order process whereby customers order computers directly from the manufacturer has great advantages in this respect. Dell, for example, builds its PCs only after they are sold to the consumer, thereby greatly reducing the inventory and risks associated with price reductions and changing consumer tastes. Making the supply chain more efficient became more important as technical change and price reductions accelerated. By 1996–97, the traditional assembly-to-distribution channel marketing system was at a competitive disadvantage to the direct-order marketing model.

The Internet reinforced the competitiveness of direct marketers and increased difficulties for traditional assemblers. It allowed direct marketers to provide better support than was possible through traditional catalog and telephone service. Companies first put technical support information on-line, then let customers configure and price PCs on-line, and finally made it possible for customers to conduct entire transactions on-line. For direct marketers, replacing telephone operators (who were simply conduits for entering orders into a computer) with an Internet-based interface did not represent a great change in technical and business strategy and allowed Internet-based sales to grow quickly.

At Dell, for example, Internet-based sales grew from $1 million per day in December 1996 to $40 million per day by February 2000, equal to 50 percent of total sales. Dell also achieved substantial savings through Internet-based sales transactions. For example, the company estimated that it saved more than $21 million through avoided order status calls in 1999. The Internet also permitted Dell to increase service to its corporate customers and improve communication with its largest suppliers, allowing them to use the Internet to find out Dell's requirements for incoming materials, receive statistics from the company's manufacturing lines, and gather data on the reliability of components supplied.

Traditional computer makers have attempted to emulate aspects of the Internet-based direct-order marketing model. Most have either been slower to implement the model or unable to implement it fully because the model puts them in direct competition with their traditional distribution chains.

Several new startup companies have formed to sell PCs from their websites or to refer customers to assemblers or distributors. Many of the startups, however, have experienced difficulty making a profit, in part because established PC companies were quick to implement Web-based sales and other activities. The startups have added an additional marketing channel but have not transformed the PC industry. The main effect of the Internet on the industry appears to have been the strengthening of the direct-order marketing business model.

*The source for material in this section, unless otherwise noted, is Kenney and Curry (2000).

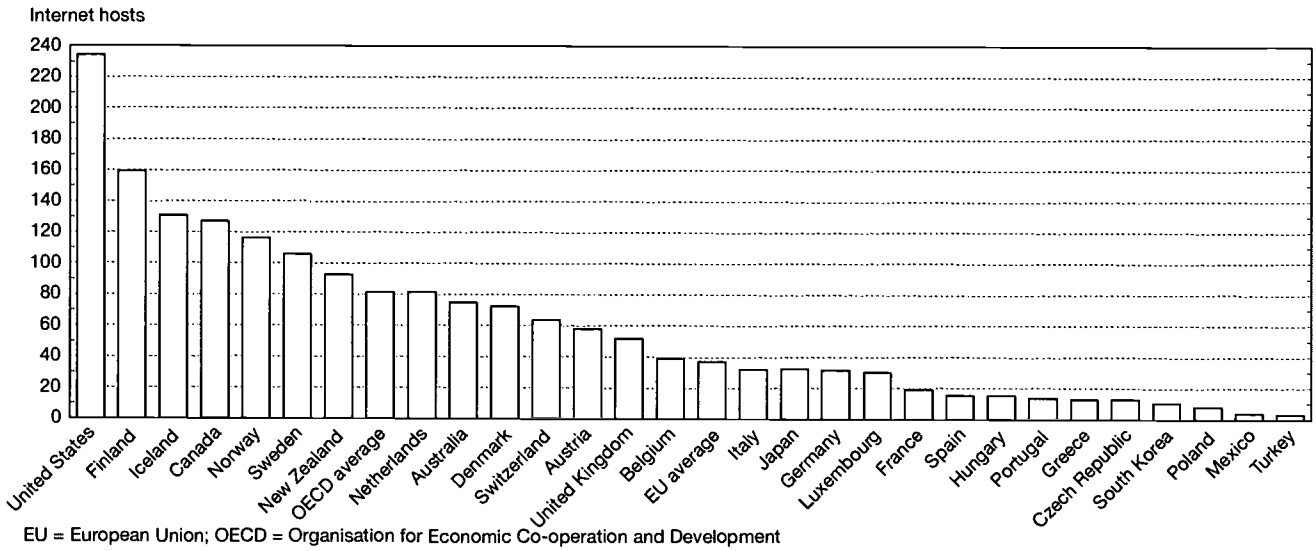
Internet and intranets to business activities carried out in companies devoted to such "old economy" activities as manufacturing, transportation, financial services, and conventional retailing. Major cost savings resulting from Internet use in the government and health sectors also are likely to contribute to overall productivity growth.

IT Effects on Income and Work

IT both creates and eliminates jobs. As jobs are created or eliminated, labor markets adjust in complex ways. Wages go up in areas (occupations or locales) in which the demand for skills exceeds the supply and go down in areas in which there are more jobs than workers. Over time, the effects of IT are likely to appear not in unemployment figures but in the wages of different occupations.

As noted by Katz (2000) in a review of the literature on computerization and wages, many studies have found that education-based wage differentials have increased in the past two decades, coinciding with the computerization of the workplace. The increases in both the wages and relative supply of

Figure 8-10.
Internet hosts, per 1,000 inhabitants in the OECD countries: October 2000



EU = European Union; OECD = Organisation for Economic Co-operation and Development

See appendix table 8-4.

Science & Engineering Indicators – 2002

educated workers are consistent with the idea that IT allows skilled workers to perform more functions and produce things that previously were in the domain of less skilled workers. This diminishes the "terms of trade" of less skilled workers, thereby reducing their relative income (Johnson and Stafford 1998; Gomery 1994).

Katz (2000) notes that within industries, relative increases in employment and wages during the 1980s and 1990s were greater for workers with more education, an indication of labor market shifts favoring workers with more skills. He also found that skill-related and organizational changes that have accompanied the computer revolution appear to have contributed to faster growth (starting in the 1970s) in the demand for skilled labor. However, factors other than technological change, including a slowdown in the increase of college-educated people entering the labor force, a trend toward globalization (especially outsourcing of low-skilled work to other countries), and a weakening of labor unions, may also contribute to rising wage differentials.

Many people have feared that automation will reduce demands on workers' conceptual talents and facility with machinery, equipment, and tools. On the other hand, IT can be expected to increase the demand for "knowledge workers" (those who manipulate and analyze information) relative to the demand for workers who do not process information as part of their jobs or those who simply enter and collate data. Case studies of specific industries, occupations, and IT show that IT can in some cases increase and in other cases reduce the level of skill required in particular jobs. (For reviews of such studies, see Attewell and Rule 1994, Cyert and Mowery 1987.) On balance, however, several studies (Autor, Katz, and Krueger 1997; Castells 1996; Berman, Bound, and Griliches 1994; Howell and Wolff 1993) using different data sets and methodologies suggest that no overall deterioration of skills is occurring in the workforce and that upgrading of skills may be widespread.

IT and the Citizenry

IT is part of the fabric of daily life, supporting activities at home, work, and school. This section addresses how IT affects citizens and society. It focuses on three areas: participation in the digital economy, IT applications in the home, and the influence of IT on government's interaction with its citizenry.

Participation in the Digital Economy

The past few years have seen widespread concern that digital technologies may be exacerbating existing differences in demographic groups' access to information and, consequently, their ability to participate fully in the information society. The term "digital divide" has been widely used to characterize demographic gaps in effective use of IT. This section begins with a brief summary of Internet access indicators worldwide. It also examines recent data on access to and use of IT (primarily the Internet) by different demographic groups in the United States, including comparisons by income, education, and race/ethnicity. Finally, it looks at Internet access among people with disabilities, reasons people do not use the Internet, and new modes of accessing the Internet.

Global Internet Access. Text table 8-3 shows the growth in Internet hosts in different areas of the world. Although rapid growth continues in much of the world, the international digital divide is still significant, and Africa appears to be falling farther behind. In October 1997, Internet host penetration in North America was 267 times that in Africa; by October 2000, the gap had grown to a multiple of 540.

A wide variation in Internet hosts per 1,000 inhabitants also exists among OECD countries. As shown in figure 8-10 and appendix table 8-4, the United States and Scandinavian countries lead, while such large economies as Germany, Japan, and France are significantly below the OECD average.

A major factor affecting Internet use across countries is telecommunications access charges. As shown in figure 8-11, a

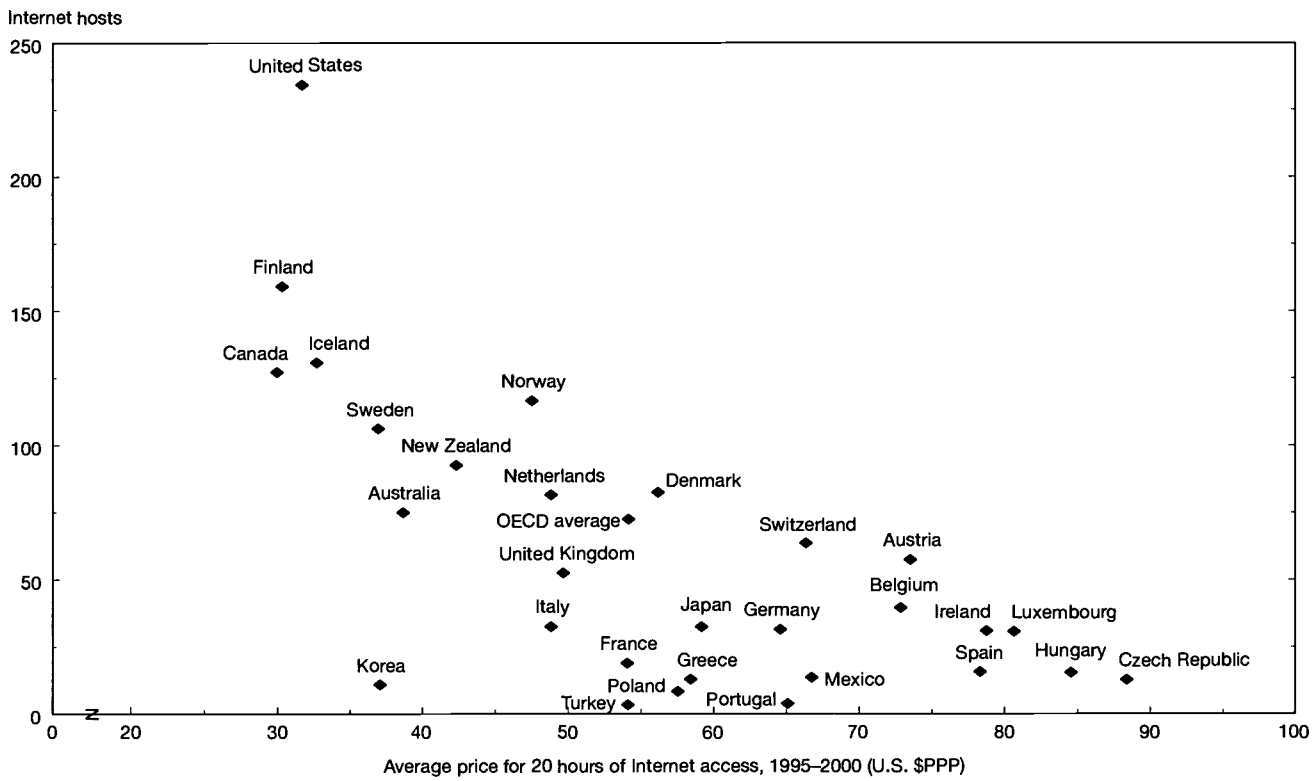
Text table 8-3.
Internet hosts, per 1,000 inhabitants: trends by world region

Region	October 1997	October 1998	October 1999	October 2000
North America	46.28	69.74	116.41	168.68
Oceania	26.81	34.76	43.84	59.16
Europe	6.13	9.45	13.41	20.22
Central and South America	0.48	0.91	1.67	2.53
Asia	0.53	0.87	1.28	1.96
Africa	0.17	0.21	0.28	0.31

SOURCE: Organisation for Economic Co-operation and Development (OECD). 2001. *Understanding the Digital Divide.* Paris. Available at <http://www.oecd.org/dsti/sti/prod/Digital_divide.pdf>.

Science & Engineering Indicators – 2002

Figure 8-11.
Internet access prices and Internet host penetration per 1,000 inhabitants: October 2000



OECD = Organisation for Economic Co-operation and Development; PPP = purchasing power parity

NOTES: Data on hosts for Luxembourg are from mid-1999. Internet access costs include value-added taxes.

SOURCE: OECD (www.oecd.org/dsti/sti/it/cm) and Telcordia Technologies (http://www.netsizer.com)

Science & Engineering Indicators – 2002

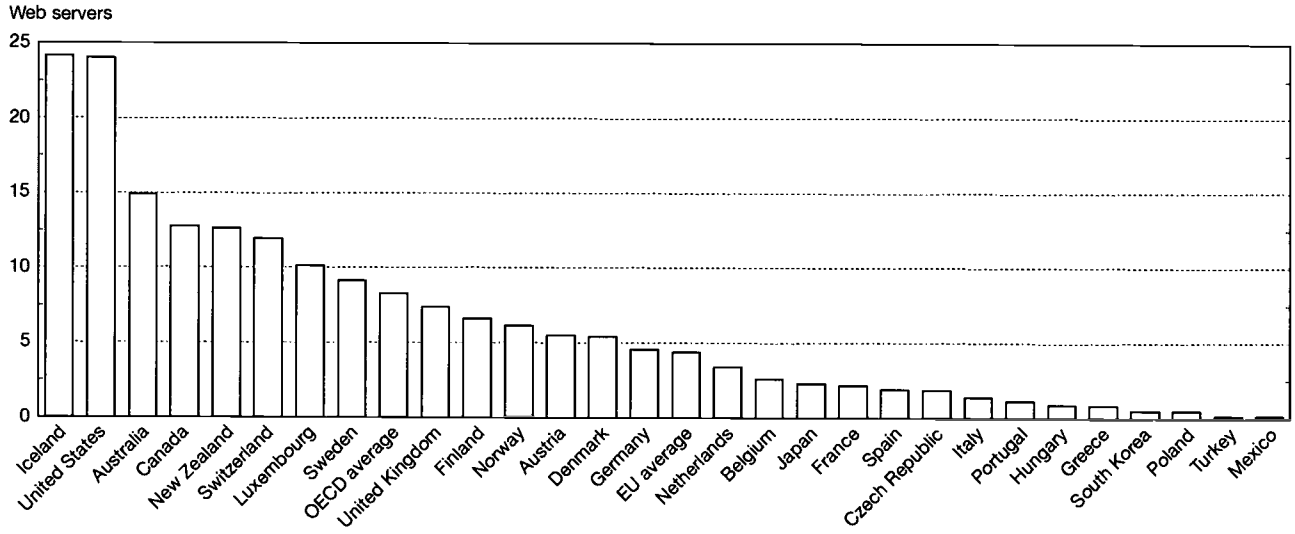
strong correlation exists between the price of Internet access and the number of Internet hosts per 1,000 inhabitants.

Because secure Web servers (those that use encryption and third-party certification) are needed for electronic transactions in both commerce and government, their number and locations are key indicators of the use of networks for business purposes. Figure 8-12 shows the number of secure Web servers per 1 million inhabitants in OECD countries as of July 2000. The United States currently leads by this measure, but servers suitable for e-commerce are dispersing around the globe. As of July 2000, more than 96,000 secure servers were operating in OECD countries—more than four times as many as in July 1998.

Indicators of Participation in the Digital Economy. In the 1980s, households that had PCs were on the cutting edge of IT use; since the mid-1990s, however, access to the Internet has become the primary indicator of a household's IT use. Because the Internet opens information resources to people in ways that unconnected PCs do not, this section emphasizes Internet access more than computer ownership.

In the future, many people may achieve Internet access through interactive televisions, personal digital assistants, and

Figure 8-12.
Secure Web servers per 100,000 inhabitants in OECD countries: July 2000



EU = European Union; OECD = Organisation for Economic Co-operation and Development

SOURCE: Organisation for Economic Co-operation and Development. *Communications Outlook – 2001*. Paris. 2001.
Based on data from Netcraft. <http://www.netcraft.com>.

Science & Engineering Indicators – 2002

wireless telephones. However, these technologies may provide considerably less access to information resources than is possible through a computer. Internet access alone ultimately may not be the key measure of ability to participate in the digital economy. It may be necessary to examine the quality of Internet access and how that access is used.

Physical access to technology is not enough to ensure participation in the digital economy (Wilson 2000). People need the kind of educational background that will prepare them to use the technology effectively to find and access information. They also need to be able to process and evaluate the information they find. In addition, the information content must be of use to them; for example, if the Internet offers little content in a person's language, then Internet access offers little benefit to that person.

Research on Home IT Diffusion. The research literature on technological diffusion shows that individuals who are affluent, better educated, and employed in higher status occupations (compared with society as a whole) tend to be early adopters of new technologies. This pattern holds true for all kinds of household products, technologies, and innovations, including PCs and Internet access. Research conducted in the 1980s and 1990s on home IT diffusion found that income and other socioeconomic factors such as education were strong predictors of early PC use (McQuarrie 1989; Dutton, Rogers, and Jun 1987; Riccobono 1986; Dickerson and Gentry 1983). Hoffman and Novak (1998) found complex relationships between home IT access (as measured by ownership of PCs) and race, income, and education. They found gaps in computer ownership that could not be accounted for by differences in income or education. When they controlled for education, they found statistically significant differences in computer ownership between blacks and whites.

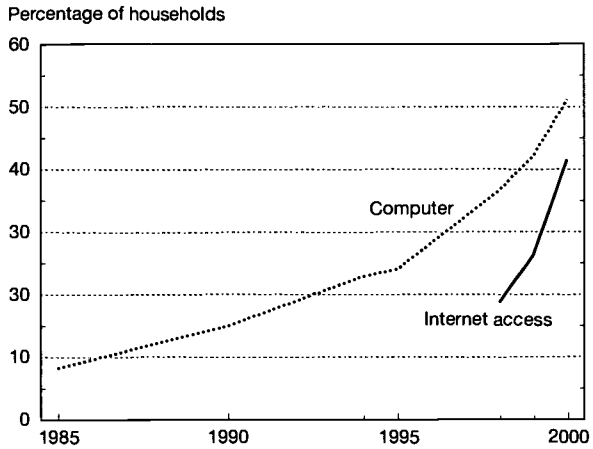
Computer and Internet Access: Recent Data From the Census Bureau's Current Population Survey. Recent data on computer and Internet access, collected by the Census Bureau in a supplement to its August 2000 Current Population Survey (CPS) (U.S. DOC 2000b), are consistent with the research literature. Because CPS is a very large survey (48,000 interviewed) and puts a heavy emphasis on quality, it provides a very reliable measure of computer and Internet access. The survey gathers information on both entire households and individuals within households.[6] Data from similar previous surveys (most recently, December 1998) can be used to identify trends in computer and Internet access.

- ***Overall Trends.*** CPS data show that as of August 2000, more than half of all households (51.0 percent) had computers, up from 42.1 percent in December 1998. (See figure 8-13 and appendix table 8-5.) The share of households with Internet access increased from 26.2 percent in December 1998 to 41.5 percent in August 2000. As of August 2000, 116.5 million Americans were on-line at some location, 31.9 million more than were on-line only 20 months earlier. (See appendix table 8-6.) The share of individuals 3 years or older using the Internet rose by one-third, from 32.7 percent in December 1998 to 44.4 percent in August 2000. (See appendix table 8-7.)

Although Internet access varies by income, education, race/ethnicity, age, and location, access has been increasing across all of these groups.

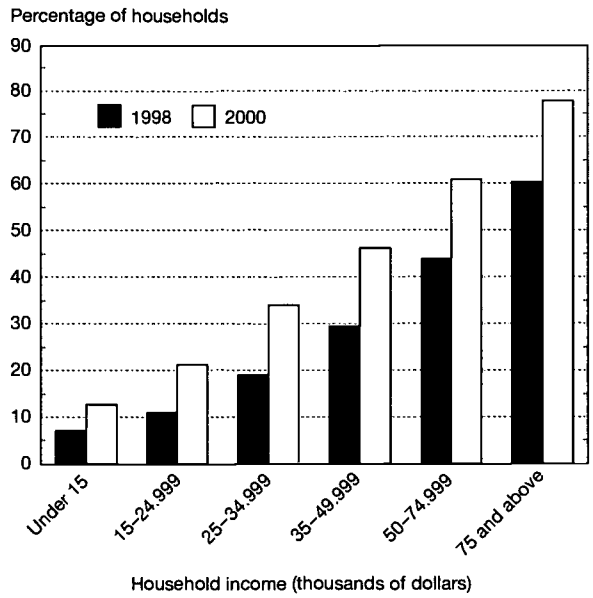
[6] The August 2000 survey gathered information on a total of 121,745 individuals, including children.

Figure 8-13.
U.S. households with a computer and with Internet access



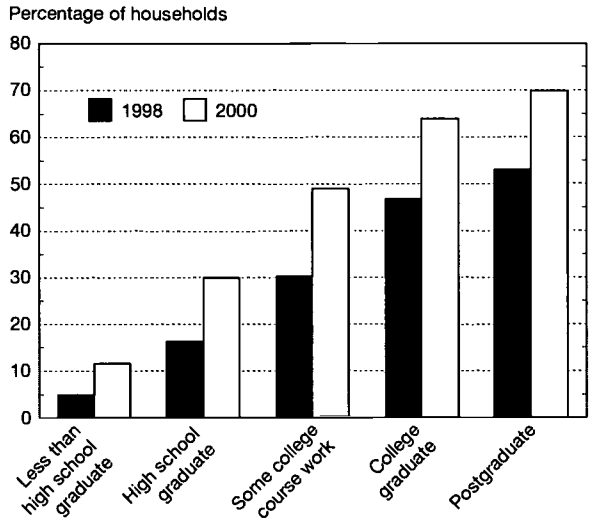
See appendix table 8-5. *Science & Engineering Indicators – 2002*

Figure 8-14.
U.S. households with Internet access, by income: 1998 and 2000



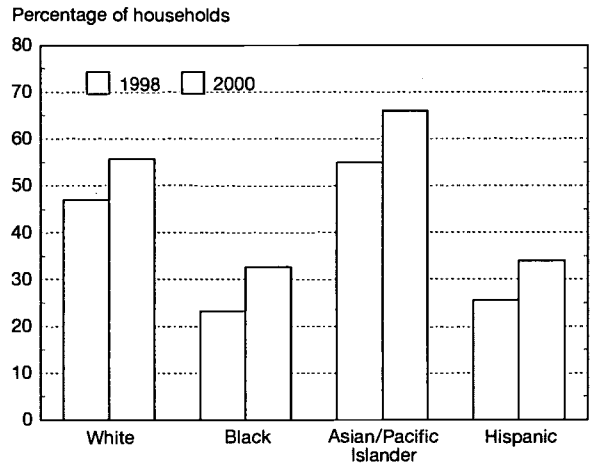
See appendix table 8-6. *Science & Engineering Indicators – 2002*

Figure 8-15.
U.S. households with Internet access by educational attainment of householder: 1998 and 2000



See appendix table 8-6. *Science & Engineering Indicators – 2002*

Figure 8-16.
U.S. households with a computer, by race/ethnicity: 1998 and 2000



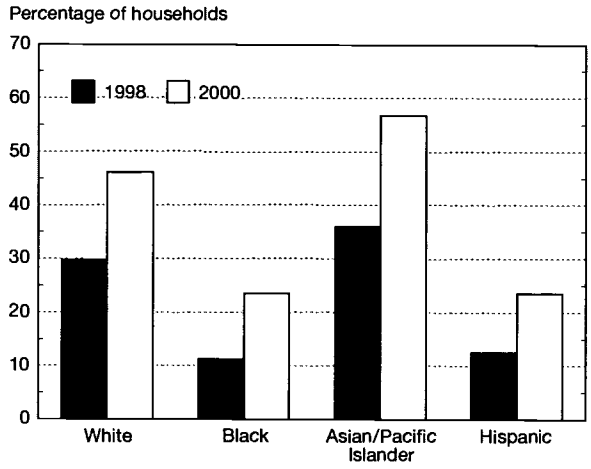
See appendix table 8-5. *Science & Engineering Indicators – 2002*

♦ ***Income.*** Figure 8-14 shows the number of households with Internet access, by income level, as of December 1998 and August 2000. It remains highest among households with the highest income, but people at every income level are increasing Internet access at home. More than two-thirds of all households that earn more than $50,000 have Internet connections.

♦ ***Education.*** Similarly, although people with the highest level of education are most likely to have Internet access, access is also expanding across every education level. (See figure 8-15.)

♦ ***Race/Ethnicity.*** As shown in figures 8-16 and 8-17, blacks and Hispanics continue to lag significantly behind whites and Asians/Pacific Islanders in both computer ownership and Internet access. In August 2000, the share of black households that owned computers was 18 percentage points below the national average (32.6 percent for black households compared with 51.0 percent for all households nationally). Similarly, the share of Hispanic households with a computer (33.7 percent) was 17 percentage points below the national average. The share of black and Hispanic households with Internet access was also approximately 18 per-

Figure 8-17.
U.S. households with Internet access, by race/ethnicity: 1998 and 2000



See appendix table 8-6. *Science & Engineering Indicators – 2002*

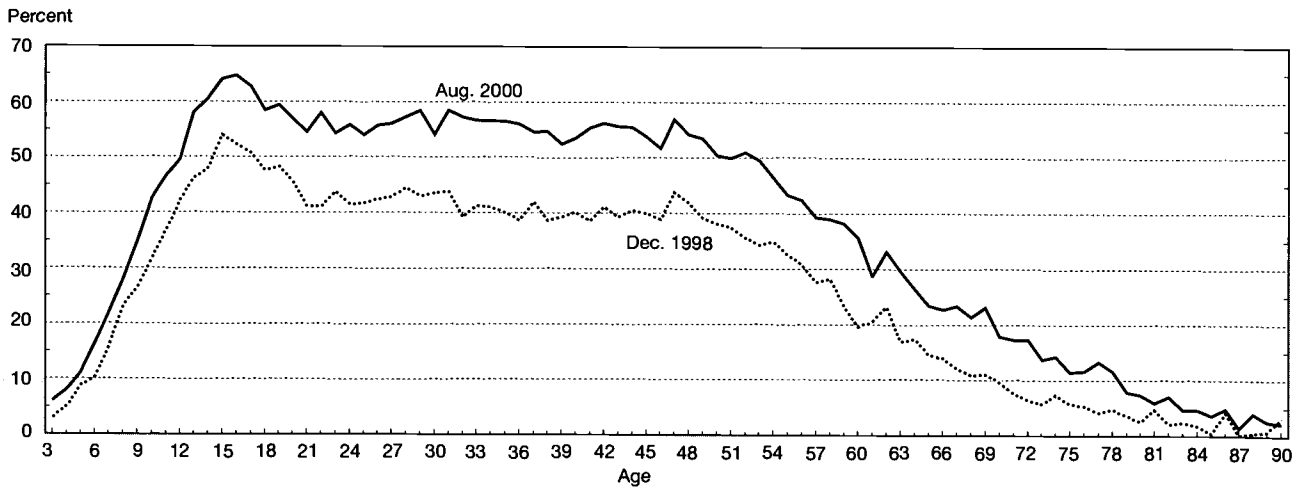
centage points below the national average in August 2000 (23.5 percent for black households and 23.6 percent for Hispanic households, compared with 41.5 percent for all households nationally). U.S. DOC (2000b) found that differences in income and education account for only about half the difference in Internet access among racial/ethnic groups.

Although Internet access is relatively low among black and Hispanic households, growth in access among these households is high. Access more than doubled for black households between December 1998 and August 2000 (from 11.2 percent to 23.5 percent) and also increased significantly for Hispanic households (from 12.6 percent to 23.6 percent). The growth rate in Internet access is higher in black and Hispanic households than in other groups.

- ***Sex.*** The disparity in Internet access between men and women has largely disappeared. In December 1998, 34.2 percent of men and 31.4 percent of women had home access to the Internet. By August 2000, 44.6 percent of men and 44.2 percent of women had home access.
- ***Age.*** There were great differences in Internet use among age groups in both December 1998 and August 2000, as shown in figure 8-18. In August 2000, more than 60 percent of teenagers and more than 50 percent of people ages 20–50 used the Internet. Individuals ages 50 and older were among the least likely to use the Internet; however, this age group had the greatest growth in use (compared with December 1998) of all age groups.
- ***Location.*** Internet access among households in rural areas was similar to access among households nationwide. In rural areas, 38.9 percent of households had Internet access in August 2000 compared with the nationwide rate of 41.5 percent.

Internet Access Among People With Disabilities. As shown in figure 8-19, people with disabilities are only half as likely to have access to the Internet as those without disabilities: 21.6 percent compared with 42.1 percent, respectively. Close to 60 percent of people with disabilities have never used a PC compared with less than 25 percent of people without disabilities. Among people with disabilities, those who have impaired vision and walking problems have lower rates of Internet access than people with other types of disabilities and are less likely to use a computer regularly than people

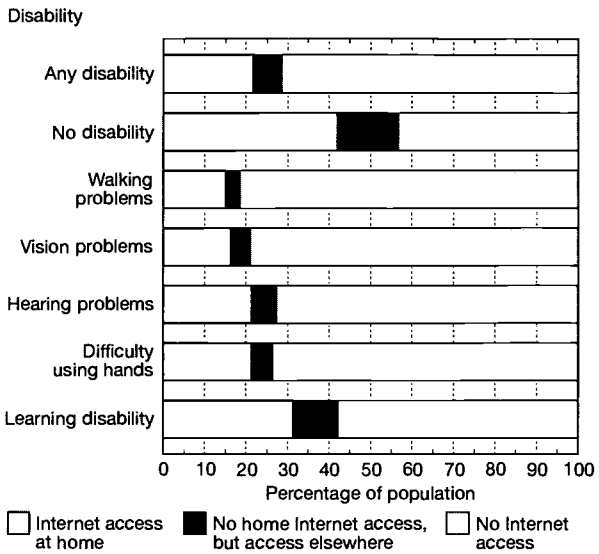
Figure 8-18
Internet use rates, by age: 1998 and 2000
(Internet use, any location)



SOURCE: U.S. Department of Commerce 2000. *Falling Through the Net: Toward Digital Inclusion, A Report on Americans' Access to Technology Tools*. Washington, DC.

Science & Engineering Indicators – 2002

Figure 8-19.
Internet access, by disability: 1999



SOURCE: U.S. Department of Commerce. 2000. *Falling Through the Net: Toward Digital Inclusion, A Report on Americans' Access to Technology Tools*. Washington, DC: U.S. Department of Commerce.

Science & Engineering Indicators – 2002

with hearing difficulties. This difference holds true for all age groups.

Lack of Internet access among people with disabilities is of special concern, because IT has the potential to improve the lives of these people. IT can make working from home more viable for people with limited mobility, turn written material into spoken language for visually impaired people, and turn speech into text for hearing-impaired people. IT does not automatically provide benefits to the disabled, however. Unless technologies are designed carefully, they can create new barriers. For example, websites frequently convey information in a visual form that is inaccessible to people who are visually impaired. Section 508 of the American with Disabilities Act requires that Federal agencies' electronic and information technology is accessible to people with disabilities, including employees and members of the public. This has made millions of Federal webpages more accessible.

The majority of individuals with disabilities are not employed (67.8 percent). Statistical analysis reveals a correlation between the employment status of people with disabilities and their home Internet access and regular use of PCs. The similarity in Internet access and computer use between people with and without disabilities is much greater among employed people than among nonemployed people. For example, among employed people, the rate of Internet access for people with disabilities is 78.3 percent of the rate for people without disabilities; among nonemployed people, that figure is only 46.6 percent.

Reasons for Not Going On-line. Why are some households and individuals not on-line? Lenhart (2001) found that half the adults in the United States do not have Internet access, and 57 percent of those who do not have access are not interested in getting access. This suggests that the booming growth of the U.S. Internet population in the past few years will slow down. Of those without Internet access now, 32 percent say they definitely will not get access, and another 25 percent say they probably will not get access. Among people without Internet access now, people over age 50 are the least likely to say they will go on-line eventually, and younger people are the most likely to say they will. The study also found that 54 percent of those who are not on-line believe the Internet is a dangerous thing, 51 percent say they do not think they are missing anything by staying away from the Internet, 39 percent say the Internet is too expensive, and 36 percent express concern that the on-line world is confusing and hard to negotiate.

DOC has found similar reasons that explain why some people do not have Internet access (U.S. DOC 2000b). Among surveyed households with annual incomes less than $15,000, one-third of respondents without Internet access (32.6 percent) cited cost as the reason and slightly more than one-quarter cited "don't want it" (26.6 percent) as the reason. In contrast, households with incomes greater than $75,000 reversed the order of importance: 30.8 percent cited "don't want it" as the reason for not having Internet access and only 9.4 percent cited cost as the reason.

Some households have discontinued their Internet access. In August 2000, 4.0 million households once had but did not currently have Internet access. That number was essentially unchanged from December 1998, when 4.1 million households reported discontinuing Internet access. In August 2000, the principal reasons cited by households for discontinuing Internet access were "no longer owns computers" (17.0 percent), followed by "can use anywhere" (12.8 percent) and "cost, too expensive" (12.3 percent). Other reasons were "don't want it" (10.3 percent), "not enough time" (10.0 percent), and "computer requires repair" (9.7 percent).

The data about people who have chosen not to have Internet access suggest that this population will remain substantial. However, as computer and telecommunication costs continued to decline and as more services become available over the Internet, some people who currently choose not to have Internet access may change their minds.

New Modes of Access. The digital divide in terms of Internet access among various demographic groups appears to be closing. However, as technology evolves, new concerns may arise about differences in access. About 10 percent of households with Internet access now have "broadband"[7] Internet access, primarily a cable modem (50.8 percent) or a digital subscriber line (DSL) (33.7 percent). Wireless and satellite technologies (4.6 percent) and other telephone-based technologies such as integrated services digital network (ISDN) (10.9 percent) account for much lower shares of broadband access. Rural areas lag be-

[7]The term "broadband" as used by U.S. DOC (2000b) includes the two most common technologies, DSL and cable modems, as well as other technologies such as ISDN. These technologies provide significantly faster data transmission, although some applications or connections may be slower than the 200 kilobits per second that the Federal Communications Commission defines as broadband.

hind central cities and urban areas in broadband penetration (7.3, 12.2, and 11.8 percent, respectively). Because broadband access is more expensive than dial-up access, its use probably will be less common in households with lower incomes.

IT Use at Home and in Communities

As the previous discussion illustrates, considerable information is now available about access to the Internet. However, information about the extent, nature, and impact of IT use in the home is more scarce. A review of the literature (National Science Foundation (NSF) 2001a) found that home computing in the 1980s has been analyzed extensively, but the more recent wave of computer adoption and Internet use by households has gone largely unexamined.

Indicators of How People Use Computers. Early research (NSF 2001a) found that home computing was used primarily for education, play, work, and basic word processing. Many early adopters used the computer less than they had initially expected. One long-term study found that nearly one-fifth of families quit using their home computer entirely within 2 years. It is unclear whether this underuse resulted from the inability of the technology to meet family needs, the lack of high-quality software for early computers, or other factors. Studies on early users of home computers found that children tended to use home computers more often and for longer periods than adults, and women and girls used home computers less often and less intensively than men and boys. Although playing games was the most common reason cited by children for using the computer, no one application actually dominated their use; they tended to use the computer about equally for playing games, learning, and writing.

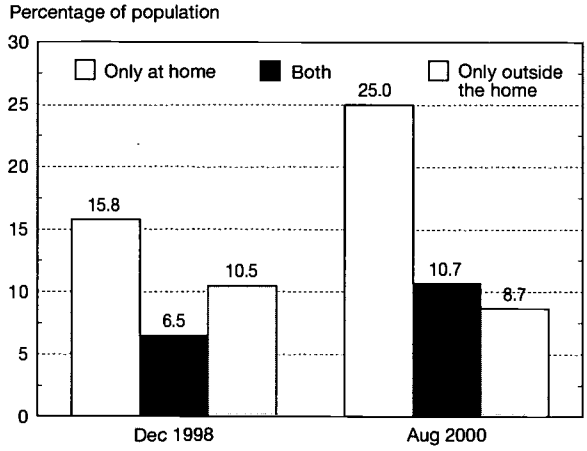
More recent data provide a picture of trends in Internet access at home and outside the home (U.S. DOC 2000b). As shown in figure 8-20, 25.0 percent of the population had access to the Internet only at home as of August 2000, an increase from 15.8 percent in December 1998. The share of the population with access to the Internet both at home and outside the home also increased from December 1998 to August 2000, from 6.5 percent to 10.7 percent. In contrast, the percentage of the population with Internet access only outside the home declined from 10.5 percent to 8.7 percent.

Schools, libraries, and other public access points continue to serve people who do not have access to the Internet at home. For example, certain groups such as unemployed people, blacks, and Asians/Pacific Islanders are far more likely than others to use public libraries to access the Internet (U.S. DOC 2000b).

As shown in figure 8-21, e-mail is the Internet's most widely used application; 79.9 percent of the population used e-mail as of August 2000 and 70.0 percent of the population used e-mail as of December 1998 (U.S. DOC 2000b). Online shopping and bill paying saw the fastest growth in use. In August 2000, 16.1 percent of Internet users reported using the Internet to search for jobs; low-income users were more likely than others to use this application.

Comparison Between Men and Women. The Pew Internet American Life Project (2000) noted that women have been more likely than men to use e-mail to enrich their important relationships and enlarge their networks. In the Pew study, more women than men said they were "attached" to e-mail and pleased with how it helped them. Among women who used the Internet, 60 percent said that e-mail exchanges have improved their connections to family members (compared with 51 percent of men), and 71 percent said that e-mail exchanges have improved their connections with significant friends (compared with 61 percent of men). Among women who said they e-mail friends, 63 percent said they communicated with significant friends more of-

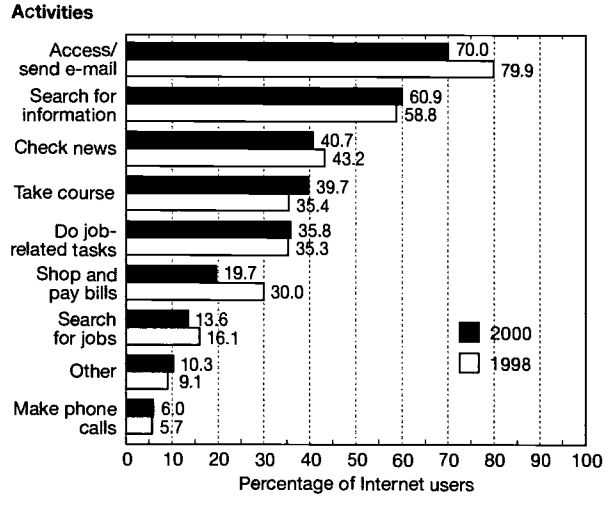
Figure 8-20.
Internet access at home and outside the home: 1998 and 2000



SOURCE: U.S. Department of Commerce. 2000. *Falling Through the Net: Toward Digital Inclusion, A Report on Americans' Access to Technology Tools*. Washington, DC: U.S. Department of Commerce.

Science & Engineering Indicators – 2002

Figure 8-21.
Online activities: 1998 and 2000



SOURCE: U.S. Department of Commerce. 2000. *Falling Through the Net: Toward Digital Inclusion, A Report on Americans' Access to Technology Tools*. Washington, DC: U.S. Department of Commerce.

Science & Engineering Indicators – 2002

ten than they had before they began using e-mail. Among both sexes, e-mail was found to increase communication in some relationships and to be a substitute for conversation in others.

The Pew study also found that women are more likely to go on-line to seek health and religious information, research new jobs, and play games. Men are more likely to go on-line to get news, shop, seek financial information, trade stocks, participate in on-line auctions, access government websites, and search for sports-related news.

On-line Medical Information. One of the top reasons Internet users access the Web is to obtain medical information. Fox and Rainie (2000) found that 52 million adults in the United States, or 55 percent of those with Internet access, have used the Web to get health or medical information. A majority of these users said they go on-line at least once a month for health information. Many said the resources they find on the Web have a direct effect on their decisions about health care and on their interactions with doctors. Among those who use the Internet to obtain health information, 48 percent said the advice they find on the Web has improved the way they take care of themselves, and 55 percent said Internet access has improved the way they get medical and health information. Among this same group, 92 percent said the information they found during their last on-line search was useful; 47 percent of those who sought health information for themselves during their last on-line search said the material affected their decisions about treatments and care.

IT Impact on Families and Individuals. Research into the actual impact of IT on families and individuals is extremely limited in scale and scope (NSF 2001a). However, some research has been conducted on time displacement, telework, psychological well-being, informatics and health care, and the effects of video games on children. The research indicates that use of IT in the home can be both beneficial and harmful. Some findings from this research are highlighted below.

Time Displacement. Home computing and Internet use apparently have not yet substantially displaced other forms of home media and entertainment, such as reading, watching television, or listening to the radio (NSF 2001a). Although some slight displacement of television viewing appears to have occurred, several analysts suggest that PCs and the Internet actually enhance media use because people begin to use other forms of media more often as they develop the habit of acquiring information.

Telework. The research on telework generally predates major changes in distributed work arrangements in large-scale organizations, so the findings from this research may have limited applicability to the contemporary workplace (NSF 2001b). The circumstances of telework have shifted over time. At first, employers allowed telework primarily to permit employees to work from home and more easily manage their family responsibilities. Now, many companies use telework as a strategy to satisfy and retain essential professional, technical, and managerial employees (NSF 2001b).

Studies indicate that telework can demonstrably enhance people's ability to balance work and family needs and reduce personal stress. On the other hand, telework can also disrupt important family dynamics and relationships and create psychological isolation. Most research on telework and distributed work has focused on efficiency and productivity, not on the impacts on individual workers or their families. The effects of telework clearly will differ from situation to situation, depending on whether an individual teleworks full time or only a few days a week, and whether an individual chooses to telework or is compelled to do so by an employer.

Psychological Well-Being. The evidence regarding the impact of computing on the psychological well-being of individuals is mixed. Some data suggest that increased Internet use is associated with social isolation, withdrawal, and stress, although actual Internet "addiction" may be limited to about 10 percent of Internet users and is not necessarily associated with how much time an individual spends on the Internet.

Kraut et al. (1998a) found evidence that increased use of the Internet was associated not only with increased social disconnectedness but also with loneliness and depression. The authors found an association between increased Internet use and "small but statistically significant declines" in social integration (as reflected by family communication and the size of an individual's social network), self-reported loneliness, and increased depression.

Conversely, Katz and Aspden (1997) found no statistically significant differences between Internet users' and nonusers' membership in religious, leisure, and community organizations (their analysis controlled for demographic differences such as age, sex, race, and education). They found that long-term Internet users actually belong to more community organizations than nonusers or former users. In addition, Katz and Aspden found that the vast majority of Internet users (whether recent or long term) reported no change in the amount of time they spent with family and friends on the telephone or in person.

Electronic Government

Like businesses, government agencies have long used IT in management information systems and research. With the advent of the Internet and especially the World Wide Web, however, IT has become a major means of government communication with citizens and other stakeholders. Governments at all levels are rapidly developing new ways of using IT to provide public services to businesses and individuals. Much government information is being made available on-line, and many government activities, from procurement to tax filings, are being conducted on-line.

The Federal Government On-line. The following are a few examples of on-line websites that provide information about the Federal Government (U.S. Working Group on Electronic Commerce 2000):

- FirstGov (<http://www.firstgov.gov>) is a single on-line portal that connects users to all government sites and has one of the largest collections of Web pages in the world. The site allows users to search all 27 million Federal agency Web pages at once.

- The Patent and Trademark Office's X-Search system (<http://www.uspto.gov>) enables anyone to use an Internet browser to search and retrieve, free of charge, more than 2.6 million pending, registered, abandoned, canceled, or expired trademark records. This is the same database and search system used by examining attorneys at the Patent and Trademark Office.
- The National Institutes of Health (NIH) maintains an on-line service (<http://www.ClinicalTrials.gov>) that provides users with information about the latest clinical research on cancer, heart disease, and other life-threatening illnesses.

Federal agencies also are making it possible for citizens to access forms and fill out applications on-line. The Social Security Administration has posted frequently used forms on its website, and individuals can apply for Social Security retirement benefits on-line. The U.S. Department of Agriculture's Forest Service has an on-line reservation system for government-administered campsites nationwide (<http://www.recreation.gov>). In addition, the U.S. Department of Education posts software and documentation for student aid on its website, and the Internal Revenue Service (IRS) posts tax forms and information on its websites and allows taxpayers to file electronically. These are but a few examples of Federal services available on-line.

The Federal Government also uses electronic procurement and payment. The General Services Administration is working toward using e-commerce to make procurement faster and cheaper. One element of this effort is the development of a U.S. Federal Public Key Infrastructure (PKI) to facilitate trusted communication among government agencies, between government agencies and their trading partners, and between the government and the public. PKI verifies the identity of the parties to an on-line transaction, ensures that data have not been altered in transit, prevents a party from falsely claiming that it did not send or receive a particular message, and makes certain that data remain confidential in transit. A number of agencies already have established operational PKIs that can authenticate and protect transactions.

The Federal Government now conducts the vast majority of its financial transactions—collections and expenditures—electronically. The U.S. Department of the Treasury collects electronically more than $1.3 trillion of Federal Government revenue—approximately two out of every three dollars collected (U.S. Working Group on Electronic Commerce 2000). In 1999, the Federal Government made 78 percent of its 959 million payments electronically, including 96 percent of salary payments, 81 percent of vendor payments, and 73 percent of benefit payments.

In addition to websites that offer agency-specific services and information, interagency websites target various segments of the population, such as small business owners, students, and senior citizens. These interagency websites are valuable to citizens because they integrate information across agencies (Fountain 2001a).

Cost Savings From Electronic Government. The cost savings from electronic government are potentially large (Fountain with Osorio-Urzua 2001). Movement from paper-based to Web-based processing of documents and payments typically generates administrative cost savings of roughly 50 percent and more for highly complex transactions (Fountain with Osorio-Urzua 2001).

State and Local Government On-line. State and local governments also are widely deploying electronic government concepts. Many significant reforms related to electronic government applications begin at the state level and then diffuse to Federal and local governments (Fountain 2001b).

Although electronic government services vary widely from state to state, several services are common to a number of states. The most common service, available in 32 states, allows users to find and apply for state government jobs on-line. The second most common service, available in 24 states, is electronic filing for personal income taxes.[8] Other common electronic government services give the public the ability to order vital records (birth, death, and marriage certificates), purchase fishing and hunting licenses and permits, search state government sex offender registries, and renew motor vehicle registrations—all on-line.

A few states offer less typical electronic government services that are both innovative and powerful. For example, North Carolina has three separate portals for citizens, businesses, and employees, with the categories and services offered in each portal oriented toward the type of visitor most likely to use it. Virginia allows users to create a personalized home page by customizing the interface and links to the services and features the user selects.

Local governments at the city, county, and town levels can vary dramatically in the socioeconomic characteristics of their citizenry and in the types of government services they offer. As a result, electronic government at the local level is applied in a variety of ways and with a variety of impacts.

The Indianapolis website (<http://www.IndyGov.org>) is a leading example of municipal government on the Web (Fountain 2001b). Innovative applications include geographical information systems (GIS) services that identify a user's local, state, and national representatives based on the user's address. A wealth of information is available on the Indianapolis website, including maps and descriptions of local recreational facilities. The website also integrates agency and departmental functions into a single, citywide portal.

Contra Costa County, in the San Francisco/San Jose region of California, also uses innovative Web services. The county's animal control department uses a digital camera to photograph stray and lost pets and then posts the photos on the Web, enabling pet owners to take a virtual visit to the pound to search for their lost pets. The county also is developing tools that allow citizens to use GIS data to design their own maps. For example, a resident could access the county Web portal, click on the GIS link, and enter a home address.

[8]The IRS's e-file program has helped State governments to implement or outsource electronic services easily. The e-file program allows commercial tax preparers to incorporate an Internet filing capability into their tax software and makes it easy for states to adopt systems compatible with e-file and the commercial software.

The individual then could query a number of GIS data sets, including property parcels and values, school locations, police and fire station locations, risk of natural disaster (flood, earthquake, etc.), political districts, and environmental hazards, and quickly produce a customized map that shows all the data requested for the area surrounding the address given.

The Internet also is affecting political processes in the United States and around the world. Political candidates are establishing websites to communicate with voters, solicit funds, and organize volunteers. Interest groups are using e-mail and websites to organize and express their views. In some cases, groups that would be very difficult to organize through traditional means, such as scientists or engineers in different parts of the country, can be mobilized through e-mail to express their views to Congress on a timely issue. Some groups are experimenting with voting via the Internet. See sidebar, "Internet Voting."

IT and S&E

The S&E community developed IT, in many cases for S&E applications. Scientists and engineers have been among the earliest and most intensive users of many IT applications. It is not surprising that IT has played a major role in the practice of S&E and in the evolution of S&E institutions.

Advances in computing, information storage, software, and networking are all leading to new tools for S&E, ranging from automated scientific instruments to supercomputers for modeling and simulation. IT has made possible new collections of data and new ways to access scientific information. As IT has advanced, applications for S&E have become more powerful and less expensive, and many applications, such as modeling and databases, have migrated from large mainframe computers and supercomputers to desktop computers. IT also has made possible new modes of communication among scientists, allowing them to collaborate more easily. IT affects how research

Internet Voting

Many people have expressed a strong interest in using the Internet to make voting more convenient. It is hoped that such a practice would increase participation in elections. Internet voting is seen as a logical extension of Internet applications in commerce and government. Election systems, however, must meet high standards of security, secrecy, equity, and many other criteria. These requirements make the development of Internet voting much more challenging than most commerce or government applications of the Internet.

The National Science Foundation supported a study and workshop to analyze the issues associated with Internet voting (Internet Policy Institute 2001). The study concluded that remote Internet voting (e.g., voting from the home or office) poses significant risks to the integrity of the voting process and should not be widely used in public elections until substantial technical and social science issues are addressed. On the other hand, it would be possible to use Internet voting systems at polling places, and such systems could offer greater convenience and efficiency than traditional voting systems. Voters could eventually choose to cast their ballots from any one of many polling places, and the tallying process would be both fast and certain. Because election officials would control both the voting platform and the physical environment, managing the security risks of such systems is feasible. Over time, it would also be possible to have Internet voting in kiosks—voting machines located away from traditional polling places—at convenient locations such as malls, libraries, or schools. Kiosk voting terminals pose more challenges than poll-site systems, but most of the challenges could, at least in principle, be resolved through extensions of current technology.

A broad range of research is needed on Internet voting systems. Research topics include the following:

- Approaches to meeting the security, secrecy, scalability, and convenience requirements of elections.
- Development of reliable poll-site and kiosk Internet voting systems that are not vulnerable to any single point of failure and cannot lose votes.
- Development of new procedures for continuous testing and certification of election systems, as well as test methods for election systems.
- Incorporation of human factors into design for electronic voting, including development of appropriate guidelines for designing human interfaces and electronic ballots and development of approaches for addressing the needs of the disabled.
- The economics of voting systems, including comparative analyses of alternative voting systems.
- The effects of Internet voting on participation in elections, both in general and with regard to various demographic groups, especially those with less access to or facility with computers.
- The effects of Internet voting on public confidence in the electoral process and on deliberative and representative democracy.
- The implications of Internet voting for political campaigns.
- Legal issues associated with and the applicability of existing statutes to Internet voting, including jurisdiction, vote fraud, liability for system failures, international law enforcement, and electioneering.

is conducted, how new products and processes are developed, and how technical information is communicated.

IT also is influencing technological innovation in society. These influences reflect not only changes in R&D processes but also changes in the market environment for innovation and the organization of innovative activities. Although some of these effects are most visible in the IT industry itself, IT also affects other industries, higher education, and the job market for scientists and engineers.

In general, relatively little scholarly research has been conducted on how IT affects S&E, and even less research has been performed on how IT affects innovation. This section highlights some of the limited work that has been done.

IT and R&D

IT has provided new tools for the simulation and modeling of complex natural, social, and engineering systems. It has enabled new methods of data collection and has made possible the creation of massive, complex, and shared data sets. It has changed the way scientific knowledge is stored and communicated. IT has facilitated the sharing of computational resources and scientific instruments among scientists and engineers in different locations and has aided communication and collaboration among large groups of researchers.

Advances in both hardware and software have supported new IT tools for R&D. Advances in software have been critical to the success of supercomputers that use thousands of microprocessors and have also enabled the analysis and visualization of complex problems. Software engineering also is enabling security technologies, distributed information management, high-confidence software systems, and numerous other areas of research that are needed in today's most advanced IT applications

The role of IT is not uniform across all areas of S&E. Some areas of research, such as high-energy physics, fluid dynamics, aeronautical engineering, and atmospheric sciences, have long relied on high-end computing. The ability to collect, manipulate, and share massive amounts of data has long been essential in areas such as astronomy and geosphere and biosphere studies (Committee on Issues in the Transborder Flow of Scientific Data 1997). More recently, IT has spread from its historical stronghold in the physical sciences to other natural sciences, engineering, social sciences, and the humanities and has become increasingly vital to sciences such as biology that historically had used IT less extensively.

Modeling and Simulation

Modeling and simulation have become powerful complements to theory and experimentation in advancing knowledge in many areas of S&E. Simulations allow researchers to run virtual experiments when actual experiments would be impractical or impossible. As computer power grows, simulations can be made more complex, and new classes of problems can be realistically simulated. Simulation is contributing to major advances in weather and climate prediction, computational biology, plasma science, high-energy physics, cosmology, materials research, and combustion, among other areas. New visualization techniques for displaying simulation data in comprehensible formats have played an important role.

Simulation also is used extensively in industry to test the crashworthiness of cars and the flight performance of aircraft (U.S. Department of Energy (DOE)/NSF 1998) and to facilitate engineering design. Computer-aided design (CAD) programs can use CAD data to visualize, animate, simulate, validate, and assemble parts digitally. In some cases, CAD programs can allow a designer to insert digital representations of humans into virtual worlds to test for ergonomics, manufacturability, maintainability, safety, and style (Brown 1999). The goal of such an approach is to address these issues early in the design stage and reduce the need for physical mock-ups and rework. Both aircraft and automobile manufacturers use CAD approaches extensively.

Modeling and simulation capabilities continue to improve at a rapid rate. DOE's Accelerated Strategic Computing Initiative program, which uses simulation to replace nuclear tests, deployed the first trillion-operations-per-second (teraops) computer in December 1996. The program deployed a 12.3-teraops computer in June 2000 and plans to operate a 100-teraops computer (with 50 terabytes of memory and 130 petabytes of archival storage) by 2005 (National Science and Technology Council 1999; U.S. DOE 2001). Research funded by the Defense Advanced Research Projects Agency, the National Aeronautics and Space Administration (NASA), and the National Security Agency is evaluating the feasibility of constructing a computing system capable of a sustained rate of 1,015 teraops (1 petaflop).

Terascale computing is expected to have applications in genetic computing, global climate modeling, aerospace and automotive design, financial modeling, and other areas. To use data from human genome research, for example, new computational tools are needed to determine the three-dimensional atomic structure and dynamic behavior of gene products, as well as to dissect the roles of individual genes and the integrated function of thousands of genes. Modeling the folding of a protein to aid in the design of new drug therapies also takes extensive computing power (U.S. DOE/NSF 1998). Celera Genomics Corporation (a genomics and bioinformatics company), Sandia National Laboratories, and Compaq entered into a partnership in January 2001 to develop algorithms and software for genomic and proteomic applications of supercomputers in the 100-teraops to 1-petaflop range, with the petaflop computer expected by 2010. Pattern recognition and data-mining software also are critical for deciphering genetic information (Regalado 1999).

Many scientists expect IT to revolutionize biology in the coming decades, as scientists decode genetic information and explore how it relates to the function of organisms (Varmus 1999). New areas of biology such as molecular epidemiology, functional genomics, and pharmacogenetics rely on DNA data and benefit from new, information-intensive approaches to research.

IT and Data

IT has long been important in collecting, storing, and shar-

ing scientific information. More recently, IT has enabled automated collection of data. For example, automated gene sequencers, which use robotics to process samples and computers to manage, store, and retrieve data, have made possible the rapid sequencing of the human genome, which in turn has resulted in unprecedented expansion of genomic databases (Sinclair 1999). In many scientific fields, data increasingly are collected in digital form, which facilitates analysis, storage, and dissemination. For example, seismic data used to measure earthquakes were once recorded on paper or film but now are usually recorded digitally, making it possible for scientists around the world to analyze the data quickly.

By 1985, 2,800 scientific and technical electronic databases (both bibliographic and numerical) already existed (Williams 1985). At that time, primarily information specialists accessed electronic databases, and many of the databases were available only for a fee. Over time, databases have expanded in number and size, and many are now widely accessible on the World Wide Web. See sidebar, "Examples of Shared Databases."

Electronic Scholarly Communication

Originally developed primarily as tools for scientific communication, the Internet and the World Wide Web continue to have a significant impact on scholarly communication in scientific and technical fields. An increasing amount of scholarly information is stored in electronic forms and is available through digital media.

Electronic Scholarly Communication Forms. Scholarly information can be placed on-line in several different forms, most of which are expanding rapidly. These forms may be classified as follows (drawing on Kling and McKim 1999 and 2000):

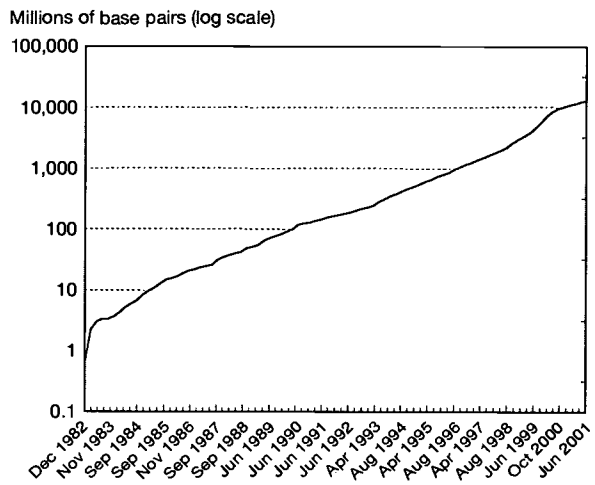
- **Pure electronic journals**—an edited package of articles that is distributed to most of its readers in electronic form. Examples include the *World Wide Web Journal of Biology* and the *Journal of the Association for Information Systems.*
- **Hybrid paper-electronic (p-e) journals**—a package of peer-reviewed articles that is distributed primarily in pa-

Examples of Shared Databases

Large shared databases have become important resources in many fields of science and social science. These databases allow researchers working on different pieces of large problems to contribute to and benefit from the work of other researchers and shared resources. Examples of such databases include the following:

- GenBank (<http://www.ncbi.nlm.nih.gov/Genbank/>) is the National Institute of Health's annotated collection of publicly available DNA sequences. As of June 2001, GenBank contained approximately 12.9 billion base pairs from 12.2 million sequence records. (See figure 8-22.) The number of nucleotide base pairs in its database has doubled approximately every 14 months. As part of a global collaboration, GenBank exchanges data daily with European and Japanese gene banks.
- The Protein Data Bank (<http://www.rcsb.org/pdb/>) is the worldwide repository for the processing and distribution of three-dimensional biological macromolecular structure data (Berman et al. 2000).
- The European Space Agency (ESA) Microgravity Database (<http://www.esa.int/cgi-bin/mgdb>) gives scientists access to information regarding all microgravity experiments carried out on ESA and National Aeronautics and Space Administration missions by European scientists since the 1960s.
- The Tsunami Database (<http://www.ngdc.noaa.gov/ seg/ hazard/tsu.html>) provides information on tsunami events from 49 B.C. to the present in the Mediterranean and Caribbean Seas and the Atlantic, Indian, and Pacific Oceans. It contains information on the source and effects of each tsunami.
- The Earth Resources Observation Systems Data Center (<http://edcwww.cr.usgs.gov/>) houses the National Satellite Land Remote Sensing Data Archive, a comprehensive, permanent record of the planet's land surface derived from almost 40 years of satellite remote sensing. By 2005, the total holdings will come to some 2.4 million gigabytes of data.

Figure 8-22.
Growth of GenBank



SOURCE: Genetic Sequence Data Bank, NCBI-GenBank Flat File. Available at <ftp://ncbi.nlm.nih.gov/genbank/gbrel.txt>.

Science & Engineering Indicators – 2002

per form but is also available electronically. Examples include *Science On-line, Cell, Nature,* and many others.

- **Electronic print (e-print) servers**—preprint or reprint servers on which authors in specific fields post their articles. The original and most widely copied preprint server is the Los Alamos physics preprint server (<http://arxiv.org/>). Started in 1991 by Los Alamos physicist Paul Ginsparg as a service to physicists in a small subfield of physics, this server has grown to cover many fields of physics, astronomy, mathematics, and computation. Other preprint servers have been developed to serve other fields, but most fields do not use preprint servers as extensively as physics.
- **Non-peer-reviewed publications on-line**—includes electronic newsletters, magazines, and working papers.
- **Personal Web pages**—maintained by individuals or research groups. Many scholars post their own work on these sites, which may include "reprints" of published material, preprints, working papers, talks and other unpublished material, bibliographies, data sets, course material, and other information of use to other scholars.

In addition, a number of services facilitate searching and provide abstracts and (in some cases) full text of articles in paper or p-e journals. These services include LexisNexis™, databases of journals sold to academic libraries, and public sources such as PubMed Central (<http://www.pubmedcentral.nih.gov/>) and PubSCIENCE (<http://www.osti.gov/pubsci>).[9] These can be considered elements of digital libraries. See sidebar, "Digital Libraries."

An example of rapid expansion in electronic scholarly communication is the Los Alamos preprint server (<http://arxiv.org/>), which continues to grow in terms of both submissions and connections. As of April 2001, it was receiving more than 2,500 new submissions each month and averaging more than 100,000 connections (for searching, reading, or downloading papers) each day. It has become the main mode of communication in some fields of physics, and 17 mirror sites have been established around the world to provide alternative access to the information in it.

Kling and McKim (2000) note that one should not expect the preprint server mode of electronic communication to expand to all fields, however. High-energy physics had a culture of wide sharing of preprints before the advent of the World Wide Web, and researchers in this field now use electronic communication extensively. Molecular biologists, by contrast, traditionally shared preprints only among smaller groups and continue to rely more on paper journals. Different fields have different attitudes about posting material on the Web prior to publication in a peer-reviewed journal. In physics, such posting is standard practice; in medicine, it is viewed as dangerous because the public may make medical decisions based on non-peer-reviewed science. The absence of e-print servers in fields such as atmospheric research, oceanography, and climate science is evidence of substantial differences in scholarly communication across fields of science.

Electronic journals also have been expanding rapidly. The Association of Research Libraries 2000 directory of scholarly electronic journals and academic discussion lists (Mogge and Budka 2000) identifies 3,915 peer-reviewed electronic journals, up from 1,049 in 1997. Friedlander and Bessette (2001) cite estimates ranging from 3,200 to 4,000 e-journals in science, technology, and medicine. Most of these are not electronic-only journals but rather are electronic versions of, or supplements to, print journals.

Electronic Scholarly Communication Benefits. Electronic scholarly communication has many potential benefits. Electronic search tools make it possible for scholars to find information more easily and quickly, and scholars do not have to worry about whether journals are missing from the library. Electronic documents potentially offer richer information than print documents. They are not constrained by page limits and can contain multimedia presentations or computer programs and data as well as text, thus enriching the information and facilitating further work with it. Additional references, com-

Digital Libraries

The digital library is a concept related to both scholarly communication and scientific databases. The concept encompasses a variety of digital collections of information, including digital versions of traditional library, museum, and archive holdings. The World Wide Web is considered an extensive but rudimentary digital library because search methods typically cover only a small part of the collections (President's Information Technology Advisory Committee 2001). Newspaper archives and genomic databases also are considered digital libraries.

A vision set forth for digital libraries is that they will let all citizens, anywhere and anytime, use any Internet-connected digital devices to search and access all of human knowledge (President's Information Technology Advisory Committee 2001). Key issues in achieving this vision include:

- improving the ability to search for information, in part by improving the "metadata" systems for describing and organizing collections;
- improving the human interfaces with the libraries;
- improving the ability to store and retrieve materials across diverse independent collections;
- developing long-term storage technologies and efficient procedures for transferring ephemeral content into long-term storage; and
- determining how to manage intellectual property rights for digital collections.

[9]PubSCIENCE is a World Wide Web service developed by DOE to facilitate searching and accessing of peer-reviewed journal literature in the physical sciences and other energy-related disciplines.

ments from other readers, or communication with the author can be linked to the document.

Electronic communication is generally thought to speed the dissemination of scientific information, and this is generally thought to increase scientific productivity. However, some scientists suggest that the Web, by speeding electronic communication, can encourage scientists to rush to become part of the latest trend, leading them to abandon other paths of research too quickly (Glanz 2001b).

There are also potential advantages for libraries. Many patrons can access the same electronic information at the same time without needing to visit the library, electronic archives eliminate the space requirements of old journal collections, and electronic media help libraries stretch limited financial resources, especially for accessions.

Electronic documents also have potential economic benefits. Once a document is prepared in electronic form, the marginal cost of providing it to additional readers is very low. Electronic documents also offer the benefit of accessibility. Electronic documents can be made available over the Internet to scholars around the world who do not have access to major research libraries. For example, the Los Alamos archive is allowing scientists in geographically isolated and small institutions to participate in leading-edge research discussions (Glanz 2001a). Several publishers have announced that they will provide free electronic medical journal access to medical schools, research laboratories, and government health departments in poor countries (Brown 2001).

Electronic Scholarly Communication Issues. All of the factors mentioned above combine to exert strong pressures for making scholarly information available electronically. Although these potential benefits support the rapid expansion of electronic communication, several issues remain to be resolved, including issues related to function, economics, and archiving.

Function. Although nonrefereed electronic publications (such as preprint servers) can be much less expensive than print journals (Odlyzko 1997), such publications do not perform all of the functions of the traditional system of printed academic journals. For example, journals organize articles by field and manage peer-review processes that help to screen out bad data and research, scholars achieve recognition through publication in prestigious journals, and universities base hiring and promotion decisions on publication records. For this reason, preprint servers are not likely to replace peer-reviewed journals.

Economics. For peer-reviewed journals (in either paper or electronic form), editing and refereeing of manuscripts and general administration account for a large share of costs (Getz 1997). At least initially, these costs remain about the same for electronic journals. In addition, electronic journals have costs associated with acquiring and implementing new technology and formatting manuscripts for electronic publication.

Electronic publication also can affect the revenue stream of print publishers. If a publisher provides a site license for a university library that enables anyone on campus to read the journal, individual subscriptions from that campus may decline. Moreover, advertisers may find electronic journals less attractive than print versions.

Publishers are currently experimenting with different ways of pricing electronic journals. Some publishers provide separate subscriptions for electronic and print versions, and the price of the electronic subscription may be higher or lower than the price of the print subscription. Others provide the electronic version at no charge with a subscription to the print version. Some publishers offer free on-line access to selected articles from the print version and regard the on-line version as advertising for the print version (Machovec 1997). Publishers of fee-based electronic journals generally protect their information from unauthorized access by making the journals accessible only to certain Internet domains (such as those of universities that have acquired a site license) or by using passwords.

Electronic resources represent an increasing share of library costs. The Association of Research Libraries (Kyrillidou 2000) reported that electronic resources (e.g., indexes and subscriptions to on-line journals) increased from 3.6 percent of library material expenses in 1992–93 to 10.5 percent in 1998–99. Overall, serial costs (including both paper and electronic serials) increased over this same period, from a median of $161 per serial in 1992 to $284 in 2000. Library budgets are under increasing pressures as they seek to satisfy demands for both paper and electronic journals.

Archiving. Another key issue is the archiving of electronic publications (Friedlander and Bessette 2001). One fundamental issue is the technical question of how to maintain records over the long term, because the electronic medium degrades and electronic formats change. Another fundamental issue is the underlying tension in electronic media between the opportunity to revise and update papers to maintain currency and the need to maintain the record. Another question to be addressed is whether an entire issue of an on-line magazine or newspaper should be preserved or whether it suffices to create a database of individual stories that can be individually retrieved but can never be reconstituted into the actual issue as it existed on the day readers first read the news. Other questions relate to responsibility for long-term preservation (whether publishers or libraries should be primarily responsible), copyright (how to issue and enforce copyrights), and maintenance (as technologies evolve, the particular technology required to view a given file may become obsolete, effectively eliminating the record).

Collaboration

Computer networking was developed as a tool for scientists and engineers, and e-mail and file transfers have long supported collaboration among scientists and engineers. Shared databases, intranets, and extranets have helped geographically separated scientists and engineers work together.

Scientific collaboration, as measured by the increase in the percentage of papers with multiple authors, has been increasing steadily for decades. (See chapter 6, "Industry, Technology, and the Global Marketplace.") Walsh and Maloney (2001) have found that computer network use is associated

with more geographically dispersed collaborations as well as more productive collaborations.

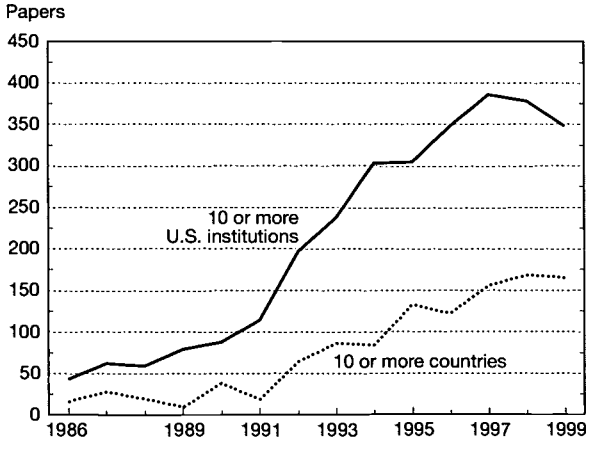
Collaborations have been growing larger in a number of fields, often because scientists are pursuing increasingly complex problems and, in some cases, also because agency funding programs encourage multi-investigator and multidisciplinary research teams. These collaborations are facilitated by IT, especially e-mail and the World Wide Web. Large-scale scientific collaborations may especially benefit from new IT. The number of research papers with authors from multiple countries or institutions has increased rapidly, a trend that has coincided with the rapid expansion of the Internet. (See figure 8-23.)

Over the past decade, advanced tools have emerged to support "collaboratories"—geographically separate research units functioning as a single laboratory (CSTB 1993). These technologies allow:

- remote access to scientific instruments over the Internet, making it possible for researchers from different sites to use a single major scientific instrument (such as a synchrotron at a national laboratory) as a network of instruments operating at different places:
- Internet-based desktop videoconferencing;
- shared access to databases and computer simulation;
- shared virtual workspaces, such as "white boards" on which researchers can sketch ideas; and
- shared electronic laboratory notebooks to capture the details of experiments.

These tools were originally developed and demonstrated through several collaboratory pilot projects, including the NSF-sponsored Space Physics and Aeronomy Research Collaboratory (<http://intel.si.umich.edu/sparc/>) and the DOE-sponsored Materials MicroCharacterization Collaboratory (<http://tpm.amc.anl.gov/MMC>) and Diesel Combustion Collaboratory (<http://www-collab.ca.sandia.gov/snl-dcc.html>).

Figure 8-23.
Papers with authors from 10 or more countries or 10 or more U.S. institutions: 1986–1999



SOURCE: CHI Research, Inc.

Science & Engineering Indicators – 2002

The collaboratory concept has moved beyond pilot projects to the point where many new large-scale projects have collaboratory components. Many of the tools used in the early pilot projects, such as Internet-based videoconferencing, are now available in inexpensive commercial software. Examples of new major research projects that have a collaboratory component include the following:

- The NIH-funded Great Lakes Regional Center for AIDS Research, a collaboratory of Northwestern University, University of Wisconsin-Madison, University of Michigan-Ann Arbor, and University of Minnesota-Minneapolis investigators (<http://www.greatlakescfar.org/cfar/>).
- NIH's Human Brain Project, a cooperative effort among neuroscientists and information scientists to develop tools for brain research (<http://www.nimh.nih.gov/neuroinformatics/index.cfm>). This project emphasizes tools to aid collaboration between geographically distinct sites.
- The NSF-funded George E. Brown, Jr., Network for Earthquake Engineering Simulation (NEES), a national networked collaboratory of geographically distributed, shared-use experimental research equipment sites (with teleobservation and teleoperation capabilities) for earthquake engineering research and education. When operational in 2004, NEES will provide a network of approximately 20 equipment sites (shake tables, centrifuges, tsunami wave basins, large-scale laboratory experimentation systems, and field experimentation and monitoring installations) (NSF 2001b).
- The NSF-funded Distributed Terascale Facility (DTF) will be a multi-site supercomputing system. It will perform 11.6-trillion calculations per second and store more than 450-trillion bytes of data, and will to link computers, visualization systems and data at the National Center for Supercomputing Applications in Illinois, the San Diego Supercomputer Center (SDSC) in California, Argonne National Laboratory in suburban Chicago and the California Institute of Technology in Pasadena (NSF 2001c).

Although collaborative research projects are being designed around IT, it is unclear whether virtual collaborations will be as successful as colocated collaborations. Teasley and Wolinsky (2001) note that collaboratories have limits. Social and practical acceptability are the primary challenges. Collaboratories do not replace the richness of face-to-face interaction, and concerns about trust, motivation, data access, ownership, and attribution can affect collaboratory performance.

Finholt (2001) notes that, although studies of early collaboratories suggest that e-mail and computer-mediated communication enhance scientific productivity and support

larger and more dispersed collaborations, electronic communication alone is not enough to enable broader collaborations. Collaboratory technologies have not dispersed to scientific users as fast as other Internet technologies (such as e-mail or the World Wide Web), which suggests that major challenges may be involved in supporting complex group work in virtual settings. Most practices and routines of research groups assume a shared space, and transferring these practices to virtual spaces can be difficult. Collaboratories may benefit graduate students and "nonelite" scientists the most, because they are the members of the scientific community least able to afford the costs of travel. Also, the increase in outside participation that results from virtual collaboration may create distractions for top researchers.

Olson and Olson (2001) note that distance collaborations work best when the work groups have much in common, the work is loosely coupled, and the groups have laid both the social and technical groundwork for the collaboration. Lacking these elements, distance collaborations are much less likely to succeed.

Collaboratory technologies raise interesting questions about the effects of IT on the organization of science and technology (S&T). Will multi-institution, electronically enabled collaborations become the norm for large-scale science projects? Will collaboratories make science more open to nonelite scientists? How do collaboratory technologies affect the productivity of S&T?

IT and Innovation

In addition to its interactions with R&D, IT influences several other elements of the innovation process, including the market environment for and the organization of innovation. The Council of Economic Advisers (2001) notes that the U.S. economy in the late 1990s was characterized by the high rate of technological innovation and by the central role of IT. The council observes that innovation in the "new" economy appears to have changed in several ways, including the intense competition and positive feedback that drive innovation, the mechanisms for financing innovation, the sources of R&D, and the innovation process itself. IT is involved in each of these changes, and many of the changes are most visible in the IT sector.

Market Environment for Innovation

The rapid pace of technological advances, together with the expectation that this pace will continue (see sidebar, "Moore's Law"), has led to an environment in which companies in most industries know they must continually innovate. As noted above, intense competition and feedback drive the development and adoption of new technologies. The availability of one technology stimulates demand for complementary technologies, which in turn lowers production costs and encourages further demand for the initial technology.

The Internet may be stimulating innovation by forcing many industries to innovate. For example, in the food industry, the fact that some companies are using electronic procurement is forcing others to do the same (Hollingsworth 1999). In some cases, IT may increase competition simply by making markets more global and bringing firms in contact with more competitors.

Lewis (2000) notes that telecommunications and IT have accelerated business processes. Technology adoption and diffusion rates are faster than they were in previous decades. In addition, the information economy has led to network effects (see sidebar, "Metcalfe's Law") in many areas, giving a major advantage to the company that is the first to bring a new product to market. If a company is not the first to market, then it needs to match and improve on the new product very quickly. The consequence of this environment is that technology transfer must occur faster and faster. Lewis argues that corporate R&D must change its traditional way of doing business, which is too slow.

The rapid improvement in IT has created opportunities in new applications such as secure Web servers or e-commerce software, which in turn create opportunities for new businesses. New forms of business activity (such as electronic marketplaces) and new IT-enabled business processes present many opportunities for innovation.

Organization of Innovation

Dewett and Jones (2001) review the literature on how IT affects organizational characteristics and outcomes. They note that although the literature contains very little information on the specific role of IT in promoting innovation, it is possible to identify many innovation-related effects of IT on organizations, including the following:

- IT can enhance the knowledge base available to each employee, enable faster scanning and monitoring of the external environment, and improve both the employees' and the organization's knowledge of best practices and relevant leading-edge technologies.
- IT can mitigate the tendency toward specialization (which can reduce people's ability to understand the context of the organization) and also can help promote innovation by better connecting specialists to the market.
- IT may increase absorptive capacity, which is the ability of an organization to recognize the value of external information, assimilate it, and apply it commercially.
- By helping organizations codify their knowledge bases, IT can promote the diffusion of knowledge.
- IT has helped organizations streamline product design by replacing traditional sequential processes with parallel processes in which employees in different functions work simultaneously, with continual interaction through electronic communication.
- IT is changing organizational forms and allowing virtual organizations. New IT-enabled organizational forms can be more responsive to pressures such as heightened market volatility, the globalization of business, increased un-

certainty in the economy, and demographic changes in labor and consumer sectors.

In contrast, electronic communication may hinder innovation by decreasing informal communication and may also lead to information overload.

Thus, IT has many possible effects on organizations, and these effects suggest a considerable positive influence on innovation. It is important to keep in mind, however, that scholarly literature on this subject is sparse.

Johannessen, Olaisen, and Olsen (2001) suggest that because IT more effectively transfers explicit knowledge than tacit knowledge, it may lead to the mismanagement of innovation. Explicit knowledge is relatively easy to express in symbols, digitize, and transfer. Tacit knowledge is rooted in practice and experience and typically is transmitted through training and doing. Companies typically focus IT investment on the explicit portion of their knowledge base and deemphasize the tacit portion. Yet much of the research literature argues that tacit knowledge is critical in determining how well a company can innovate and compete.

IT also has led to changes in the organization of innovation beyond the boundaries of individual organizations. The Council of Economic Advisers (2001) notes that innovation traditionally has been isolated within large companies. Today, innovation increasingly is performed by both large and small companies that collaborate with each other and with academic institutions and government agencies.

With the expansion of the world's supply of scientists, technologists, and knowledge workers and of the knowledge bases available to them, access to external knowledge sources is becoming an increasingly important factor in the ability of organizations to participate in innovation. IT has helped organizations coordinate highly dispersed innovation activities by providing them with new management techniques, software, and communication systems. One aspect of the trend toward dispersion of innovation activities is the outsourcing of innovation. Pharmaceutical companies have long outsourced basic research to universities, institutes, and government laboratories. Many large pharmaceutical companies rely on small technology companies for innovation and then acquire these companies. In the computer and automotive industries, manufacturers have long relied on component makers for design and engineering work. Much of the innovation in these industries takes place at the interface between manufacturers and their innovative suppliers. IT has made outsourcing more attractive for companies (Quinn 2000) by facilitating the process with advances in modeling and simulation, collaborative tools, and management software.

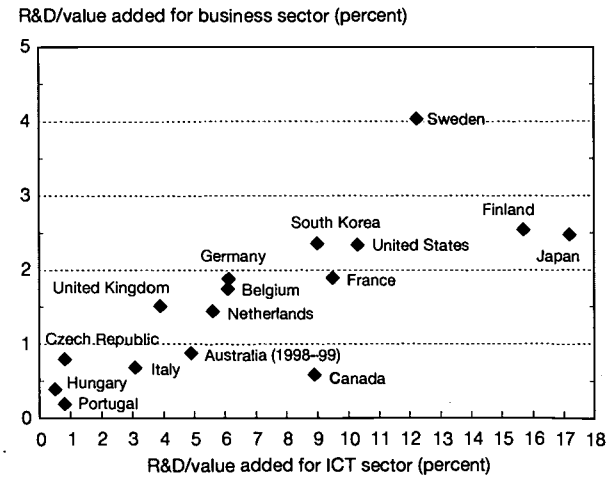
One example of new organization in innovation is open source software development (Lerner and Tirole 2001). In open source software development, the source code is made broadly available. Users can modify the software, but their modifications are also returned to the community or organization that oversees the development of the software. A number of open source software programs are widely used, including Linux (a PC operating system), Apache (Web server software), and Sendmail (which underlies e-mail routing on the Internet). Participation in open source projects is voluntary. Although participants appear to be motivated by altruism, they do benefit from their efforts. Programmers who donate their time benefit from recognition, and companies that support the programmers benefit from improved programs and better monitoring and absorption of external technology (Lerner and Tirole 2001). A number of companies make money not by selling the software, which is freely available, but by selling complementary services (e.g., documentation, installation software, and utilities). The President's Information Technology Advisory Committee recommended that the Federal Government support open source software development for high-end computing.

Innovation in IT

The IT sector accounts for a large and growing part of R&D and innovation in the United States and other countries. The information and communication technology (ICT) sector is more R&D intensive than industry as a whole. Figure 8-24 compares the ratio of R&D to the value added for the ICT sector with the same ratio for the overall business sector in OECD countries. For most countries, the ICT sector is about five times more R&D intensive than the business sector as a whole; however, countries vary widely in the R&D intensity of their IT industries. Some of the countries that are the most innovative in IT, including Sweden, Finland, Japan, and the United States, have the most R&D-intensive ICT industries.

Analyses of patent data suggest that innovation in IT is somewhat different from innovation in other areas of S&T. Hicks et al. (2001) found that compared with other areas of technology, IT patents cite scientific literature less exten-

Figure 8-24.
Ratio of R&D to value added in the ICT and total business sectors: 1997



ICT = Information and communications technologies

SOURCE: Organisation for Economic Co-operation and Development. 2001. *Measuring the ICT Sector*. Paris. Tables 2 and 3. Available at <http://www.oecd.org/dsti/sti/it/prod/measuring_ict.htm>.

Science & Engineering Indicators – 2002

sively.[10] In addition, the median age of patents cited by IT patents (termed the technology cycle time) is less than the median age of scientific papers cited (termed the science cycle time). Technology cycle times are faster in IT (6–6.5 years) than in other areas of technology. The analysts concluded that IT patents cite other technology patents more extensively than scientific papers because IT is moving too fast for scientific research to keep up.

Growth in IT patenting activity does not seem to be accompanied by growth in research publishing activity (Hicks et al. 2001). Based on documents referenced in patents, IT patents seem to draw on a particularly diverse set of nonpatent, nonresearch technical documentation that includes nonpatented software. It appears that nonresearch technical work may underlie innovation in IT more extensively than is the case in other technologies and that IT innovation is less directly dependent on scientific research than are many other technologies. Hicks et al. (2001) also note that patenting (one measure of innovative activity) is accelerating in IT. The IT patents share of all U.S. patents increased from 9 percent in 1980 to 25 percent in 1999. IT patents per $1 million of company R&D expenditures nearly doubled between 1990 and 2000. Similar increases were not observed in other areas. Although such statistics might simply indicate an increased propensity to patent in the IT sector, the extent to which IT patents are cited by other patents has increased, which suggests that the quality of IT patents has not deteriorated.

IT and Higher Education

IT pervades higher education. As the demand for IT workers has grown, university priorities have shifted accordingly, and a separate certification and training system for IT workers also has emerged. IT is increasingly used in instruction, and distance education continues to expand. IT may lead to further restructuring of colleges and universities. This section highlights some of the ways in which IT is affecting higher education.

IT Credentialing

Adelman (2000) analyzes the new system of credentialing that has arisen in ICT industries during the past decade. Companies and industry or professional associations have created more than 300 discrete certifications since 1989. Approximately 1.6 million individuals had earned about 2.4 million IT certificates by early 2000, most since 1997. Students outside the United States earned about half of the certificates. To earn a certificate, a candidate must pass an exam administered by a third party. A large industry has arisen to prepare candidates for these exams. This industry includes organizations that provide courses, tutorials, practice exams, self-study books, and CD-ROMs. Although some traditional four-year colleges and community colleges prepare students for these certification exams, much of the industry that supports IT certification is outside higher education as traditionally defined.

[10]IT in this discussion of patents consists of computers, peripherals, telecommunications, semiconductors, electronics, and software. Hicks et al.'s analysis covers patent activity between 1980 and 1999.

IT in Instruction

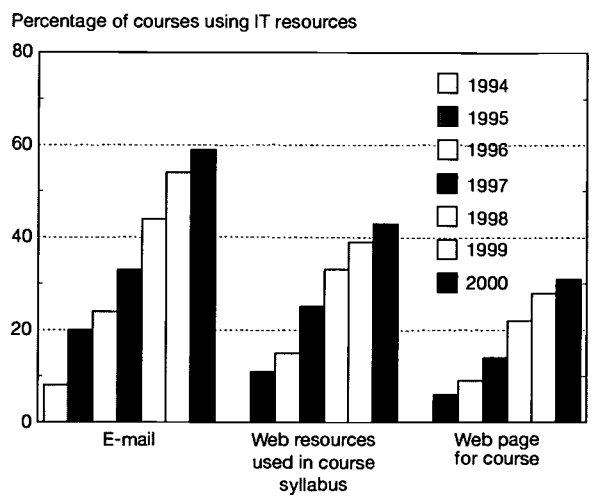
The Campus Computing Project (2000) found that IT use in college courses is increasing. There are indications that IT use is leveling off; nevertheless, e-mail, the Internet, and course Web pages are being used in more courses every year. (See figure 8-25.)

In some cases, decisions about IT use are left to individual professors. However, some universities (such as the University of California, Los Angeles) have required professors to establish Web pages for each course and to put syllabuses online. Support for the increased use of IT on college campuses has not been universal. Many professors and administrators enthusiastically embrace new technologies, and others prefer to wait for other institutions to find out which new technologies are useful in improving the quality of education.

Much of the new IT being used in scholarly communication and research can be used in instruction as well. Students can use on-line scholarly literature, participate in on-line scientific experiments, and learn from computer modeling and simulation. The future is likely to bring many additional IT applications in instruction.

Kulik (forthcoming) reviewed 44 studies from the 1990s on the effects of instructional technology in college courses. The studies focused on five computer applications: computer algebra systems, computer use (tutoring, simulations, and animations) in science, and computer-assisted language learning. In each study, instructional outcomes for students taught with and without computer help were compared. The instructional outcome measured most often in the studies was student learning. Kulik found that over the years, instructional technology has proven to be more and more effective in improving learning in college courses. Studies in the 1990s show a greater positive effect of instructional technology than stud-

Figure 8-25.
Use of technology in college instruction



SOURCE: Campus Computing Project. Available at <http://www.campuscomputing.net>.

Science & Engineering Indicators – 2002

ies in the 1980s and earlier decades. The growing effectiveness of instructional technology coincides with the dramatic improvements in computing and with improvements in instructional software.

Although computer technologies are helping to improve student learning, they can also make it easier for students to cheat and plagiarize. The Internet contains many collections of school papers that students can download and use for their classes.

Distance Education

Distance education is not new. An estimated 100 million Americans have engaged in distance study, mostly correspondence courses, since 1890 (Distance Education and Training Council 1999), and in the 1960s there was widespread optimism about the use of television in education. IT is providing significant new tools for distance education. Many schools are either establishing distance education programs for the first time or expanding existing programs.

In on-line distance courses, the instructor typically e-mails "lectures" or posts them on a website, and students submit assignments and have "discussions" via e-mail. Courses often supplement textbooks with Web-based readings. Participants also may meet in a chat room at a certain time for on-line discussions. Courses also may have on-line bulletin boards or Web conferences, in which participants ask and respond to questions over time. In the not-too-distant future, as Internet bandwidths increase, video lectures and videoconferencing will become more common in on-line courses. Some courses may use more elaborate systems (so-called MUD/MOOs[11]) for group interaction, as well as groupware programs that involve simultaneous viewing of graphics and use of a shared writing space (e.g., white boards) (Kearsley 2000). Some courses may also use computer simulations over the Internet.

Distance education offers several potential advantages: it allows students to take courses that are not available locally; it allows students to balance coursework with their career and family life; and it can make education more available to people who are employed, especially those who are older and in midcareer or those who have family responsibilities. For universities, it offers a way to expand enrollment without increasing the size of the physical plant.

Although distance education traditionally is regarded as involving the delivery of courses to remote locations, the techniques of distance education, especially on-line education, can be incorporated in on-campus instruction as well. Universities are finding that significant numbers of on-campus students sign up for distance education courses when they are offered. At the University of Colorado in Denver, for example, more than 500 of 609 students enrolled in distance education courses were also enrolled in regular on-campus courses (Guernsey 1998). On-line courses can be more convenient for on-campus students, giving them greater flexibility in scheduling their time. Professors can augment their on-line courses with Web-based materials and guest lecturers in remote sites.

Distance Education Trends. The National Center for Education Statistics has conducted two surveys of distance education in postsecondary education institutions: the first in the fall of 1995 and the second in the 1997/98 academic year (National Center for Education Statistics (NCES) 1999b). The first survey covered only higher education institutions, but the second survey covered all postsecondary educational institutions. These surveys document that distance education is now a common feature of many higher education institutions, and its popularity is growing. The majority of courses are at the undergraduate level and are broadly distributed across academic subjects.

The number of higher education institutions offering distance education is growing. In 1997/98, 44 percent of all two- and four-year institutions offered distance education courses compared with 33 percent in fall 1995. Distance education is more widely used in public four-year institutions than in private four-year institutions, but private institutions are also increasing their use of it. In 1997/98, distance education was offered by 79 percent of public institutions (compared with 62 percent in fall 1995) and 22 percent of private institutions (compared with 12 percent in fall 1995).

Distance education course offerings and enrollments are growing more rapidly than the number of institutions that offer distance education. The number of courses offered in two- and four-year higher education institutions doubled from 25,730 in fall 1995 to 52,270 in 1997/98. The increases were fairly similar across all categories of institutions (two- and four-year, public and private, and all enrollment-size categories). Course enrollments also increased sharply, more than doubling from 753,640 in fall 1995 to 1,632,350 in 1997/98 (NCES 1999b).

The availability of degrees that can be completed exclusively with distance education courses has remained essentially constant. Of higher education institutions that offer distance education, 23 percent offered degrees in fall 1995 and 22 percent did so in 1997/98 (NCES 1999b).

Technologies used for distance education have changed significantly. In fall 1995, the most widely used technologies were two-way interactive video (57 percent) and one-way prerecorded video (52 percent). These were still widely used in 1997/98 (56 and 48 percent, respectively). Internet-based courses, however, expanded greatly. Of all the institutions that offered distance education courses in 1997/98, 60 percent offered asynchronous (not requiring student participation at a set time) computer-based instruction and 19 percent offered synchronous (real-time) computer-based instruction (NCES 1999b).

Significance of On-line Distance Education. Despite substantial (and growing) experience with on-line distance education, thorough assessments of its effectiveness have been relatively few. Existing evidence suggests that, at least in some circumstances, it can be very effective. The rapid growth and reported success of some on-line distance education programs indicate that they are providing acceptable learning experiences. A review of the literature on on-line classes (Kearsley, Lynch, and Wizer 1995) found that compared with traditional classes, student satisfaction was higher, measured student achievement

[11]MUD stands for multi-user domain or multi-user dungeon (reflecting its origins in games), and MOO stands for MUD, object-oriented.

was the same or better, and student-instructor discussions usually were more frequent. On the other hand, some case studies document that on-line distance education can be frustrating for both students and instructors. The growth of on-line distance education has far-reaching implications for higher education. Although on-line education may expand the pool of people who have access to education, it may also take students away from traditional education. Some scholars express concern that it will undermine the traditional college experience. Some question whether it can match the quality of face-to-face instruction. Moreover, the kind of intellectual and social community that characterizes the college experience may be much harder to achieve through distance learning.

IT Issues for Universities

IT in general and distance education in particular raise new issues for universities. Distance education brings universities into competition with each other in a new way. Because distance education courses are available to anyone anywhere, they allow universities to compete for students outside their own geographic areas. Top-tier universities such as Stanford and Duke are marketing Internet-based master's degrees to national audiences. New distance education–based universities such as Jones International University (<http://www.jonesinternational.edu>), the first on-line-only university to gain accreditation; the University of Phoenix on-line (<<http://online.uophx.edu>>); and Western Governors University (<http://www.wgu.edu>) are marketing courses that compete with the continuing education services of universities and colleges that in the past had been the only providers of such services in their regions. Some distance education providers see opportunities to market American university degrees to large student populations abroad. The reverse is also happening: the United Kingdom's Open University, which began providing distance education in the United Kingdom in 1971 and has established a good reputation there, has started an operation in the United States (Blumenstyk 1999a). In contrast to many institutions that are viewing Web-based course materials as a new source of revenue, MIT announced in 2001 that it would make nearly all of its course materials available for free on the Web over the next ten years (Massachusetts Institute of Technology, 2001).

In addition, distance education is creating new markets for companies that sell print materials and software to assist in on-line courses (Blumenstyk 1999b). Publishers such as McGraw-Hill and software companies such as Microsoft and Oracle have developed and are marketing on-line courses (Morris 1999). These commercial on-line courses represent another potential source of competition for universities, especially in preparing students for IT credentialing.

Distance education technologies also raise questions about the role of professors. Some view these technologies as new tools for professors. Others, however, foresee "mass production" education in which packaged multimedia courses will reduce the importance of professors (Noble 1998). The expanding and potentially lucrative new market for on-line course materials raises the issue of whether professors or the university should own the intellectual property embodied in on-line courses. The American Association of University Professors has taken the position that professors rather than institutions should retain primary property rights for on-line course materials (Schneider 1999) and has questioned the accreditation of Jones International University (Olson 1999).

Brown and Duguid (2000) note that colleges and universities provide three essential functions to learners: access to an authentic community of learning, resources to help learners work within these communities, and widely accepted representations of learning and work (such as degrees and transcripts). Brown and Duguid also note that many proposals for new "virtual universities" fail to provide one or more of these functions. Conventional universities serve all of these functions by combining five elements: students, faculty, research, facilities, and an institution able to provide an accepted degree. Brown and Duguid suggest that these elements will remain but that new technologies will allow the elements to be in a looser configuration, not necessarily combined in a single collocated organization.

The IT Workforce

During the 1996–2000 period, the rapid expansion of IT development and application during a period of full employment in the overall economy led to concerns about the availability of IT workers. In 2001, however, the cooling of the economy (especially in the IT sector) has, at least temporarily, ameliorated these concerns.

The Bureau of Labor Statistics has projected the future demand for IT workers (U.S. DOC 1997, 1999b, 2000c) for six core occupational classifications: computer engineers, systems analysts, computer programmers, database administrators, computer specialists, and all other computer scientists. These projections indicate that between 1998 and 2008, the United States will require more than 2 million new workers in these six occupations.

One indicator of the supply of IT workers is the number of computer science degrees awarded. After increasing sharply in the early 1980s, that number declined sharply after 1986 and has only begun to increase again since 1996. (See chapter 2, "Higher Education in Science and Engineering.")

The IT industry asserted that a serious shortage of IT workers exists, and many companies in various industries indicated that they needed more IT-trained workers to meet the growing demand. However, the existence of a shortage of IT workers was the subject of debate. Some employee groups believed there were enough trained technical professionals but that industry had not tapped existing labor pools (especially older engineers). The debate has been especially polarized over the issue of whether to allow more foreign workers with technical training to enter the country on temporary H-1B visas.

Several studies have examined the IT workforce issue (CSTB 2001; Freeman and Aspray 1999; Johnson and Bobo 1998; Lerman 1998; U.S. DOC 1999b). (See also chapter 3,

"Science and Engineering Workforce.") These studies generally reached the following conclusions:

- **During 1996–2000, the IT labor market was somewhat tighter than the overall labor market.** Existing data, however, cannot prove or disprove that such a shortage existed. Federal data are limited by untimely reporting, out-of-date occupational descriptions, and incompatibilities in supply-and-demand data collected by different agencies.
- **The IT labor market is not homogeneous.** Supply-and-demand characteristics vary by region, industry segment, and specific skill. Because IT product cycle times are very fast, the industry pays a premium for people who already have specific current skills and do not require training to be effective. Competition is especially intense for people with specific "hot" skills in specific markets.
- **People enter IT careers in a variety of ways.** IT workers include people who majored in IT-related disciplines at the associate, bachelor's, master's, and doctoral degree levels; people from other science, engineering, and business fields; and people from nontechnical disciplines who have taken some courses in IT subjects. Many IT workers enter the field through continuing education programs and for-profit schools. Workers are taking advantage of new modes of instruction delivery such as distance learning.

Labor markets tend to be cyclical. In response to the tight conditions in the IT labor market during 1996–2000, wage increases attracted more people to the field, and many initiatives around the country were set up to help expand the IT workforce. Slower growth and even layoffs in the IT industry have also reduced demand for IT workers.

Conclusion

IT continues to develop rapidly as the key underlying technologies of semiconductors, disk drives, and network communications improve at exponential rates. Constant improvements in the underlying technologies make possible new IT applications that affect all areas of society, including the economy, households, government, and the R&D enterprise.

Throughout society, the utility of IT applications tends to advance much more slowly than the underlying technologies. A doubling of processing speeds, for example, does not bring a doubling of utility. The effective implementation and use of IT are the result of a complex process that requires not only adoption of a technology but also changes in organizations and institutions. As part of this process, individuals and organizations actively adapt (and sometimes resist) the technologies. As a result, the effects of IT on society often take place more slowly than visionaries predict. Nevertheless, the effects—driven by the continual change in underlying technologies—are substantial over time.

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Appendix A
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Appendix B
Index

Note: Numbers in **boldface** indicate appendix tables; page numbers followed by *f* and *t* refer to text figures and tables, respectively.

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