SCIENCE AND ENGINEERING INDICATORS 2000

VOLUME 1

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Volume 1

NSB NATIONAL SCIENCE BOARD

Recommended Citation

National Science Board, *Science &*
Engineering Indicators – 2000. Arlington, VA:
National Science Foundation, 2000 (NSB-00-1)

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402
Stock Number 038-000-00597-9

National Science Board

Letter of Transmittal

NATIONAL SCIENCE BOARD
4201 Wilson Boulevard
ARLINGTON, VIRGINIA 22230

January 13, 2000

The Honorable William J. Clinton
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 fourteenth in the series of biennial Science Indicators reports, *Science and Engineering Indicators–2000*. 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. In honor of the 50th anniversary of the National Science Board and the National Science Foundation, the Board decided to develop a special historical theme for *S&E Indicators–2000.* The report reflects on the conditions that characterized U.S. science and engineering 50 years ago as compared to the current state of the Nation's S&E enterprise.

The report enclosed contains analyses of key trends that illuminate the scope, quality, and vitality of research and education in the Nation and in an international context. In addition to a special history chapter, the report presents trends in U.S. and international R&D funds and alliances, on the S&E workforce, on science and mathematics education from the elementary level through graduate school and beyond, and on public attitudes and understanding of science and engineering. *S&E Indicators–2000* also devotes a chapter to the significance of information technologies for science and the daily lives of our citizens in schools, the workplace, home, and community.

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

With this report the National Science Board recognizes one of the most faithful readers, supporters, and critics of science and engineering, Congressman George E. Brown, Jr., who died in 1999. Congressman Brown was a friend of science and an extraordinary leader whose distinguished career in public service for three decades as a member of the U.S. House of Representatives enlightened science and technology policy.

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, Bennett I. Bertenthal, former Assistant Director, and Wanda E. Ward, Acting Assistant Director. Primary responsibility for the production of the volume was assigned to the Science and Engineering Indicators Program, under the direction of Jennifer Sue Bond of the Division of Science Resources Studies (SRS); Lynda Carlson, Division Director; Mary J. Frase, Deputy Division Director; and Jeanne E. Griffith, former Division Director. The Directorate for Education and Human Resources (EHR), Luther S. Williams, former Assistant Director, and Judith S. Sunley, Interim Assistant Director, also contributed to portions of the report.

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NSF's Office of Legislative and Public Affairs (OLPA), under the guidance of Julia A. Moore, Director, and Michael C. Sieverts, Acting Director, provided media and Congressional liaison support for the report. Special thanks go to Mary E. Hanson and Bill Noxon for media support and Joel M. Widder, Deputy Director, David Stonner, and Shirley Day for Congressional relations support.

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Introduction: Celebrating the Past, Anticipating the Future

This edition of *Science and Engineering Indicators* is being released in the year 2000—the 50th anniversary of the creation of the National Science Foundation (NSF). In recognition of this event, the National Science Board (NSB) resolved to adopt a special historical theme for *Science and Engineering Indicators – 2000* considering the objectives that characterized U.S. science and engineering 50 years ago as a context for examining the current state of the Nation's science and engineering (S&E) enterprise.

The National Science Foundation Act of 1950, which President Harry S Truman signed into law on May 10 of that year, gave NSF the mandate, " . . . to promote the progress of science; to advance the national health, prosperity, and welfare; and for other purposes."[1] From its creation, the collection, analysis, and dissemination of quantitative information on the status of science and technology in the United States were an integral component of NSF's responsibilities. As the Nation moves into the 21st century, information on science, engineering, research, and education is assuming an ever more important role in our economy and society.

The National Science Board is responsible, by law, for developing on a biennial basis, a report " . . . on indicators of the state of science and engineering in the United States."[2] The *Science and Engineering 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. The chapters that follow contain analyses of key trends that illuminate the scope, quality, and vitality of research and education in the Nation and in an international context. Understanding these trends helps to prepare decisionmakers, scientists and engineers, and the public to deal with their consequences and challenges.

In addition to an historical chapter, the report presents trends in U.S. and international research and development (R&D) funds and alliances, in the S&E workforce, in science and mathematics education from the elementary level through graduate school and beyond, and in public attitudes and understanding of science and engineering. *Science and Engineering Indicators – 2000* also devotes a chapter to the significance of information technologies for science and the daily lives of our citizens in schools, the workplace, home, and community.

NSF was created near the end of a period in which the country's science and engineering resources were mobilized for World War II. What emerged in peacetime was a system designed to facilitate partnerships in support of a broader set of national science and technology (S&T) objectives. Although the specific issues evident in documents from the late 1940s differ from those that are familiar today, several current policy concerns have antecedents from that period. The chapters of *Science and Engineering Indicators – 2000* recall notable themes, but their emphasis is on the current S&T enterprise, as has been the case for all earlier editions in the *Science and Engineering Indicators* series.

Enduring Themes

A number of issues that were of concern prior to the founding of the NSF have continued to be of interest to decisionmakers. Indeed, they have been monitored in *Science and Engineering Indicators* reports over the years. Chapter 1 discusses these enduring themes in more detail. The following provides a brief summary of some of them and indicates where they are treated in the report:

- **Support and performance of R&D.** The funding and conduct of R&D has always been viewed as essential to the Nation. Funding by both the Federal and industrial sectors has grown impressively over the years and the relative importance of each has varied over the period. Striking the correct balance among defense-related and health-related R&D, and R&D in other fields has been an ongoing concern. Chapter 2 presents R&D expenditures by sector, field, and type of research in the United States and abroad. Chapters 6 and 7 concentrate on activities in the academic sector and the industrial sector, respectively.
- **Role of the Federal Government in the support of basic research.** Federal Government support of basic research has been central to the development of a thriving U.S. university system. That support continues today as an essential investment in the performance of research. New patterns of collaboration in innovation enrich the United States as the world's premier graduate research and education system. Chapter 6 provides an in-depth analysis of academic research and education, personnel, and outputs.
- **Human resources for science and engineering.** The importance of human resource development and the necessity of providing a trained S&T workforce and educated citizenry have been a consistent Federal concern. The

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[1] *National Science Foundation Act of 1950*, Public Law 81-507 (Stat. 149).

[2] "The National Science Foundation Act of 1950, as amended, states that the Board is responsible for "rendering to the President for submission to Congress in each even-numbered year a report on indicators of the state of science and engineering in the United States." *NSF Statutory Authority*, Section I, Sec.4 [j][1], 6.

deficit of trained scientists and engineers resulting from World War II was critical at the time of NSF's founding. The potential contributions of foreign students were recognized even before the participation of women and U.S. minorities became a priority. The role of women, minorities, and persons with disabilities is now regarded as vital to future S&T capabilities. While chapter 3 provides an in-depth analysis of the S&E workforce by training and occupation, chapter 4 discusses the role of higher education in the education and training of scientists and engineers. Both chapters present data on domestic diversity patterns and information on the training, utilization, and mobility of foreign scientists and engineers.

- **Importance of science and mathematics education.** In the post-World War II era, it was clear that improved education at all levels from pre-college through graduate training was essential. This is equally true today. Many of the same concerns and problems endure and even though some progress has been made, more is necessary. Chapter 5 summarizes data and analysis of elementary and secondary mathematics and science, including comparisons of U.S. student performance with that of students in other countries. There is no greater challenge than renewal of a skilled workforce and of citizens able to use their knowledge of science and mathematics in their daily lives. Chapter 8 updates information on public attitudes toward science and technology and discusses what the public does and does not understand regarding several science and engineering topics and issues. It also indicates where people get their information—including from the World Wide Web.

- **R&D and innovation as a key to economic growth.** Early on, science and technology were seen as key to economic growth, competitiveness, and jobs. Other countries have expanded their technological capabilities and technical information is more easily transferred across borders. Chapter 7 offers information on industry, technology, and the global marketplace and discusses aspects of the innovation system such as venture capital, patenting activities, and global technology trade patterns and capabilities. After World War II, it was recognized that new discoveries lead to the emergence of new technologies and economic growth and vice versa. Chapter 9 examines one area of scientific advancement—information technology (IT)—developed from a confluence of different disciplines that is transforming our economy and changing the conduct of research and education.

- **International cooperation in science and technology and globalization patterns.** The importance of international S&T cooperation and competition was already recognized when NSF was created. However, the growth in collaboration and S&T capabilities globally could not be fully envisioned at the time. Each of the nine chapters in *Science and Engineers Indicators – 2000* highlights international comparisons: R&D expenditures, globalization patterns, and alliances (chapter 2); utilization of foreign S&E's, graduate training of foreign S&E students, and international patterns of S&E mobility (chapters 3 and 4); international scientific cooperation in terms of coauthorship and citation (chapter 6); interactions and trade patterns between economies in intellectual property and technology (chapter 7); international comparisons of student performance assessments in mathematics and science (chapter 5) and of public perceptions of science and technology (chapter 8). Chapter 9 discusses how information technologies make worldwide communications easier and faster, particularly the effects of personal computer penetration and Internet access in various countries on collaborative research.

Evolution of the *Science and Engineering Indicators* Reports

The form of the Board's first report, *Science Indicators – 1972,* was suggested by Roger W. Heyns, a member of the National Science Board from 1967–76, who became the chairman of its first Science Indicators Committee. He suggested that for its mandated 1973 annual submission to the President and Congress, the Board might consider preparing a report analogous to periodic reports that assessed various economic and social trends in terms of quantitative data series known as social indicators. Preparation of such a report, he further suggested, could draw on the proven capabilities of the NSF staff in gathering and analyzing quantitative data on the U.S. and international science and engineering enterprise. The National Science Board accepted Heyns' suggestion, naming its fifth report to the Congress, *Science Indicators – 1972*.[3] The positive reception accorded the first *Indicators* volume confirmed the wisdom of the statutory requirement that the Board issue these reports on a biennial basis.

On May 19, 1976, in testimony before the House of Representatives' Subcommittee on Domestic and International Scientific Planning, Heyns highlighted some of the main purposes and functions of the *Indicators* reports:[4]

- to detect and monitor significant developments and trends in the scientific enterprise, including international comparisons;
- to evaluate their implications for the present and future health of science;
- to provide the continuing and comprehensive appraisal of U.S. science;
- to establish a new mechanism for guiding the Nation's science policy;
- to encourage quantification of the common dimensions of science policy, leading to improvements in research and development policy-setting within Federal agencies and other organizations; and

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[3] *Science Indicators – 1972* (NSB-73-1).

[4] *Science and Engineering Indicators - 1993, pg. xi*, Washington, DC: US Government Printing Office, 1993. (NSB 93-1).

- to stimulate social scientists' interest in the methodology of science indicators as well as their interest in this important area of public policy.

Over the years the Board has continued to expand and refine the *Science & Engineering Indicators* reports. The current issue, *Science & Engineering Indicators – 2000*, is the 14th in the biennial series. This important national and international data resource is part of the Board's larger responsibility in the area of national science and technology policy.

The Act further authorizes the Board to advise the President and Congress on matters of science and engineering policy (Sec. 4 [j][2]). In accordance with this broader obligation, the Board has issued a series of occasional papers commenting on selected trends in the *Indicators* report to focus attention on issues of particular current and long-term importance regarding the Nation's science and engineering enterprise.

Today, the need for quantitative data to assist in decisionmaking is even stronger than it was when the Board first began this effort. The U.S. science and technology enterprise is in transition. The Nation is changing its priorities for R&D investment and faces a number of challenges in balancing the Federal budget. And, of course, science and engineering have always had a global dimension. As globalization intensifies, *Science & Engineering Indicators – 2000* emphasizes international comparisons in the data and analyses it presents.

New Features of this Report

Science & Engineering Indicators – 2000 begins with a special historical chapter, with historical sidebars featured in many other chapters as well. The report ends with a chapter on the significance of information technologies for science and the daily lives of our citizens in schools, the workplace, home, and community. In between these chapters, the report updates the indicators on key topics and issues that have appeared in previous reports. For example, *Science & Engineering Indicators – 2000* provides new and enhanced indicators and analyses in the following areas:

- globalization and international comparisons—including extended coverage of emerging economies and developing countries;
- output indicators—including, for the first time, coverage of the publications and citation patterns of the social sciences;
- enhanced information on partnerships, alliances, and collaborations—particularly international S&T cooperation;
- public attitudes topics—including data on attitudes toward biotechnology and the public's use of information technologies;
- increased information on foreign scientists and engineers and international mobility patterns;
- discussion of school reforms, technology in schools, and distance learning in universities;
- age and retirement trends for scientists and engineers;
- developments in IT—including electronic commerce, the existence of a "digital divide," and evidence of use of the World Wide Web by governments around the world;
- modes of financial support and debt burden of science and engineering Ph.D.s;
- increased coverage of R&D in the service sector; and
- updated data on venture capital funds.

A Continuing Responsibility

The Strategic Plan of the National Science Board recognizes the important role of the *Science & Engineering Indicators* series and pledges to continue to develop and improve the series.[5] The plan states:

> As the Federal budget and policy processes have accentuated the demand for greater accountability and benchmarking, the data historically available through *S&EI* have become increasingly valuable for analyzing key trends that illuminate the scope, quality, and vitality of research and education. Thus, *S&EI* serves two critical purposes: first, as the report of record on the health of the enterprise; and second, as the basis for further analysis by all users generally and by the Board in particular. To insure that S&EI effectively supports these goals, the National Science Board reviews the report's effectiveness with each biennial cycle. The policy and planning demands of the coming years make this task more compelling than ever.

To position *Science & Engineering Indicators* for the 21st century, the Board committed to conducting a comprehensive review of *Science & Engineering Indicators*, including the utility, timeliness, and accessibility of the data for users; and reviewing the effectiveness of the report as a basis for decision making on major policy issues related to science and engineering.

Each of the chapters of *Science & Engineering Indicators – 2000* received extensive external technical peer review. The Board believes that this process has greatly improved the report, and wishes to thank those reviewers who contributed their time and efforts. Their names are listed in "Contributors and Reviewers."

To make the data and analyses more accessible, the report is available in hardcopy, on CD-ROM, and on the World Wide Web (http://www.nsf.gov/sbe/srs/stats.htm). This website also contains new data on the reported indicators, as they become available.

An innovation with this edition is dividing the report into two volumes. Volume 1 contains the text and the index, and Volume 2 contains the appendix tables. This year's edition takes advantage of widespread access to computer CD-ROM readers by including Volumes 1 and 2 in PDF format and the

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[5] National Science Board, *National Science Board Strategic Plan*, November 19, 1998, NSB 98-215, 18-19.

appendix tables in Volume 2 also in Excel format on the CD attached to the back cover of Volume 1. For readers who might prefer to access the appendix tables in printed form, Volume 2 is available on request from NSF (see the back inside cover for ordering information).

Other innovations in the form, content, and accessibility of *Science and Engineering Indicators* will be examined in the coming decade. The Board welcomes the opportunity and challenge to develop new and refined indicators that capture and document changes in the national and global science and engineering enterprise.

In the last *Science and Engineering Indicators* report of the century, the Board would like to recognize the partnership it has had not only with the Executive Branch but also with the Congress. The science and technology policy to be forged in the next millennium will be better informed by data. The National Science Board hopes that members of the Congress will find *Science & Engineering Indicators – 2000* of assistance as they grapple with the many issues related to science, technology, and the knowledge-based economies of the 21st Century.

Chapter 1
Science and Technology in Times of Transition: the 1940s and 1990s

Contents

Introduction

Chapter Background

The National Science Board's (NSB) *Science and Engineering Indicators – 1998* report contained several cross-cutting themes; namely,

- increasing globalization of science, technology, and the economy;
- greater emphasis on science and engineering education and training;
- structural and priority changes in the science and engineering enterprise; and
- increasing impacts of science and technology on our daily lives.

Many of the trends discussed in detail in the remaining chapters of *Science and Engineering Indicators – 2000* suggest the persistence of these themes, supporting the Board's conclusion about their importance in characterizing the policy context of the U.S. science and engineering enterprise in this time of transition to the 21st century.

Publication of *Science and Engineering Indicators – 2000* coincides with the 50th anniversary of the creation of the National Science Foundation (NSF) in 1950. As the NSB and NSF prepare to make a transition into their second half-century, the Board believes it would be useful to reflect on the conditions that characterized U.S. science and engineering 50 years ago. NSF was created near the end of another significant time of transition from a period in which the country's science and engineering resources were mobilized for World War II to a period in which a system designed to facilitate partnerships in support of a broader set of national objectives had been put in place. Although the specific issues and concerns evident in documents from the late 1940s differ from those that are familiar today, several current science policy themes have antecedents dating from the period. A better understanding of the origins of these enduring themes can help in planning for the future.

Each of the remaining chapters of *Science and Engineering Indicators – 2000* touches upon notable themes and issues from the 1940s that are germane to the specific topics it considers. However, their emphasis is on the current situation, as has been the case for all earlier editions in the *Science and Engineering Indicators* series. The purpose of this chapter is to set the stage for the brief historical notes presented in these chapters by comparing and contrasting the resources available within the U.S. science and engineering enterprise, its organization, and significant science policy issues in the 1940s and in the 1990s. In effect, it presents two "snapshots," taken 50 years apart, and in that respect differs from the later chapters in this report, as well as chapters that have appeared in earlier reports in this series.

Chapter Organization

The next section of this chapter, "Highlights of the First Time of Transition: 1945–51," provides an overview of some of the principal congressional and administration decisions and actions that shaped U.S. science policy between the end of World War II and the establishment of the first Presidential Science Advisory Committee (PSAC) in April 1951.

"Early Visions/Key Policy Documents" considers the contexts of, and the visions contained in, two key policy documents from that first time of transition: *Science—The Endless Frontier* (Bush 1945a), delivered to President Harry S Truman in July 1945, and *Science and Public Policy* (Steelman 1947), delivered to Truman in August 1947.

Almost from the outset, the Board and Foundation have assigned a high priority to gathering and disseminating quantitative and qualitative information relevant to science policy. "Monitoring the Condition of the Science and Engineering Enterprise" discusses the expansion of activities in this area, culminating with the Board's decision to issue its first *Science Indicators report* in 1973 (NSB 1973).

All recent U.S. presidents, beginning with Franklin D. Roosevelt, have recognized the importance of science and engineering to the Nation. President Truman was the first to do so in a public address that he gave in September 1948 at the 100th anniversary meeting of the American Association for the Advancement of Science (AAAS) (Truman 1948). A section entitled "Presidential Statements" compares and contrasts the themes in that speech with those in the address of President William J. Clinton at the 150th anniversary meeting of the AAAS in February 1998 as a means of examining continuities and changes in U.S. science policy during the past half-century (Clinton 1998).

"Current Visions/Key Policy Documents" offers a snapshot of the current period of transition by highlighting two key policy documents from the 1990s: *Science in the National Interest* (Clinton and Gore 1994) and *Unlocking Our Future* (U.S. House of Representatives Science Committee 1998). A section entitled "Advances in Science and Engineering" follows, with illustrative examples of advances that have occurred in large measure from the policies set in place in the 1940s and maintained in broad outline during the ensuing half-century.

Similarities and distinctions between the earlier time of transition and the current situation are examined in more detail in "Enduring Themes: Continuity and Change," where the emphases associated with significant themes identified by the key documents from the 1940s are compared and contrasted with those in the key documents of the 1990s. Specific trends and issues are highlighted in the succeeding chapters of *Science and Engineering Indicators – 2000.*

"Current Emerging Themes," the final section of the chapter, identifies themes that the Board believes will be important in the first decade of the new century, several of which it intends to address in detail in a series of forthcoming occasional papers.

Highlights of the First Time of Transition: 1945–51

The National Science Foundation Act of 1950,[1] which President Truman signed into law on May 10 of that year, gave NSF the mandate "to promote the progress of science; to advance the national health, prosperity, and welfare; and for other purposes." The breadth of this mandate indicates that a bipartisan majority existed in Congress about the significance of science and engineering in addressing matters of national importance. NSF's creation occurred near the end of the time of transition in which the basis of U.S. science policy was established and many of the principal issues and concerns comprised by that policy were articulated. But the concept of a National Science Foundation had emerged several years earlier. (See text table 1-1.)

Emergence of a Concept

More than a year before World War II ended on September 2, 1945, a few members of Congress and a handful of officials in the Roosevelt Administration had foreseen the essential roles that science and engineering would play during peacetime. Early in 1944, Senator Harley M. Kilgore (D-WV), a member of a Select Committee chaired by Senator Harry S Truman (D-MO) investigating the war production effort, introduced a bill to create a National Science Foundation (Kevles 1977). While Kilgore's National Science Foundation would have given priority to Federal Government laboratories in the disposition of funds, it would also have been authorized to award research contracts and scholarships to colleges and universities. Kilgore's colleagues in the Senate convinced him that hearings on his proposed bill should be postponed until after the end of the war.

In November 1944, President Franklin D. Roosevelt addressed a letter to Vannevar Bush, his *de facto* science advisor, asking for his advice on how the lessons learned from the World War II organization of science and engineering could be applied in peacetime. Bush's response came seven months later in July 1945, when he delivered the requested report, *Science—The Endless Frontier,* to President Truman (Bush 1945a). By the end of that month, Senator Warren Magnuson (D-WA) had introduced legislation to implement the centerpiece recommendation of what is commonly referred to as the Bush report: namely, to establish a National Research Foundation to provide Federal funds for research to nonprofit institutions outside of the Federal Government (including

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[1] National Science Foundation Act of 1950, Public Law 81-507 (Stat. 149).

Text table 1-1.
Highlights of the first transition

Year	Month	Science policy events	Other events
1944	February	Kilgore legislation introduced in Senate	
	November	Roosevelt's letter to Bush	Roosevelt reelected
1945	April		Death of Roosevelt
	May		End of World War II in Europe
	July	*Science—The Endless Frontier*	
	September		End of World War II in the Pacific
	October	Senate hearings on NSF began	
1946	August	AEC and ONR created	
	October	Steelman board established	
1947	June		Marshall Plan announced
	August	*Science and Public Policy*	
1948	February		First electronic computer
	September	Truman speech at AAAS meeting	
	November		Truman reelected
1950	May	NSF created	
	June		Korean War began
	December	Truman addressed first NSB meeting	United Nations forces abandon Pyongyang and Seoul
1951	April	First NSF director sworn in; SAC/ODM established	Gen. MacArthur relieved of command of United Nations troops in Korea
	July	NSF Annual Report, with R&D expenditure data included	

Science & Engineering Indicators – 2000

civilian defense research and medical research) and to award scholarships and fellowships to aspiring scientists and engineers. Within a few days, Senator Kilgore reintroduced a revised version of his earlier bill.

The Kilgore and Magnuson bills differed both in the types of institution given priority for research support and in their proposed administrative structure. Deep-seated disagreements on the latter issue persisted and delayed the creation of NSF for almost five years. Between 1945 and 1950, a vigorous public debate took place on the institutional framework for science. That debate, which included the nature of a National Science Foundation, took five years to resolve; during this period, both the Office of Naval Research (ONR) and the National Institutes of Health (NIH) were created, reducing the scope of the proposed foundation.[2]

Congressional Initiatives

Joint hearings on the Magnuson and Kilgore bills, which began in October 1945, were among the first in a series of congressional debates and administration actions whose outcomes determined the character of Federal Government support for, and involvement with, science and technology that has largely persisted for the past half-century. Congress, for the first time, began to deal with significant science- and technology-related issues on a more or less continual basis. Its extensive, open-to-the-public committee hearings called heavily on members of the public and the scientific community as it sought to forge new policies and create a new organizational framework for Federal Government science.

The most controversial issue addressed by Congress during the immediate postwar years had to do with whether the control of nuclear energy should remain with the military or be consigned to civilian hands (Smith 1965). On August 1, 1946, following extensive and frequently impassioned hearings that involved many of the younger scientists who had been engaged in the ultra-secret World War II work to produce nuclear weapons, Congress established the Atomic Energy Commission (AEC), to be governed by a five-member commission of presidentially appointed civilians.[3]

On August 1, 1946, Congress also created the ONR.[4] Both AEC and ONR soon began to support university research in fields broadly related to their respective missions. Two years later, NIH within the Public Health Service began to follow suit by supporting research through contracts to the Nation's medical schools. Prior to that time, the agency's research program had focused on specific health-related problems and was carried out largely intramurally. Thus by the time NSF was created in May 1950, several Federal mission agencies had already gained considerable experience in funding university research.

Administration Actions

On October 17, 1946, in response to the rapid expansion in the Federal Government's organization for science, President Truman established the President's Scientific Research Board (PSRB) chaired by John R. Steelman, who became The Assistant to the President on January 1, 1947. The first of five volumes of PSRB's report, entitled *Science and Public Policy* and commonly referred to as the Steelman report (Steelman 1947), was released on August 27, 1947. This report analyzed, and made recommendations about, the entire Federal science and technology system; the relations between research in the Federal Government, industrial, and academic sectors; and the condition of science teaching at all levels, from the primary grades through graduate school. It based its analysis of the state of the Nation's science and technology enterprise on extensive sets of data and several specially commissioned studies.

The President drew on the Steelman report to propose a national science policy in his September 1948 address to AAAS (Truman 1948). One element of his proposed policy—to create a National Science Foundation—was fulfilled when Congress passed the National Science Foundation Act of 1950.[5]

The Act that Truman signed into law in May 1950 defined NSF as "an independent agency . . . [to] consist of a National Science Board and a Director."[6] Accordingly, the Foundation was officially activated when the Board convened for the first time on December 12, 1950, in the White House (England 1983, 123). President Truman joined the first NSB meeting and addressed the Board. Thereafter, the chairman reported to the President on actions taken by the Board during the morning session. Those actions consisted of the election of the chairman (James B. Conant) and vice chairman (Edwin B. Fred), establishment of a committee to recommend to the President names of people who might be appointed to the position of director of NSF, and establishment of an executive committee.

Impacts of the Korean War

President Truman had a great deal on his mind at the time he addressed the NSB's first meeting. A month earlier, the People's Republic of China had intervened in the Korean War.[7]

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[2] See England (1983, 25–110).

[3] An Act for the Development and Control of Atomic Energy, Public Law 585, 79th Congress, 2nd Session.

[4] An Act to Establish an Office of Naval Research in the Department of the Navy, Public Law 588, 79th Congress, 2nd Session. The Secretary of the Navy had used his emergency authority to create ONR on a temporary, interim basis in May 1945.

[5] Several long-forgotten controversies delayed the Congress's passage of this Act, perhaps because the value of basic research was not sufficiently understood a half-century ago. These controversies were resolved through the patient work of several key individuals. William D. Carey in the Bureau of the Budget (BoB) continued to insist to his colleagues that the creation of a National Science Foundation was critical to the long-term interests of the Nation. Elmer Staats, his direct supervisor, and Willis Shapley, his BoB colleague, aided him in his crusade.

No doubt the single individual, in addition to Carey, who deserves credit for negotiating the compromise between the scientific community and the Truman Administration and Congress for the creation of a National Science Foundation was Dael Wolfle, at that time executive secretary of the American Psychological Association and also secretary of the AAAS-based Intersociety Committee for a National Science Foundation.

[6] Public Law 81-507, Section 2.

[7] The Korean War began on June 25, 1950 (six weeks after NSF was created), when North Korean troops crossed the 38th parallel into South Korea and within two days captured Seoul.

On the day Truman met with the Board, United Nations' forces abandoned the North Korean capital of Pyongyang, which they had captured in September 1950, and within a few days abandoned Seoul, the South Korean capital, as well. There was justifiable concern that it might not be possible to confine the worsening military situation to Korea. By that time, the White House had already commissioned William T. Golden, a New York investment banker, to prepare a report on how the Nation's scientific resources might be mobilized to address any wider military emergency (Blanpied 1995, xiv–xliv). Whether or not such a wider emergency would occur, it was abundantly clear that both the Congress and the Administration would thenceforth accord a high priority to defense-related research and development (R&D).

Despite the Korean emergency, the NSB adopted a long-term view as it proceeded to work out the policy implications of NSF's charter and develop plans to implement its programmatic mission. At the conclusion of its third meeting on February 13–14, 1951, the Board issued a public statement that disavowed any direct NSF involvement with defense-related research, while reemphasizing that "the fundamental objective of the National Science Foundation is the promotion of basic research and education in the sciences throughout the country."[8]

On December 18, 1950, less than a week after the first meeting of the NSB, Golden addressed a memorandum to the President recommending that he appoint a full-time science advisor to assist in mobilizing science for defense purposes and, additionally, provide high-level oversight of the entire Federal science organization. President Truman accepted the essence of this recommendation when, on April 19, 1951, he established the Scientific Advisory Committee to the White House Office of Defense Mobilization (SAC/ODM), a body that was destined to evolve into a full-scale presidential scientific advisory system.[9]

With the creation of SAC/ODM, all principal elements of the U.S. Government's science structure were in place, including a protopresidential advisory and coordination system[10] and the six agencies—or their predecessors—that have long accounted for more than 90 percent of Federal R&D expenditures.[11] Most changes made in that structure during the next 50 years were designed to adapt it to the evolving political, economic, and social environment in which the U.S. science and technology enterprise functions and to the spectacular growth of the enterprise itself.

One important refinement in the Federal Government's organization for science and technology was the creation of the Defense Science Board (DSB), which was chartered to "canvass periodically the needs and opportunities presented by new scientific knowledge for radically new weapons systems." Initially, DSB, which met for the first time on September 20, 1956, was an advisory body to the Assistant Secretary of Defense (Research and Development). During the next few years, as the Defense Department was reorganized to reflect the increasing importance of science and technology to its mission, the status of DSB was elevated to that of an advisory body to the Secretary of Defense. DSB currently consists of 32 members who are appointed for terms ranging from one to four years and selected on the basis of their preeminence in the fields of science and technology and their applications to military operations, research, engineering, manufacturing, and acquisition processes. It also includes the chairs of seven advisory bodies to other Defense Department organizations as *ex officio* members.

Investments

From the outset, the NSB assumed responsibility to gather, analyze, and disseminate quantitative information on the condition of the U.S. science and engineering enterprise. The first *National Science Foundation Annual Report*, covering fiscal year (FY) 1951 (July 1, 1950, to June 30, 1951) and issued under the guidance of the Board, included data estimates from the Department of Defense Research and Development Board on R&D expenditures by the Federal Government and "other" sources, from 1940 through 1952, in addition to data on R&D performance by the industrial, Federal Government, and academic sectors over the same period. It also reproduced more detailed data from the Bureau of the Budget (BoB) on R&D expenditures by the principal Federal agencies from 1940 to 1950.[12] NSF was not represented in the latter tabulation, since it had been created only during the final months of FY 1950, with a budget of $225,000 to defray administrative startup costs during its first year.

The Foundation's second annual report, covering the period from July 1, 1951, to June 30, 1952, extended the data on Federal R&D expenditures through FY 1952. (See text table 1-2.) NSF was included for the first time, Congress having appropriated an estimated $1.1 million for R&D expenditures from a total FY 1952 appropriation for NSF of $3.5 million.[13] NSF's

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[8] References to National Science Board actions during its first meetings are taken from the unpublished minutes of those meetings.

[9] From a letter written by Harry S Truman, dated April 19, 1951, to Oliver E. Buckley; see Blanpied (1995, 72–4).

[10] On November 7, 1957, a month after the Soviet Union launched Sputnik I, President Dwight D. Eisenhower created a full-scale Presidential Advisory System when he elevated SAC/ODM into the President's Science Advisory Committee and named James R. Killian, Jr., president of the Massachusetts Institute of Technology, as his full-time science advisor; see "The Precarious Life of Science in the White House," by David Z. Beckler (Holton and Blanpied 1976, 118).

[11] Four of these agencies still exist in their 1951 form: the Department of Defense, NIH (now within the Department of Health and Human Services), NSF, and the U.S. Department of Agriculture. In 1958, as one response to the launching of Sputnik I by the Soviet Union in October 1957, the scope of the National Advisory Committee for Aeronautics, created in 1915, was expanded and the agency renamed the National Aeronautics and Space Administration. AEC was subsumed into the Energy Research and Development Agency in 1975, which in turn was absorbed into the Department of Energy when the latter department was created in 1977.

[12] Prior to 1976, the U.S. Government fiscal year began on July 1 of the succeeding calendar year, rather than on October 1 as it does at present.

[13] In 1945, *Science—The Endless Frontier* (Bush 1945a, 40) had recommended a budget of $33.5 million for the Foundation's first year, which would have been approximately $47.1 million in 1951 constant dollars. However, the National Science Foundation Act of 1950 included an amendment limiting the agency's appropriation to $15 million per year, or approximately $95 million in constant 1999 dollars. NSB had requested $13.5 million for NSF for FY 1952; Congress reduced it to $3.5 million ($20 million in 1999 constant dollars) on the grounds that the imperatives of the Korean War precluded anything more. The $15 million limitation was removed in 1953.

Text table 1-2.
Federal R&D appropriations for Fiscal Year 1952

	Amount of U.S. dollars (in millions)		Percent	
Agency	1952 current	1998 constant	Total	Non-DOD
Department of Defense (DOD)	890.0	5,071.6	70.6	
Non-DOD	370.2	2,109.5	29.4	100.0
Atomic Energy Commission	162.9	928.3	12.9	44.0
Public Health Administration[a]	38.5	219.4	3.1	10.4
National Advisory Committee for Aeronautics	49.4	281.5	3.9	13.3
National Science Foundation	1.1	6.3	0.1	0.3
Agriculture Department	51.7	294.6	4.1	14.0
Commerce Department	15.4	87.8	1.2	4.2
Interior Department	31.9	181.8	2.5	8.6
Other	19.3	110.0	1.5	5.2
Total	1,260.2	7,181.1	100.0	

NOTE: Details may not sum to totals because of rounding.

[a]Includes National Institutes of Health.

SOURCE: National Science Foundation, *Second Annual Report* (Washington, DC: U.S. Government Printing Office, 1952).

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total budget for that year also included $1.53 million for graduate and post-doctoral fellowships. The remaining funds were allocated for administration, and for miscellaneous activities, including scientific translations.

Despite the fact that its R&D appropriation for FY 1952 was $1.1 million, compared with the total Federal R&D budget of more than $1.2 billion, NSF already occupied a unique position in the Federal system. It was—and remains—the sole agency chartered to support research and education across all fields of science and engineering. In addition, Congress expected NSB, its policymaking body, to deal with issues transcending the Foundation's programmatic mission. Among other things, NSF (by law the National Science Board and Director) was "authorized and directed" to develop and encourage the pursuit of a national policy for the promotion of basic research and education in the sciences; .to foster the interchange of scientific information among scientists in the United States and foreign countries; and .to correlate the Foundation's scientific research programs with those undertaken by individuals and by public and private research groups."[14]

The evolution of the Board's involvement in monitoring the state of science and engineering, culminating with the transmission of the first *Indicators* report (NSB 1973) to President Richard M. Nixon in 1973, is discussed in "Monitoring the Condition of the Science and Engineering Enterprise."

Early Visions/Key Policy Documents

Both the size and complexity of the U.S. science and engineering enterprise have grown substantially since the creation of NSF. Despite this, a striking continuity with the present is discernible in the visions of science–government relations that emerged in the immediate aftermath of World War II. These early visions were encapsulated in two key policy documents: *Science—The Endless Frontier* (July 1945) and *Science and Public Policy* (August 1947). Although differing in many respects, both reports emphasized the need for a strong commitment to genuine partnerships and linkages among the industrial, academic, and Federal Government research sectors, a commitment that is among the unique strengths of the U.S. system.

Science—The Endless Frontier (1944–45)

The impetus for *Science—The Endless Frontier,* as already noted, was a letter addressed to Vannevar Bush by President Franklin D. Roosevelt on November 17, 1944, 10 days after President Roosevelt's reelection to an unprecedented fourth term. The President's letter asked for advice on how lessons learned from the mobilization of science and engineering during World War II might be used in peacetime "for the improvement of the national health, the creation of new enterprises bringing new jobs, and the betterment of the national standard of living" (Bush 1945a, 3).

Creation of the Office of Scientific Research and Development

That the President would seek guidance on these matters from Vannevar Bush, who was director of the wartime Office of Scientific Research and Development (OSRD) was natural enough, since Bush had been serving as his *de facto* science advisor for more than a year before the United States entered World War II in December 1941. On June 12, 1940, seven days after the German army invaded France, Bush, president of the Carnegie Institution of Washington and a former Dean of Engineering at the Massachusetts Institute of Technology (MIT), met with the President to propose that he should

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[14] Public Law 81-507, Section 3(a).

create a National Defense Research Council (NDRC). NDRC's charge would be to explore, in detail, the problem of organizing the Nation's scientific resources in preparation for what both men were certain would be the inevitable entry of the United States into what was still primarily a European conflict. Roosevelt accepted this proposal, naming Bush chairman of NDRC.[15]

A year later, Roosevelt decided that the rapidly escalating military crisis abroad required the creation of an agency with broader authority than NDRC. Accordingly, in June 28, 1941, he issued an executive order creating OSRD within the Executive Office of the President, stating that OSRD was to:

> .serve as a center for mobilization of the scientific personnel and resources of the Nation in order to assure maximum utilization of such personnel and resources in developing and applying the results of scientific research to defense purposes .[and] to coordinate, aid, where desirable, supplement the experimental and other scientific and medical research activities relating to national defense carried on by the Departments of War and Navy and other departments and agencies of the Federal Government.[16]

NDRC, chaired by James B. Conant, was retained as one of two components of OSRD; a Medical Research Committee was created as its other component.[17]

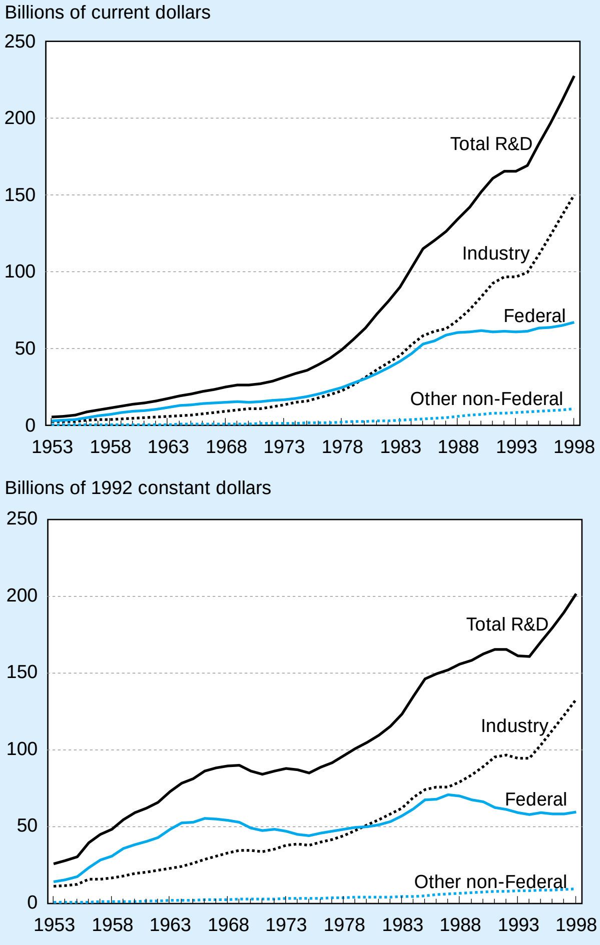
OSRD was authorized to mobilize the Nation's science and engineering resources for the impending entry of the United States into World War II. To do so, Bush and his senior colleagues faced the formidable tasks of working with appropriate staff in the Departments of War and Navy to identify and establish priorities for defense-related research projects; identifying and assembling the scientists and engineers capable of dealing with those projects; providing them with the resources they required; and finally ensuring that their results moved expeditiously into wartime production.

The Prewar U.S. R&D Enterprise

While the science and engineering resources available to OSRD were reasonable, they were also scattered. By 1940, the three sectors that still account for most of the Nation's research performance—industrial, government, and academic—were already well established. However, their relative importance and the relationships between them differed from what they are today. Then as now, industry was the principal supporter and performer of R&D. A total of $345 million was estimated to have been expended for R&D in the United States in 1940, with industry investing $234 million, or almost 68 percent of this amount.[18] Although industrial investments were roughly the same proportion of total national expenditures as at present, from 1951 (the first full year of the Korean War) until 1980, industry's share of total national R&D expenditures was less than that of the Federal Government. (See figure 1-1 and text table 1-3.)

In 1940, the Federal Government ranked a distant second, expending an estimated $67 million for R&D, or less than 20 percent of total national R&D expenditures, during that same year. In fact, Federal R&D expenditures in 1940 were only slightly more than twice the $31 million expended by universities and colleges. The remaining $13 million was accounted for by state governments, private foundations and research institutes, and nonprofit industrial research institutes. No reliable prewar data are available on R&D performance expenditures. However, it is reasonable to assume that the bulk of the industrial and Federal Government expenditures went to

Figure 1-1.
National R&D funding, by source: 1953–98



See appendix tables 2-5 and 2-6.

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[15] Other NRDC members included James B. Conant, president of Harvard University (and later the first chairman of NSB); Karl T. Compton, president of MIT; and Frank B. Jewett, president of the National Academy of Sciences and chairman of the board of the Bell Telephone Laboratories.

[16] Executive Order 8807, "Establishing the Office of Scientific Research and Development in the Executive Office of the President and Defining Its Functions and Duties."

[17] When OSRD was abolished at the end of 1947, the contracts that its Medical Research Committee still retained with several of the Nation's medical schools were turned over to NIH. These transfers initiated the transition of NIH from an agency that had previously supported research primarily in its own laboratories, to one of the world's foremost supporters of biomedically related research, as well as the Federal agency with the largest basic research budget.

[18] R&D expenditure estimates are given by Bush (1945a, app. 3, 86) and Steelman (1947, vol. I, 10).

Text table 1-3.
Estimated R&D expenditures, by source for selected years

Expenditures (in millions)	Total	Industry	Federal	Universities and colleges	Other[a]
1940 current dollars	345	234	67	31	13
1998 constant dollars	3,617	2,453	702	325	136
Percent of total	100	67.8	19.4	9.0	3.8
1947 current dollars	1,160	450	625	45	40
1998 constant dollars	7,645	2,966	4,119	297	264
Percent of total	100	38.8	53.9	3.9	3.4
1957 current dollars	9,908	3,470	6,233	51	155
1998 constant dollars	50,345	17,629	31,669	259	788
Percent of total	100	35.0	62.9	0.5	1.6
1967 current dollars	23,346	8,146	14,563	200	439
1998 constant dollars	99,326	34,655	61,957	849	1,866
Percent of total	100	34.9	62.4	0.9	1.9
1977 current dollars	43,456	19,645	22,155	569	1,089
1998 constant dollars	103,258	46,678	52,642	1,351	2,586
Percent of total	100	45.2	51.0	1.3	2.5
1987 current dollars	126,255	62,683	58,548	2,262	2,762
1998 constant dollars	171,309	85,052	79,441	3,069	3,747
Percent of total	100	49.6	46.4	1.8	2.2
1998 current dollars	227,173	149,653	66,930	4,979	5,611
Percent of total	100	65.9	29.5	2.2	2.5

NOTE: Details may not sum to totals because of rounding.

[a] Includes state governments and nonprofit institutions.

SOURCES: For 1940, Vannevar Bush, Science—*The Endless Frontier: A Report to the President on a Program for Postwar Scientific Research* (1945a). Reprinted by NSF (Washington, DC: 1990). For 1947, John R. Steelman, *Science and Public Policy* (Washington, DC: U.S. Government Printing Office, 1947). Reprinted by Arno Press (New York: 1980). For 1957–98, National Science Foundation, *National Patterns of R&D Resources*. (Arlington, VA: biennial series).

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support R&D in their own respective facilities, whereas all academic expenditures for this purpose supported academic research.

Despite the absence of reliable data, it is widely acknowledged that a good deal of academic research prior to World War II qualified as applied research according to current definitions. Additionally, academic research, whether basic or applied, was concentrated in a relatively small number of institutions. According to *Science—The Endless Frontier,* during the 1939/40 academic year, 10 of the estimated 150 research universities in the United States performed $9.3 million or 35 percent of the total $26.2 million in research performed in the natural sciences and engineering by the academic sector, while 35 of these 150 universities performed $16.6 million or 63 percent of the academic total (Bush 1945a, 122).

Prior to World War II, institutional partnerships among the Nation's three research sectors were the exception rather than the rule. Department of Agriculture programs that had supported research in the Nation's land grant colleges since the late 19th century constituted one prominent set of exceptions. Precedents set by the National Advisory Committee on Aeronautics (NACA), the predecessor of the National Aeronautics and Space Administration (NASA), were more pertinent to the OSRD system. NACA, which was created in 1915 and consisted of representatives from both the Federal Government[19] and industry, operated facilities that conducted R&D related to problems of civil and military aviation. The bulk of NACA's research was conducted in these in-house facilities, which were taken over by NASA when the latter agency was created in 1958. However, during the 1920s, NACA also began to award occasional contracts to university engineering schools. In 1939, it had 12 contracts with 10 universities (Dupree 1957, 366).

With these exceptions, the Federal Government provided no support for university research prior to 1941. Faculty in university science and engineering departments occasionally worked in their private capacities as consultants to Federal research bureaus. But any suggestion that the Federal Government should initiate an openly available program to fund university research on no grounds other than its intrinsic merit would have been considered an unwarranted intrusion into the affairs of those institutions. Rather, research in the academic sector was supported by income on endowment (in the case of private universities); by state funds (in the case of public universities); by grants from private, nonprofit foundations such as the Carnegie Corporation, the Rockefeller

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[19] One of the original Federal Government members of NACA was Franklin D. Roosevelt, then serving as Assistant Secretary of the Navy in the Wilson Administration.

Foundation, and the Commonwealth Fund; and on occasion by private industry.

The OSRD System

The OSRD system was collegial and decentralized. Rather than electing to become a scientific "czar" who would centralize and control all aspects of the wartime research effort, Bush assumed the roles of buffer and arbitrator between the scientists and engineers engaged in wartime research and the Federal Government's technical bureaus, particularly those in the Departments of War and Navy. During World War I, many of the scientists and engineers who had engaged in defense research were given temporary military commissions, then sent to work at existing defense laboratories (Dupree 1957, 302–25). In contrast, the OSRD system was based on the novel assumption that, except in very special cases, research could best serve wartime needs if scientists and engineers continued in their civilian status and worked in settings where research was carried out in peacetime—be they academic or industrial. That is, industrial and academic organizations worked in partnership with the Federal Government rather than under its direct control. Because Bush enjoyed direct access to President Roosevelt, he was able to convince him (although not all the old line Federal scientific bureaus) that this decentralized system would be more effective in achieving the desired result of adapting U.S. scientific resources rapidly for national defense purposes than a system based on the World War I model.

In fact, the system was superbly effective. Radar was developed and refined at the Radiation Laboratory at MIT by scientists and engineers brought there from several institutions. The Oak Ridge, Tennessee, facility, where the rare, fissionable isotope of uranium ($^{235}U_{92}$) was separated, was managed by the General Electric Company. Even the ultra-secret Los Alamos, New Mexico, laboratory, where the R&D leading to the first nuclear bombs was performed, was managed by the University of California under a contract with the Army rather than directly by the Federal Government.

Following its creation in 1946, AEC took over from the Army its management contracts with the General Electric Company, the University of California, and several other organizations that had managed these World War II facilities, and the facilities themselves came to be known as Federally funded research and development centers (FFRDCs). Many are still managed by the same academic or industrial organization that managed them during World War II through contracts with the Department of Energy. Additional FFRDCs have been created since World War II, some of which, such as the Fermi National Accelerator Laboratory in Batavia, Illinois, and the Stanford Linear Accelerator Center (SLAC), house large-scale facilities where basic research is conducted by university-based user groups.[20]

Wartime experiences had demonstrated the potential for productive partnerships among the Nation's principal research sectors. They also demonstrated the importance of university scientists (and thus, by implication, the academic sector) in conceptualizing and demonstrating the feasibility of novel, often risky research ideas—such as many of the concepts underlying radar and nuclear weapons. Additionally, they suggested that, even in wartime, the effective conduct of research required that science be insulated, as much as possible, from conventional political processes. These experiences conditioned the vision articulated by *Science—The Endless Frontier.*

Responding to Roosevelt

President Roosevelt's November 1944 letter to Bush on the peacetime implications of lessons learned from the World War II mobilization of science and engineering requested responses to four questions. These questions dealt with (1) the expeditious declassification of secret wartime research results, (2) the need to develop a program to support health-related research, (3) conditions through which the government could provide aid to research activities in public and private organizations, and (4) the feasibility of creating a program for discovering and developing scientific talent. To address the President's request, Bush convened four committees consisting primarily of distinguished nongovernment scientists and engineers, charging each committee to prepare a report, with recommendations, on one of President Roosevelt's four questions.[21] Bush's own 40-page synthesis of the resulting committee reports constituted the body of *Science—The Endless Frontier* (Bush 1945a); the four committee reports, each consisting of an in-depth response to one of the President's questions, appeared as appendices.

Bush and his committees carried out their assigned tasks during months of mounting exuberance. By the time *Science—The Endless Frontier* was submitted to President Truman in July 1945, World War II was drawing rapidly to a close. Germany had surrendered on May 8, the first nuclear weapon was due to be tested on July 16, and the defeat of Japan was all but assured—even though informed military opinion estimated that another year and as many as 1 million American casualties would be required. The United States and its allies had achieved military supremacy, and science and engineering had made indispensable contributions to that outcome.

Bush and his colleagues welcomed the opportunity to take the lead in planning for the future and, in particular, to capitalize on the recognition that the importance of academic research had received in the OSRD system. However, they insisted that any government program to organize science for peacetime purposes had to be consistent with the traditional norm of scientific autonomy that, to a remarkable extent, had

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[20] Other agencies, including the Department of Defense and NASA, also support FFRDCs through contracts with nongovernment organizations; cf. NSB (1996a, 4-26–4-29).

[21] These were the Medical Advisory Committee, chaired by W.W. Palmer, Bard Professor of Medicine, Columbia University; the Committee on Science and the Public Welfare, chaired by Isaiah Bowman, president of The Johns Hopkins University; the Committee on Discovery and Development of Scientific Talent, chaired by Henry Allen Moe, secretary-general of the Guggenheim Foundation; and the Committee on Publication of Scientific Information, chaired by Irvin Stewart, executive assistant to the director of OSRD and later president of the University of West Virginia.

remained largely intact during the wartime years (Reingold 1987; Blanpied 1998).

A National Research Foundation

Bush and his four committees seized the opportunity provided by President Roosevelt's November 1944 letter to advance what could only be regarded at that time as a bold and innovative proposition. Simply stated, *Science—The Endless Frontier* argued that the Federal Government had not only the authority, but also the *responsibility,* to ensure a continued supply of research results by (1) supporting research in nonprofit institutions—primarily, although not exclusively, basic research in universities—and (2) offering scholarships and fellowships to aspiring scientists and engineers.[22] An essential element of the report's proposition that the Federal Government should support research in nonprofit organizations was its insistence that the support should be provided solely on the basis of scientific merit, as judged by those with the necessary professional experience and background to make that determination. "It is my judgment," Bush wrote, "that the national interest in scientific research and scientific education can best be promoted by the creation of a National Research Foundation" (Bush 1945a, 34).[23] The new responsibilities envisioned for the Federal Government were too novel and too important to be entrusted to any existing agency. The final paragraph of *Science—The Endless Frontier* stressed that early action by Congress to create the National Research Foundation was "imperative" (Bush 1945a, 40).

In keeping with his wartime experiences, Bush recommended that the new agency should be isolated as much as possible from conventional political processes. Its board of directors (or what *Science—The Endless Frontier* referred to as its "members") would be appointed by the President and would consist of "citizens selected only on the basis of their interest in and capacity to promote the work of the agency. They should be persons of broad interest in and understanding of the peculiarities of scientific research and education" (Bush 1945a, 33). The National Science Foundation Act of 1950 adhered to this dictum by legally defining NSF as a Director and a National Science Board to consist of 24 members "eminent in the fields of basic sciences, medical science, engineering, agriculture, education, and public affairs."[24]

Promotion of Research in Industry

The line of reasoning that *Science—The Endless Frontier* presented in arriving at its centerpiece recommendation is worth reviewing, since it was to become a major foundation of U.S. science policy for many years. In keeping their own *laissez-faire,* free-market philosophy, Bush and his colleagues were adamantly opposed to any Federal Government interference with the prerogatives of private industry, except in the area of national defense. Industry alone, they argued, was equipped to determine which basic research results in the public domain were worth exploiting for possible commercial purposes and how they should be exploited. This position was summarized in a familiar passage from *Science—The Endless Frontier,* namely, that "The most important ways in which the Government can promote industrial research are to increase the flow of new scientific knowledge through support of basic research, and to aid in the development of scientific talent" (Bush 1945a, 7).

Prior to World War II, the large majority of the basic research results that industry required were foreign imports, primarily from Europe. But European research capabilities had been devastated by World War II. Therefore, the Bush report argued, the United States would henceforth have to assume primary responsibility for obtaining its own basic research results.

Centrality of Universities

Science—The Endless Frontier's central proposition that Federal science policy should focus on the support of research in nonprofit institutions (mainly colleges and universities) strongly if implicitly suggested that universities, which prior to World War II were on the periphery of the U.S. research system, should be thenceforth regarded as occupying its vital center. This line of argument was persuasive; much of the most innovative wartime research had been carried out in university or quasi-university settings by university scientists and engineers. With the partial exception of the United Kingdom, no other country had had a similar experience. As one result, the postwar emergence of universities as the primary performers of basic research has been virtually unique to the United States.

Other Issues

Science—The Endless Frontier was never intended to be a complete blueprint for U.S. science policy. In fact, much of its enduring impact is explained by the fact that it focused on a few key ideas and advanced them persuasively. The most enduring of those ideas are in the category that would later be referred to as "policy-for-science": that is, issues having to do with funding levels, sources, incentives, and priorities for research, and the development and utilization of human resources for science and engineering, for example.

In contrast, considerably less attention was paid to issues in the "science-for-policy" category—those concerned with the uses of scientific knowledge and capabilities for governance or, more broadly, in the service of the larger society. *Science—The Endless Frontier* did recognize the vital importance of science to society; its opening paragraphs state emphatically that "without scientific progress no amount of achievement in other directions can insure our health, prosperity, and security as a nation in the modern world" (Bush 1945a, 5). Additionally, adequate responses to President Roosevelt's queries, such as declassification of wartime re-

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[22] Bush was familiar with the legislation to create a National Science Foundation that had been introduced by Senator Kilgore in 1944, which was a revised version of an earlier 1943 bill. In fact, Kilgore had sought Bush's advice on certain aspects of its revision (Kevles 1977).

[23] Soon after the start of congressional hearings in October 1945, the name National Science Foundation rather than National Research Foundation was adopted for the proposed agency. See England (1983).

[24] Public Law 81-507, Section 4(a).

search results, required specific science-for-policy recommendations. Finally, the report stressed the desirability to "coordinate where possible research programs of utmost importance to the national welfare" (Bush 1945a, 31), but offered few hints on how that might be accomplished other than through a nongovernmental oversight and advisory committee.

Several of these themes and issues considered by *Science—The Endless Frontier,* such as those that addressed the President's first question on the declassification of wartime research results, are now of little interest save to students of the postwar period. Others retain their currency, even though their context has changed considerably. These include the following:

- integration of defense research into the overall national system,
- human resources for science and engineering,
- research in Federal mission agencies,
- tax and patent policies, and
- international exchange of scientific information.

These and other issues were also treated, often at greater length, in *Science and Public Policy*—which was intended to be both a policy-for-science and science-for-policy document—when it was prepared beginning in late 1946. They are thus identifiable as among the principal science policy themes during the first time of transition, as discussed below.

Use of Data

Although Bush included an occasional quantitative reference in the body of *Science—The Endless Frontier,* he relied almost entirely on his wide experience and his persuasive rhetoric, rather than on data-based analysis, to press his case for a National Research Foundation. The four appended committee reports relied more heavily on data. They included, for example, tables listing national research expenditures from 1920 to 1944 and details of research expenditures in selected university departments and companies (Bush 1945a, 123, 127–9). Human resources data included numbers of Ph.D.s awarded by the scientific field from 1935 (Bush 1945a, 177–9). Several related tables, referred to, collectively, as the education pyramid, provided data on enrollments in educational institutions from primary grades through college and graduate school for all students, but with no breakdown for enrollments in science (Bush 1945a, 166–76). These data provided a basis for arguing that too many otherwise able students were being lost to higher education because of their inability to pay the required costs so that the provision of Federal Government-supported scholarships and fellowships, based on academic promise, would be in the national interest.

That the bulk of the data contained in the committee reports predated 1941 provides a clue to why *Science—The Endless Frontier* contained relatively little quantitative information: namely, the wartime conditions prevailing in 1944–45 precluded the provision of the resources that would have been necessary to conduct the studies that would have been needed to obtain a more detailed, quantitative picture of the U.S. science and engineering enterprise. Additionally, financial and human resources data considered critical to national mobilization would almost certainly have been classified. After the war ended, it was possible once again to collect and/or declassify data on various aspects of U.S. society, including those related to science and engineering. Many of these categories of data were compiled and analyzed in the August 1947 report of the President's Scientific Review Board entitled *Science and Public Policy* (Steelman 1947).

Science and Public Policy (1946–47)

Context

In November 1944 when President Roosevelt addressed his four questions to Vannevar Bush, only he and a handful of OSRD colleagues, a few members of Congress and their key staff, along with several officials in BoB, had given much serious thought to issues of science and government in the postwar era (Kevles 1977). Within the next two years, the rapidly increasing significance of the Federal Government's role in science and engineering had become obvious, as had the impact of Federal policies and actions on the industrial and academic research sectors.

Given the pervasive character of the Federal role, the BoB had become convinced by the end of 1945 that it required an institutionalized source of expert advice to assist it in its task of formulating and implementing science- and technology-related policies and programs. It believed that what by then was being referred to as a National Science Foundation, particularly what a pending congressional bill proposed as its governing board of eminent nongovernment presidential appointees, could provide the advice it required.

However, although the general idea of an agency to support research in nonprofit organizations, provide scholarships and fellowships, and serve as a source of policy advice attracted bipartisan congressional support, there were serious differences within the Congress and between the Congress and the Truman Administration on specific details, including the scope and administrative structure of the proposed agency. When, in June 1946, the 79th Congress adjourned before the House of Representatives had considered a Senate bill to create a National Science Foundation,[25] several BoB staff members, including Elmer Staats, William Carey, Willis Shapley, and Charles Kidd, began to explore other options to carry out the functions they had hoped a National Science Foundation and its Board would fulfill. Accordingly, they persuaded President Truman to issue an Executive Order on October 17, 1946, to create a President's Scientific Research Board charged "to review current and proposed research and development (R&D) activities both within and outside of the Federal Government."

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[25] The failure of the 1946 legislation was the first of several failed attempts to reconcile conflicting views on the organization of the proposed agency that were to delay enactment of enabling legislation until May 1950 (England 1983, Blanpied 1998).

PSRB was chaired by John R. Steelman, director of the Office of War Mobilization and Reconversion within the Executive Office of the President, who on January 1, 1947, was appointed *the* Assistant to the President. Steelman, an economist who had helped settle two potentially crippling labor disputes early in 1946, enjoyed the confidence of, and ready access to, President Truman. Among his other duties, he oversaw and coordinated the work of the White House staff so that he became, in effect, the first White House Chief of Staff.[26]

Scope and Content

The President's Executive Order had charged Steelman, as PSRB chairman, to submit a report:

> .setting forth (1) his findings with respect to the Federal research programs and his recommendations for providing coordination and improved efficiency therein; and (2) his findings with respect to non-Federal research and development activities and training facilities .to insure that the scientific personnel, training, and research facilities of the Nation are used most effectively in the national interest.[27]

The first volume of the PSRB's report, entitled *Science and Public Policy* and commonly referred to as the Steelman report, was published on August 27, 1947. Consistent with the President's charge, the report balanced considerations of policy-for-science and science-for-policy. The analysis, conclusions, and recommendations contained in the first 68-page summary volume, aptly entitled "A Program for the Nation," spanned the entire range of Federal and non-Federal science and technology activities, including the international dimensions of U.S. science policy. Much of the text was supplemented with imaginative graphics, which were used to support its arguments, conclusions, and recommendations. These were based on detailed, extensive data and analysis contained in the report's four succeeding volumes, all of which were released by the end of October 1947.[28]

Taken together, the Steelman report's five volumes compose what was by far the most complete and detailed description of the U.S. science and technology system (particularly its Federal component) that had been produced up to that time. The four background volumes of *Science and Public Policy,* in their extensive use of data and survey results (a good deal gathered specifically for the report), their analyses, and their use of charts, can be regarded as a precursor for what was to become, beginning in 1972, NSB's biennial series of *Science and Engineering Indicators* reports.

Themes and Issues

Research Expenditures

A unique feature of "A Program for the Nation," the first summary volume of *Science and Public Policy,* was its use of 10-year projections, or scenarios, to support its recommendations regarding the resources required by the U.S. science and engineering enterprise to provide it an adequate basis to assist in addressing national objectives. Perhaps its most significant projection was in the form of a recommendation to double national R&D expenditures during the succeeding 10 years, that is, by 1957 (Steelman 1947, vol. I, 13, 26). In 1947, total U.S. R&D expenditures were estimated to be slightly more than $1 billion. (See text table 1-4.) According to this scenario, national R&D expenditures should reach an annual level of $2 billion—or 1 percent of national income (that is, Gross Domestic Product, GDP)—by 1957, requiring greater increases in public than in private spending.

The report went on to recommend explicit functional targets for Federal R&D expenditures to be achieved by 1957: 20 percent for basic research, 14 percent for research in health and medicine, 44 percent for nonmilitary development, and 22 percent for military development (Steelman 1947, 28).

Basic Research Support

Basic research was singled out as the principal arena for concerted Federal action by both *Science—The Endless Frontier* and *Science and Public Policy.* Both reports urged Con-

Text table 1-4.
Estimated 1947 U.S. R&D expenditure, by source and character of work

Source	Total	Basic research	Applied R&D
1947 current dollars (in millions)			
Federal Government			
War and Navy departments ..	500	35	465
Other departments	125	20	105
Federal total	625	55	570
Industry	450	10	440
University	45	35	10
Other	40	10	30
U.S. total	1,160	110	1,050
1998 constant dollars (in millions)			
Federal Government			
War and Navy departments ..	3,295	231	3,065
Other departments	824	132	692
Federal total	4,119	362	3,757
Industry	2,966	66	2,900
University	297	231	66
Other	264	66	198
U.S. total	7,645	725	6,920

NOTE: Details may not sum to totals because of rounding.

Applied R&D = Applied Research and Development

SOURCE: John R. Steelman, *Science and Public Policy* (Washington, DC: U.S. Government Printing Office, 1947). Reprinted by Arno Press (New York: 1980). *Science & Engineering Indicators – 2000*

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[26] Members of PSRB included the secretaries of all cabinet departments with significant science and technology programs, including War, Navy, Agriculture, Commerce, and Interior, as well as the heads of several noncabinet agencies, including NACA (the precursor of NASA), AEC, the Tennessee Valley Authority, the Veterans Administration, and importantly, Vannevar Bush as director of OSRD.

[27] Executive Order 9791, "Providing for a Study of Scientific Research and Development Activities and Establishing the President's Scientific Research Board" (Steelman 1947, vol. I, 70–1).

[28] The titles of the five volumes of *Science and Public Policy* (the Steelman report) were vol. I, "A Program for the Nation"; vol. II, "Science in the Federal Government"; vol. III, "Administration of Research"; vol. IV, "Manpower for Research"; and vol. V, "The Nation's Medical Research."

gress to enact legislation to create a National Science Foundation; the latter recommended that the proposed agency should be authorized “to spend $50 million in support of basic research its first year …rising to an annual rate of $250 million by 1957” (Steelman 1947, 31–2).

Defense Research

OSRD’s wartime achievements were based in large measure on the active participation of nongovernment civilian scientists and engineers in all aspects of military R&D, from planning through implementation. Vannevar Bush was determined to maintain civilian involvement, and in some cases even civilian control, over the most critical defense-related research projects in the postwar era. “Military preparedness,” as *Science—The Endless Frontier* argued, “requires a permanent, independent, civilian-controlled organization, having close liaison with the Army and Navy, but with funds direct from Congress and the clear power to initiate military research which will supplement and strengthen that carried on directly under the control of the Army and Navy” (Bush 1945a, 33). That is, Bush took the position that defense research policy should be an integral component of overall Federal research policy.

By August 1947, a special task force of the Defense Research Board (which Bush chaired) in the newly created Department of Defense was preparing its own report and recommendations so that the Steelman Board excluded itself from any detailed examination of defense research, other than to recommend that more weight should be given to nondefense research than was the case in 1947.[29]

Human Resources for Science and Engineering

The development of scientific talent was of particular concern in the late 1940s. World War II had demonstrated that the availability of adequate numbers of well-trained scientists and engineers, rather than a lack of financial resources, was the limiting factor in undertaking or completing essential research projects. The war itself had led to what both reports referred to as a severe “deficit” in trained scientists and engineers resulting from the fact that young people who would have obtained degrees in science and engineering had been prevented from doing so as a result of their service in the Armed Forces. Many trained scientists and engineers had also been among the casualties of the war. *Science and Public Policy* emphasized that, unless and until these deficits were corrected, the U.S. research enterprise could not use significant additional funding to maximum advantage.

In 1947, there were an estimated 137,000 scientists, engineers, and technicians engaged in R&D and/or teaching. Among these, 25,000 had Ph.D.s in the physical and biological sciences (Steelman 1947, vol. I, 15–8). During 1941, the number of Ph.D.s awarded in the physical and biological sciences had reached a peak level of 1,900. By comparison, fewer than 800 Ph.D.s were awarded in these fields during 1945. Although the number of Ph.D.s awarded had risen to approximately 1,600 by 1947, *Science and Public Policy* estimated that the rate of Ph.D. conferrals in science would have to increase to 3,800 per year by 1957 to provide adequate human resources for the Nation.

Both *Science—The Endless Frontier* and *Science and Public Policy* recommended that the Federal Government should support a substantial program of scholarships at the undergraduate level and fellowships at the graduate level to alleviate these human resource deficits. *Science and Public Policy* argued that Federal aid should not be limited to students in science and engineering. Rather, it should be part of a more extensive Federal Government program designed, in part, to relieve wartime deficits in other areas as well.

Science and Public Policy emphasized that the condition of science education at the primary and secondary levels was an essential determinant of the health of the U.S. science and engineering enterprise. Volume IV, devoted entirely to human resources issues, included an analysis of the results of an extensive survey, entitled “The Present Effectiveness of Our Schools in the Training of Scientists,” commissioned from AAAS (Steelman 1947, 47–162). The AAAS report dealt with the entire mathematics, science, and engineering education system from the primary grades through graduate school.

Science and Public Policy also recognized that the working conditions of scientists and engineers could have a decided impact on their productivity and, therefore, on the condition of the U.S. research enterprise. Accordingly, it commissioned a detailed survey on attitudes of government, industry, and academic scientists toward their work from the National Opinion Research Center at the University of Denver (Steelman 1947, vol. III, 205–52).

Role of the Federal Government

World War II having ended, it was generally agreed that the bulk of the Nation’s R&D performance would once again—indeed should once again—take place outside of the government. On the other hand, it was increasingly clear that the Federal Government’s role in the national R&D enterprise had become indispensable. There was a broad consensus that its direct role should include support for research in its own laboratories, provision of funds for basic research in universities and for university facilities, and a scholarship and fellowship program for promising young scientists and engineers. Additionally, the Federal Government should monitor the condition of science and technology in the country and seek means to encourage partnerships among the industrial, academic, and Federal Government research sectors to meet essential national goals. There was much less unanimity on the extent to which the Federal Government should be involved

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[29] The task force, chaired by Irvin Stewart, formerly executive assistant to the director of OSRD and at that time president of the University of West Virginia, issued its report, entitled *Plans for Mobilizing Science*, in 1948. Because of objections by high level Pentagon officials, it did not reach President Truman’s desk until shortly before the start of the Korean War. One of the charges to William T. Golden as special consultant to the White House was to determine the applicability of the Stewart report in the environment of the Korean War.

in the support of nondefense applied research or civilian development.

Internal Government Coordination

Consistent with President Truman's charge in establishing PSRB, *Science and Public Policy* documented in detail the Federal Government's rapidly expanding science and technology programs, noting that they were dispersed across many agencies with little or no coordination among them, except by means of the annual budget process managed by BoB. As one means to improve this situation, it recommended that an interagency committee should be established "to secure maximum interchange of information with respect to the content of research and development programs" and that the Federal Government's role with respect to the national science and technology enterprise should be monitored continually to obtain "an over-all picture of the allocations of research and development functions among the Federal agencies" (Steelman 1947, vol. I, 61).

The report went on to emphasize that science policy issues might often require attention at the highest levels of government. Accordingly, it asserted that "There must be a single point close to the President at which the most significant problems created in the research and development program of the Nation as a whole can be brought into top policy discussions" (Steelman 1947, vol. I, 61).

International Dimensions

The U.S. scientific community was eager to reestablish international communication and information exchange that had been disrupted by World War II. Types of Federal assistance suggested by *Science—The Endless Frontier* and *Science and Public Policy* included funding travel to international scientific meetings, encouraging visits to the United States by outstanding foreign scientists, supporting translations of foreign journals, and awarding international fellowships. *Science and Public Policy* predicted that "the future is certain to confront us with competition from other national economies of a sort we have not hitherto had to meet" (Steelman 1947, vol. I, 4). Despite this, it went on to argue that it was in the national interest to lend "every possible aid to the re-establishment of productive conditions of scientific research and development in all those countries [of Europe and Asia] willing to enter whole-heartedly into cooperation with us" (Steelman 1947, vol. I, 5). The report suggested that such aid might include assistance in the reconstruction of research facilities in Europe as a component of the Marshall Plan, which had been proposed two months before its release.[30] It also suggested several more modest measures, including international fellowships for U.S. science and engineering students and more experienced investigators to work abroad, and a program for shorter term visits by senior U.S. researchers to allow them to reestablish international connections interrupted by World War II. Reciprocally, it recommended that U.S. universities should be encouraged to admit qualified foreign science and engineering students, particularly into their graduate programs (Steelman 1947, vol. I, 38–40).

Looking into the future and beyond the principal prewar scientific powers, the Steelman report noted that:

> Currently great progress is being made in India in the construction of new scientific research laboratories and in the training of hundreds of first-rate research workers.[31] In the same way Chinese scientific development may be expected to go forward rapidly, and great progress is being made in our neighbor American Republics (Steelman 1947, vol. I, 41).

In short, *Science and Public Policy* took the view that U.S. science policy should be based on a long-term view, particularly with regard to its international dimensions, and that what it tacitly assumed would be short-term problems in other countries should not be allowed to obscure the rising importance of science on a global level.

Monitoring the Condition of the Science and Engineering Enterprise

"A Program for the National Science Foundation"

Science—The Endless Frontier and *Science and Public Policy* had both envisioned a science policy implemented in a genuine peacetime context, albeit with due regard for national security needs. As it happened, the final elements of the U.S. Government's science and technology organization were put in place during the early stages of the Cold War. NSF was created barely six weeks before the start of the Korean War on June 25, 1950, and the first protopresidential Science Advisory Committee, established on April 19, 1951, was created as a response to the Korean crisis on the recommendation of William T. Golden.

As background for the report on science and national security that the White House commissioned in September 1950, Golden interviewed a wide range of scientists, military experts, and politicians, including Bush, Steelman, and three prominent scientists whom President Truman had nominated as members of the first NSB on November 2, 1950: Detlev W. Bronk, a biologist who was president of The Johns Hopkins University and of the National Academy of Sciences (NAS); James B. Conant, a chemist and president of Harvard University; and Lee A. DuBridge, a physicist and president of the California Institute of Technology.

While the main purpose of Golden's interviews was to determine whether in view of the Korean crisis an organization similar to OSRD should be created, he frequently inquired as well about the role that the newly created NSF should play among other agencies of the Federal Government. Golden summarized his conclusions in a February 13, 1951, memo-

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[30] Secretary of State George C. Marshall announced the intention of the United States to provide funds for the reconstruction of Europe's infrastructure in an address at the Harvard University commencement on June 7, 1947.

[31] The first volume of the Steelman report was released less than two weeks after India achieved its independence from Great Britain on August 15, 1947.

randum entitled “Program for the National Science Foundation” (Blanpied 1995, 67–72).

Near the beginning of his memorandum, Golden noted that, as a result of the Korean emergency, “Federal funds for research and development of all kinds within the Department of Defense alone, which originally approximated $500 million for FY 1950, are expected to be in the neighborhood of $1,250,000,000 for FY 1952.”

It would be tempting, he conceded, for the newly created NSF (which, at the time Golden wrote his memorandum still did not have a director[32]) to attempt to capitalize on this situation. However, he went on, “it may be worth repeating that in accordance with the spirit of the Act [of May 10, 1950] the National Science Foundation should confine its activities to furthering basic scientific studies and that it should not dilute its effectiveness by supporting studies of directly military or other applied character. To do so would seriously impair the long-term mission of the National Science Foundation without materially contributing to the war effort.”

Consistent with this long-term view and the high probability that NSF’s financial resources would very likely be constrained at least as long as the Korean emergency continued, Golden suggested that a high priority should be assigned to human resources development in the form of a fellowship program. “In view of the disruption of the educational process inherent in the mobilization effort it would be unwise not to undertake some such fellowship program in order to insure the continuing production of scientific leaders over the longer term .The cost of such a fellowship program is very small in relation to its potential value and to the total cost of Government’s scientific research program.”

More broadly, and with the long-term mission of NSF still in view, Golden recommended that steps should be taken to assess the status of the Nation’s science and technology system as a first step in determining the agency’s future directions. In essence, he suggested that the Foundation, under the guidance of the Board, should prepare to engage in serious priority-setting based on sound data. To this end, Golden recommended that “the Foundation, promptly after the appointment of a Director, might proceed to the following principal undertakings”:

1. Prepare a comprehensive review detailing the significant areas of basic science which are now being studied within the United States, showing these separately for research supported by universities, by industry and by the Government. To the extent practicable the pattern should also indicate work in process in friendly foreign countries.

2. Prepare a comparable survey detailing the existing support of graduate and undergraduate education in the sciences by the many public and private agencies so engaged.

3. Study the scientific manpower resources of the United States: a) as specifically called for in the Act, by taking over, completing, and keeping current the detailed National Scientific Register[33]; and b) by preparing quantitative analytical studies of available and prospective scientific and technical manpower.

4. Review basic research activities of other Government agencies and in cooperation with them develop proposals for transferring appropriate portions of these programs to the National Science Foundation. In this connection, and to provide background for its work, the Board might wish to invite other Government agencies engaged in or supporting basic research activities to make descriptive presentations of their programs to the Board.

Golden concluded his February 13 memorandum by observing that “preparations of studies of the aforementioned character are primarily tasks for the staff under the Director but the members of the 24-man Board .are particularly well qualified to plan and determine their undertakings and to give guidance to the staff in the areas of their specialties.”

The director of BoB transmitted Golden’s memorandum to James B. Conant, chairman of the NSB, on February 15, 1951. The minutes of the Board’s fourth meeting, held on March 8–9, 1951, stated that Golden’s memorandum had been received, but that no specific action was taken on it. This is not surprising, since the Board had to deal with a particularly full agenda for that meeting. Its principal business was to finalize and approve the Foundation’s budget request to Congress for FY 1952. Also, on the first day of the meeting, the Board was informed of President Truman’s intention to nominate Alan T. Waterman, chief scientist at ONR, as the NSF’s first director (England 1983, 126–7). The nominee joined the Board on the second day of its meeting. The Senate consented to Waterman’s nomination later that month, and on April 6, 1951, he was sworn in as NSF director by Supreme Court Associate Justice William O. Douglas.

Congressional and Presidential Directives

Despite the fact that the NSB took no direct action on Golden’s memorandum at its March 8–9, 1951, meeting, his suggestion that the policy-for-science of the U.S. Government and the programs of NSF should be based on sound quantitative information was widely shared. In addition to reproducing BoB data on R&D expenditures by Federal agency in its FY 1951 Annual Report, the agency began to publish its *Federal Funds for Research and Development* series during that same fiscal year. Data in the first editions in this series were limited to Federal funds for R&D in nonprofit institutions. However, the coverage expanded to include Federal R&D support in all categories of performer and was also reported by character of work, by field of science, and by agency.

Congress was particularly concerned about the adequacy of human resources for science and technology. The National

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[32] President Truman announced his intention to nominate Alan T. Waterman as NSF’s first director on March 8, 1951.

[33] The National Scientific Register was established in the Office of Education within the Federal Security Agency in June 1950 following a determination by the National Security Resources Board that a registry of available scientific personnel would be vital to national security. It was transferred to NSF on January 1, 1953.

Science Foundation Act of 1950 explicitly directed the agency "to maintain a register of scientific and technical personnel and in other ways provide a central clearinghouse for information covering all scientific and technical personnel in the United States, including its Territories and possessions."[34]

To carry out this mandate, NSF assumed responsibility for the National Scientific Register from the U.S. Office of Education on January 1, 1953,[35] expanding its coverage significantly in partnership with several science and engineering societies. NSF's third annual report, covering the period from July 1, 1952, to June 30, 1953, included the first survey results on human resources for science and engineering carried out in response to this congressional directive. The agency also issued brief, periodic bulletins with human resources data in specific fields of science and of application.

Evidently the quality and utility of these early quantitative studies were quickly recognized, since an Executive Order issued by President Eisenhower on March 4, 1954, required, among other matters, that:

> The Foundation shall continue to make comprehensive studies and recommendations regarding the Nation's scientific research effort and its resources for scientific activities, including facilities and scientific personnel, and its foreseeable scientific needs, with particular attention to the extent of the Federal Government's activities and the resulting effects upon trained scientific personnel. In making such studies, the Foundation shall make full use of existing sources of information and research facilities within the Federal Government.[36]

One reason why President Eisenhower may have singled out NSF as the most appropriate agency to conduct such studies was the unique partnership among the industrial, academic, and Federal Government sectors reflected in the congressionally mandated composition of the NSB, "so selected as to provide representation of the views of scientific leaders in all areas of the Nation."[37] Congress also recognized the Board's ability to speak with authority on matters pertaining to the vitality of the U.S. science and engineering enterprise. In 1968, the House Committee on Science and Technology, chaired by Emilio Q. Daddario (D-CT), held a series of oversight hearings resulting in the first major set of amendments to the National Science Foundation Act of 1950. Among other things, these amendments provided for a presidentially appointed deputy director, authorized NSF to support applied research, and explicitly authorized support for research in the social sciences. The Daddario amendments also required that:

> The [National Science] Board shall render an annual report to the President, for submission on or before the 31st day of January of each year to the Congress, on the status and health of science and its various disciplines. Such report shall include an assessment of such matters as national scientific resources and trained manpower, progress in selected areas of basic scientific research, and an indication of those aspects of such progress which might be applied to the needs of American society. The report may include such recommendations as the Board may deem timely and appropriate.[38]

Finally, Congress officially concurred with, and made more explicit, the Executive Order issued by President Eisenhower in 1954 by authorizing and directing NSF:

> (6) to provide a central clearinghouse for the collection, interpretation, and analysis of data on scientific and engineering resources and to provide a source of information for policy formulation by other agencies of the Federal Government.
>
> (7) to initiate and maintain a program for the determination of the total amount of money for scientific and engineering research, including money allocated for the construction of the facilities wherein such research is conducted, received by each educational institution and appropriate nonprofit organization in the United States, by grant, contract, or other arrangement from agencies of the Federal Government, and to report annually thereon to the President and the Congress.[39]

Science Indicators – 1972, et seq.

Roger W. Heyns, a psychologist who served as a member of the NSB from 1967 to 1976 and who became president of the American Council on Education in 1972, suggested that, for its mandated 1973 annual submission to the President and Congress, the Board might consider preparing a report analogous to periodic reports that assessed various economic and social trends in terms of quantitative data series known as social indicators. Preparation of such a report could draw on the proven capabilities of NSF staff in gathering and analyzing quantitative data on U.S.—and international—science and engineering enterprise. The NSB accepted Heyns' suggestion, naming its fifth report to Congress, *Science Indicators – 1972* (NSB 1973). The positive reception accorded to this first *Indicators* volume encouraged the Board to continue to issue these reports on a biennial basis.[40]

In May 19, 1976, testimony before the House of Representatives' Subcommittee on Domestic and International Scientific Planning, Heyns highlighted some of the main purposes and functions of the *Indicators* reports:

- to detect and monitor significant developments and trends in the scientific enterprise, including international comparisons;

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[34] Public Law 81-507, Section 3(a).

[35] See footnote 33.

[36] Executive Order 10521, "Concerning Government Scientific Research," Section 2. Reissued and amended on March 13, 1959.

[37] Public Law 81-507, Section 4(a).

[38] National Science Foundation–Function–Administration, Public Law 90-407, enacted July 18, 1968.

[39] Public Law 90-407, Section 3(a)(6) and (7).

[40] According to H. Guyford Stever, who was NSF director from 1972 to 1976, one of the first significant policy impacts of *Science Indicators – 1976* occurred as a result of a meeting that he and representatives of NSB had with then-Vice President Gerald R. Ford in the spring of 1974. Vice President Ford was particularly interested in the charts showing that other countries were increasing their R&D/GDP investments whereas the comparable ratio for the United States was decreasing. Soon after becoming President in August 1974, Ford set about increasing Federal R&D investments.

- to evaluate their implications for the present and future health of science;
- to provide continuing and comprehensive appraisal of U.S. science;
- to establish a new mechanism for guiding the Nation's science policy;
- to encourage quantification of the common dimensions of science policy, leading to improvements in research and development policysetting within Federal agencies and other organizations; and
- to stimulate social scientists' interest in the methodology of science indicators as well as their interest in this important area of public policy (NSB 1993b, xi).

Heyns clearly regarded the periodic preparation of the *Indicators* reports in terms of partnerships involving producers, users, and science policy scholars. The Board has called on all these groups over the years as it seeks to expand and refine these reports in order to reflect both the principal issues enduring in and changing science policy and the best scholarly thinking on quantification of these issues.[41]

In 1982, Congress officially recognized the unique significance of the *Indicators* reports by requiring that, instead of more broadly defined annual reports on the status and health of science required by the 1968 amendment to the National Science Foundation Act, "The Board shall render to the President, for submission to the Congress no later than January 15 of each even numbered year, a report on indicators of the state of science and engineering in the United States." [42]

This same legislation also encouraged submission of other reports on important science- and engineering-related issues, stating that "The Board shall render to the President for submission to the Congress reports on specific, individual policy matters related to science and engineering and education in science and engineering, as the Board, the President or the Congress determines the need for such reports."

Beginning with the 1987 edition, and consistent both with this legislation and the changing character of the U.S. research enterprise, the titles of these mandated biennial reports became *Science and Engineering Indicators*.

Presidential Statements

U.S. presidents from Franklin D. Roosevelt through William J. Clinton have demonstrated their recognition of the importance of science and engineering in a number of ways: through, for example, annual budget submissions to Congress, organizational initiatives designed to improve the effectiveness of the Federal Government's research and policy-making systems, and programmatic initiatives using science and engineering to advance critical items on their broad policy agenda. (See sidebar, "Major Presidential Science Policy Initiatives.") However, few presidents have given public addresses focused primarily on their science policies. The first notable exception was a speech delivered by President Truman in September 1948 during the first time of transition. Almost exactly 50 years later, in February 1998 during the current time of transition, President Clinton also delivered a public science policy address.[43] A comparison between these two speeches indicates both the endurance of several key science policy themes over the past half-century and the significant changes in emphasis that have occurred during that time.

Harry S Truman, 1948

President Truman delivered his address at the opening session of the Centennial Meeting of AAAS in Washington, D.C. (Truman 1948). A report of his speech was featured the next day on a front-page article in *The New York Times*. Truman used the occasion to propose a national science policy whose five principal elements were drawn directly from the report Steelman published a year earlier.

First, the President called for a doubling of total national R&D expenditures over the next 10 years so that, by 1958, those expenditures would exceed $2 billion and would be equal to 1 percent of GDP, or what he referred to as national income. The occasion of President Truman's AAAS address marked the first instance in which a leading political figure proposed that U.S. national R&D investments should be gauged in terms of GDP. As it happened, by 1958, national R&D investments had far exceeded the challenge that President Truman had laid down 10 years earlier. According to official estimates, in 1948, national R&D expenditures were slightly less than 0.5 percent of GDP; by 1958, that ratio was estimated to have been 2.36 percent. Changes in the Department of Defense's accounting system during the 1948–58 period make it difficult to compare R&D expenditures over that period.[44] But it is reasonable to assume that the R&D/GDP ratio, calculated according to the prevailing accounting practices of 1948, would have been closer to 2 than to 1 percent by 1958.

When President Truman spoke to AAAS, however, he could not have foreseen two of the principal reasons for the spectacular increases in national R&D expenditures that were to occur during the next decade: first, a rapid growth in defense R&D following the invasion of South Korea in June 1950; second, substantial increases for basic research and space-related R&D following the launching of Sputnik I by the Soviet Union in

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[41] Papers presented at a symposium organized to critique the first, 1972 report were published in Elkana et al. (1978).

[42] Congressional Reports Act, Public Law 97-375, Section 214, enacted December 21, 1982.

[43] President Dwight D. Eisenhower announced the appointment of a full-time science advisor in a national radio address on November 7, 1957. President John F. Kennedy made a major science policy address at the Centennial celebration of NAS on October 23, 1963 (NAS 1963). President James E. Carter spoke at NAS on April 23, 1979, on the occasion of its annual meeting (*Weekly Compilation of Presidential Documents* 1979).

[44] Beginning in FY 1953, the Department of Defense began to include salaries and related expenses of personnel engaged in R&D in its estimates of R&D expenditures, resulting in an increase of approximately $1 billion in its estimated R&D expenditures between FY 1952 and FY 1953 (NSF 1968, 221, note c).

Major Presidential Science Policy Initiatives

♦ **Franklin D. Roosevelt (1933–45)** requested the first comprehensive survey and analysis of Federal science and technology resources and programs, entitled Research—A National Resource (1938). In 1941, he created the Office of Scientific Research and Development to mobilize the Nation's science and engineering resources for World War II, and in November 1944 asked for recommendations on how the lessons learned in mobilizing science for war could serve the Nation in peacetime.

♦ **Harry S Truman (1945–53)** worked with Congress to shape legislation creating three major agencies: the Atomic Energy Commission (1946), the Office of Naval Research (1946), and the National Science Foundation (1950). Truman also established the Science Advisory Committee to the White House Office of Defense Mobilization, the first presidential advisory system.

♦ **Dwight D. Eisenhower (1953–61)** established the President's Science Advisory Committee and appointed a full-time science advisor (1957). He oversaw the launching of the first U.S. satellites and proposed legislation to create the National Aeronautics and Space Administration (July 29, 1958). Eisenhower also worked with Congress to craft legislation—The National Defense Education Act (September 2, 1958)—which significantly increased U.S. Government support for science and engineering education at all levels.

♦ **John F. Kennedy (1961–63)** set the goal of sending a man to the moon by the end of the decade. He established the Office of Science and Technology within the Executive Office of the President in June 1962. He also proposed and oversaw implementation of a presidential-level bilateral science and technology agreement with Japan, the first such bilateral agreement entered into by the United States. Kennedy delivered a major science policy address at the National Academy of Sciences on October 23, 1963, as part of its 100th anniversary celebration.

♦ **Lyndon B. Johnson (1963–69)** emphasized science in service to society by making use of social science data as the basis for his War on Poverty and other components of his Great Society program. In inaugurating Medicare in June 1966, he noted that, as President, he had an obligation to show an interest in how the results of biomedical research are applied. Johnson also maintained U.S. leadership in space.

♦ **Richard M. Nixon (1969–74)** presided over the creation of high-level bodies charged with providing advice on science- and technology-related issues, including the Council on Environmental Quality within the Executive Office of the President (March 1970), the National Advisory Committee on Oceans and Atmosphere (August 1971), and the White House Energy Policy Office (June 1973). His War on Cancer initiative led to considerable increases in Federal funding for biomedical research. Nixon also realized a goal of a predecessor when Neil Armstrong walked on the moon in July 1969.

♦ **Gerald R. Ford (1974–77)** agreed with Congress that the presidential advisory system, abolished in 1973, should be reestablished, leading to a May 1976 Act creating the Office of Science and Technology Policy. His annual budget requests included increases in Federal expenditures for nondefense R&D, which had been declining in constant dollar terms since 1968.

♦ **James E. Carter (1977–81)** initiated Federal research programs aimed at developing renewable energy sources, including solar energy and fusion, and established programs to assist industry to demonstrate the feasibility of extracting oil from coal and oil shale. He signed the first bilateral science and technology agreement with the People's Republic of China in 1979.

♦ **Ronald W. Reagan (1981–89)** substantially increased defense R&D expenditures, particularly for his Strategic Defense Initiative, commonly called "Star Wars." He established modest programs within the National Bureau of Standards (now the National Institute for Standards and Technology) to provide research support to industry. Reagan also negotiated a significant expansion in the U.S.–Japan bilateral science and technology agreement, which included Japanese support for U.S. researchers to work in Japan.

♦ **George W. Bush (1989–93)** oversaw the development of the Federal Government's first technology policy, which was intended to augment and extend the established bipartisan consensus on science policy. He increased the size and scope of the National Institute for Standards and Technology's industrial research support programs. With Bush's encouragement, D. Allan Bromley, The Assistant for Science and Technology, emphasized strengthened international scientific interactions, initiating a biannual series of off-the-record meetings with his G-7 counterparts (known as the Carnegie Group meetings) and taking the lead in establishing the Megascience Forum within the Organisation for Economic Co-operation and Development.

♦ **William J. Clinton (1993–2001)** established links between science and technology policy and economic policy with his 1993 policy statement entitled Technology: The Engine of Economic Growth (Clinton and Gore 1993) and reaffirmed his commitment to university research and to science and mathematics education by endorsing them in Science in the National Interest (Clinton and Gore 1994). Clinton has been a strong advocate of improvements in science education and has expanded Federal support for information technologies substantially through long-term, coordinated interagency initiatives.

October 1957. Federal expenditures increased from $625 million in 1948 to $6.8 billion in 1958 ($5.4 billion in 1948 constant dollars). But Federal expenditures alone did not account for all the increase that occurred during the decade after President Truman's speech. During that same decade, industrial R&D investments rose from an estimated $450 million to approximately $3.7 billion in 1958, almost $3.0 billion in 1948 constant dollars (NSF 1998, 82–93, table B-6).

The *second* element of President Truman's proposed science policy was to place greater emphasis on basic research and medical research. Today, there exists a strong bipartisan consensus that both categories of research need to be adequately supported, even though they are rarely linked as explicitly as in President Truman's AAAS address.

The *third* element of President Truman's proposed science policy—that a National Science Foundation should be established—was, of course, accomplished 21 months later when, on May 10, 1950, he signed the National Science Foundation Act of 1950 into law.

The *fourth* element—that more aid should be granted to universities, for both student scholarships and research facilities—indicated recognition by the administration of the importance of universities to the national research enterprise. Concerns about the World War II human resources deficit discussed in both *Science—The Endless Frontier* and *Science and Public Policy* no doubt underlay President Truman's call for more scholarships. Today, concerns about human resources for science and engineering focus on the composition and distribution of highly trained personnel across disciplines and sectors, while the need to provide adequate facilities for university research remains a perenial issue.

As the *fifth* and final element of his proposed science policy, President Truman stressed the need for better coordination of the work of the Federal research agencies, reflecting the desire of BoB for assistance in maintaining better oversight of the burgeoning Federal R&D enterprise. That concern began to be addressed in April 1951 when President Truman established the SAC/ODM, a body that enjoyed some access to the President and that, in November 1957, was elevated into the PSAC by President Eisenhower.

Having enumerated these elements of his proposed science policy, the President devoted the remainder of his speech to some of the major national needs that U.S. science was being called upon to address, as well as the support that science required in order to address those needs. In 1948, Cold War tensions were rapidly escalating. Not surprisingly, then, the President focused sharply on the obligations of U.S. science to continue to support national security objectives. Significantly, he singled out what he called "pure—or fundamental—research" as an area of the highest importance to the country's long-term national defense requirements.

The President suggested that the Federal Government had two obligations in connection with the U.S. research system: first, to see that the system received adequate funds and facilities; second, to ensure that scientists were provided with working environments where research progress was possible. Regarding the second of these obligations, he stressed that, "pure research is arduous, demanding, and difficult. It requires intense concentration, possible only when all the faculties of the scientist are brought to bear on a problem, with no disturbances or distractions." He went on to urge that, to the greatest extent possible, the pursuit of research should be insulated from day-to-day political concerns.

Near the conclusion of his address, President Truman spoke about the need for greater public awareness of the importance of research to the Nation:

> The knowledge that we have now is but a fraction of the knowledge we must get, whether for peaceful use or for national defense. We must depend on intensive research to acquire the further knowledge we need .These are truths that every scientist knows. They are truths that the American people need to understand (Truman 1948, 14).

New knowledge requirements, he emphasized, must encompass all disciplines:

> The physical sciences offer us tangible goods; the biological sciences, tangible cures. The social sciences offer us better ways of organizing our lives. I have high hopes, as our knowledge in these fields increases, that the social sciences will enable us to escape from those habits and thoughts which have resulted in so much strife and tragedy (Truman 1948, 15).

"Now and in the years ahead," he concluded, "we need, more than anything else does, the honest and uncompromising common sense of science. When more of the peoples of the world have learned the ways of thought of the scientist, we shall have better reason to expect lasting peace and a fuller life for all."

William J. Clinton, 1998

On February 13, 1998, during the current time of transition, President Clinton addressed AAAS at its 150th anniversary meeting in Philadelphia (Clinton 1998). As might have been expected, President Clinton made explicit reference to his predecessor's speech as a means for highlighting the revolutionary changes that had occurred as a result of advances in science and engineering during the intervening half-century. That two of his references were to fields that did not even exist in President Truman's day—namely, space science and information technology—provides one measure of the scope of those changes.

President Clinton's speech touched on many of the issues that President Truman had raised 50 years earlier, although with strikingly different emphases. President Truman's first point was that total national R&D investments should be doubled, reflecting the *Science and Public Policy*'s contention that the overall level of those investments was inadequate to the broad needs of the Nation. By contrast, President Clinton was able to remind his audience that the FY 1999 budget proposal that he had recently submitted to Congress included substantial increases for most of the principal Federal research agencies.[45]

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[45] *Budget of the United States Government for Fiscal Year 1999*, p. 93–104.

President Truman had linked basic research with medical research in urging that greater emphasis be given to both. President Clinton spoke more broadly about an expanded commitment to discovery. In noting advances that had occurred in health research, he reminded his audience that these advances had depended upon progress in a wide range of science and engineering fields.

Both presidents spoke about the conditions required for the conduct of high quality research. But where President Truman focused on insulating research from short-term political issues, President Clinton stressed the need for a long-term, stable funding environment.

Perhaps the most telling contrast between the two speeches was with the specific emphases placed on the national objectives that research should serve. President Truman spoke at length about science, engineering, and national security, which was appropriate in a year in which Cold War tensions were markedly increasing. However, the national security theme was entirely absent from President Clinton's speech. Rather, his emphasis was on the economy, the environment, and quality of life. President Clinton also spoke about social responsibility, noting that "it is incumbent upon both scientists and public servants to ensure that science serves humanity always, and never the other way around." As an example, he referred to ethical problems associated with advances in biotechnology, a reference that President Truman could not possibly have made, since the structure of the DNA molecule, a prerequisite for modern, molecular-based biotechnology, was not to be discovered until 1953.

A good deal of President Truman's speech had to do with the obligations of the Federal Government toward science; in contrast, President Clinton emphasized the need for strengthened partnerships between science and other national sectors.

Both presidents touched on the public understanding of science: President Truman stressing the need for Americans to understand the special needs of research; President Clinton, the need to increase public awareness of the promise of science for the future.

Both Presidents Truman and Clinton concluded their remarks by looking toward futures that appeared very different in 1948 and 1998. President Truman's optimism was guarded, reflecting the still fresh memories of World War II and the uncertainties inherent in the deepening Cold War. In contrast, President Clinton's concluding remarks, which linked advances in knowledge with fundamental American values, were buoyant:

> I believe in what you do. And I believe in the people who do it. Most important, I believe in the promise of America, in the idea that we must always marry our newest advances and knowledge with our oldest values, and that when we do that, it's worked pretty well. That is what we must bring to the new century (Clinton 1998, 10).

Current Visions/Key Policy Documents

Science in the National Interest (1994)

The concept of a National Science Foundation began to take shape in 1944, near the end of a period in which national defense had dominated the Nation's agenda. Only a handful of visionaries in science and government understood that a well-articulated policy would be required in order for the Nation to derive optimum peacetime benefits from science and engineering.

As the 1990s opened, the United States faced the novel challenge of redefining its goals and priorities in the post-Cold War era. By then, the importance of science and engineering to the United States had been firmly established. Indeed, they had assumed a significance that the visionaries of the 1940s probably could not have anticipated. Implementation of the recommendations of *Science—The Endless Frontier* and *Science and Public Policy*, which their authors had assumed would occur in a time of peace, actually took place during a period when national defense considerations once again dominated the national agenda. Thus, with the Cold War over, it was useful to rearticulate the importance of science and engineering to the Nation and redefine their roles in an era in which social and economic concerns were destined to increase in importance relative to national security concerns.

The organization of science and technology within the Federal Government also evolved during the Cold War era in response to changing political, economic, and social circumstances. In May 1976, the U.S. Congress, with the encouragement of President Gerald R. Ford, created the Office of Science and Technology Policy (OSTP) within the Executive Office of the President, in effect reconstituting the Office of Science and Technology (OST), which had been created by President John F. Kennedy in 1962 and abolished by President Richard M. Nixon in 1973. The National Science and Technology Policy, Organization and Priorities Act of 1976 also provided for an external presidential committee analogous to PSAC, which President Nixon abolished at the time he abolished OST. This provision was finally implemented in 1989 when D. Allan Bromley, the President's Assistant for Science and Technology, convinced President George Bush to establish the President's Council of Advisors on Science and Technology. In a coordinated action, Bromley reinvigorated the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET), a body consisting of the heads of all U.S. Government agencies with significant science and technology responsibilities. In 1993, President Clinton expanded the membership of FCCSET to include the heads of appropriate agencies within the Executive Office of the President, renaming it the National Science and Technology Council (NSTC).

In 1994, 50 years after Senator Harley Kilgore (D-WV) introduced his first bill to create a National Science Foundation and President Roosevelt requested advice from Vannevar Bush on the organization of science in the post-World War II era, the OSTP, in cooperation with the leading Federal science and technology agencies, convened a Forum on Science in the National Interest at NAS. Approximately 200 individuals from academia, industry, professional societies, and government participated in this event, suggesting the current breadth and reach of the U.S. science and engineering enterprise. *Science in the National Interest*, published in August 1994, summarized its results (Clinton and Gore 1994).

The organization of the Forum on Science in the National Interest, and the auspices under which it was convened, exemplified some of the important changes that had occurred in the status of science during the previous 50 years—in part as a result of recommendations made during the first period of transition. *Science—The Endless Frontier* was based upon the private deliberations of four *ad hoc* committees of prominent scientists convened to respond to a November 1944 letter from President Roosevelt. *Science and Public Policy* was prepared by a handful of mid-level staff within the Executive Office of the President, who consulted with colleagues in other Federal agencies and augmented their work by means of commissioned reports from nongovernment organizations. One of its recommendations was to establish a mechanism to bring important science policy issues to the attention of the highest levels of government.

OSTP, which convened the January 31–February 1, 1994, forum, was created to ensure that important science policy issues would, in fact, receive attention at the highest levels of the Federal Government. The fact that that agency even existed and was able to bring together approximately 200 individuals broadly representative of the Nation's science and engineering interests to articulate a vision for the future rather than relying on a group of select committees or staff within the Federal agencies suggests the changed social context in which science policy is viewed since the first time of transition.

Although the key documents of the 1940s argued persuasively that investments in science would yield significant benefits, they offered no specific, detailed examples. In contrast, *Science in the National Interest* included a variety of one-page, illustrated descriptions of benefits derived from those investments.

The most striking example of an advance that has occurred as a result of research investments was the simple, almost taken-for-granted fact that the entire text of *Science in the National Interest* was made available by way of the Internet, a development that even visionaries who predicted the bright future of information and communications technologies could not have dreamed of 50 years ago.

Science in the National Interest noted explicitly that its preparation did, in fact, occur during a time of transition. After paying its respects to the visionaries of the late 1940s, its second chapter, entitled "A Time of Transition," went on to articulate the new context in which national science policy must be formulated:

> The end of the Cold War has transformed international relationships and security needs. Highly competitive economies have emerged in Europe and Asia, putting new stresses on our private sector and on employment. The ongoing information revolution both enables and demands new ways of doing business. Our population diversity has increased, yielding new opportunities to build on a traditional American strength. Health and environmental responsibility present increasingly complex challenges, and the literacy standards for a productive and fulfilling role in twenty-first century society are expanding beyond the traditional "three R's" into science and technology (Clinton and Gore 1994, 3).

The report then suggested a framework for national science policy in terms of five goals regarded as essential to permit the U.S. scientific and engineering enterprise to address essential national objectives:

1. Maintain leadership across the frontiers of scientific knowledge.
2. Enhance connections between fundamental research and national goals.
3. Stimulate partnerships that promote investments in fundamental science and engineering and effective use of physical, human and financial resources.
4. Produce the finest scientists and engineers for the twenty-first century.
5. Raise scientific and technological literacy of all Americans (Clinton and Gore 1994, 7).

While stressing the desirability of reexamining and reshaping U.S. science policy, *Science in the National Interest* also emphasized that the core values that have enabled the Nation to achieve so much should be kept clearly in view. A strong commitment to investigator-initiated research and merit review based on evaluation by scientific peers should be regarded as foremost among those core values.

Unlocking Our Future (1998)

In October 1945, the U.S. Senate convened hearings on proposed legislation to create a National Science Foundation that involved a large number of witnesses from different sectors of the science and engineering enterprise, from education associations, BoB, and several old-line executive branch scientific bureaus. These and other, subsequent congressional hearings on issues such as control of nuclear energy or research in the military departments were instrumental in focusing widespread public attention on the importance of science and engineering in the postwar era. They also initiated a tradition of sustained congressional interest and attention to U.S. science policy. (See sidebar, "Congressional Science Policy Hearings and Studies.")

Following that tradition, on February 17, 1997, the Speaker of the House of Representatives acknowledged the need to reexamine the assumptions underlying U.S. science policy by requesting that the House Science Committee undertake a special study. Accordingly, Representative Vernon Ehlers (R-MI), a Ph.D. physicist and former college professor, was asked to lead a Committee study of "the current state of the Nation's science and technology policies" and to outline "a framework for an updated national science policy that can serve as a policy guide to the Committee, Congress, and the Nation" (U.S. House of Representatives Science Committee 1998, 6). The full Science Committee held seven hearings in order to obtain inputs for the study. In addition, Committee members and staff met with individuals and groups interested in reexamining U.S. science policy. Finally, the Committee took advantage of advances in information and communications technology by establishing a Web site to elicit comments and suggestions from the public, and the report itself was first made available to the public with the use of the Internet. The Committee successfully completed its work with the release of the report, entitled *Unlocking Our Future: Toward a New National Science Policy*—which was first made available to the public by way of the Internet—on September 24, 1998.

The Ehlers study was guided by a vision statement, which also provided the foundation for its report, namely, "The United States of America must maintain and improve its preeminent position in science and technology in order to advance human understanding of the universe and all it contains, and to improve the lives, health, and freedom of all peoples" (U.S. House of Representatives Science Committee 1998, 7).

Unlocking Our Future noted that three basic components of the scientific enterprise needed to be strengthened to ensure that this vision would be realized:

> First, we must ensure that the well of scientific discovery does not run dry, by facilitating and encouraging advances in fundamental research;
>
> Second, we must see that .discoveries from this well must be drawn continually and applied to the development of new products or processes, to solutions for societal or environmental challenges, or simply used to establish the foundation for further discoveries;
>
> Finally, we must strengthen both the education we depend upon to produce the diverse array of people who draw from and replenish the well of discovery, as well as the lines of communication between scientists and engineers and the American people (U.S. House of Representatives Science Committee 1998, 12).

The report went on to discuss these components in considerable detail in terms of themes and issues that, along with those articulated in *Science in the National Interest*, provide a useful counterpoint to the themes and issues set forth in the key documents of the first time of transition.

Themes and Issues

Science in Service to Society

Because the objective of both *Science in the National Interest* and *Unlocking Our Future* was to reexamine science policy in a changing economic, political, and social context, both laid considerable emphasis on science in service to society. *Science in the National Interest* asserted that "We must reexamine and reshape our science policy both to sustain America's preeminence in science and to facilitate the role of science in the broader national interest" (Clinton and Gore 1994, 3).

Both reports emphasized the importance of research to health, economic prosperity, national security, environmental responsibility, and improved quality of life, as well as its contribution to the general culture. *Unlocking Our Future* also stressed the importance of science and engineering results to decisionmaking:

> We believe this role for science will take on increasing importance, particularly as we face difficult decisions related to the environment. Accomplishing this goal will require, among other things, the development of research agendas aimed at analyzing and resolving contentious issues, and will demand closer coordination among scientists, engineers, and policymakers (U.S. House of Representatives Science Committee 1998, 5).

Research Investments

Both reports acknowledged the indispensable role that Federal research investments play in maintaining the preeminence of the U.S. science and engineering enterprise and tacitly assumed that a broad bipartisan consensus to maintain that support would persist. According to *Science in the National Interest*,

> To fulfill our responsibility to future generations by ensuring that our children can compete in the global economy, we must invest in the scientific enterprise at a rate commensurate with its growing importance to society. That means we must provide physical infrastructure that facilitates world class research, including access to cutting-edge scientific instrumentation and to world-class information and communication systems (Clinton and Gore 1994, 1).

Unlocking Our Future emphasized that:

> Science—including understanding-driven research, targeted basic research, and mission-directed research—must be given the opportunity to thrive, as it is the precursor to new and better understanding, products and processes. The Federal investment in science has yielded stunning payoffs. It has spawned not only new products, but also entire industries (U.S. House of Representatives Science Committee 1998, 4).

Character of the Research System

Both reports agreed that, although adequate Federal support would continue to be essential to the science and engineering enterprise and would almost certainly continue to be forthcoming, its level would continue to be constrained. Therefore, it would be necessary to establish priorities for Federal support, taking into account the current and future character of the research system and its ability to contribute to societal goals. *Unlocking Our Future* stressed the need to take into account the entire Federal Government science and technology system, including the mission agencies, in determining priorities for Federal investments: "Research within Federal government agencies and departments ranges from purely basic knowledge-driven research, to targeted basic research, applied research and, in some cases, even product development" (U.S. House of Representatives Science Committee 1998, 16).

Congressional Science Policy Hearings and Studies

♦ **Hearings on National Science Foundation legislation (October–November 1945).** Joint hearings on two separate bills to create a National Science Foundation were held by the Senate Committee on Military Affairs starting on October 8, 1945, and extending to November 2 (England 1983). (See "Congressional Initiatives.") These hearings, which involved approximately 100 witnesses, provided the first occasion for a wide-ranging exploration of the status and future potential of science–government relations, including Federal support for research and education, and government organization for science. Representatives of *ad hoc* groups of nuclear physicists who were opposed to continued control of nuclear energy by the War Department used these hearings as the first opportunity to air their views in Congress, leading eventually to a decision of Senator Brien McMahon (D-CT) to introduce legislation (through another committee) that led to the creation of the Atomic Energy Commission on August 1, 1946. These hearings also resulted in a compromise bill to create a National Science Foundation, which passed the Senate in July 1946 but died when the House of Representatives declined to consider it.

♦ **Hearings on space policy (1957–58).** On November 25, 1957, six weeks after the Soviet Union launched Sputnik I on October 4, the Preparedness Subcommittee of the Senate Armed Services Committee convened hearings on U.S. space activities under the chairmanship of Senate Majority Leader Lyndon B. Johnson (D-TX) (U.S. House of Representatives 1980, 5–27). One immediate outcome was the establishment by the Senate of a Committee on Space Astronautics, chaired by Johnson, on February 6, 1958. The House followed suit on March 5 by establishing a Select Committee on Astronautics and Space Exploration chaired by House Majority Leader John McCormack (D-MA), with Representative Gerald R. Ford (R-MI) one of six minority members. Hearings before the Senate and House Committees resulted in the enactment of legislation to create the National Aeronautics and Space Administration on July 29, 1958. As a result of the impressive achievements of its Select Committee, the House also decided to establish a Standing Committee on Science and Astronautics on January 3, 1959.

♦ **Review of the National Science Foundation (1965–68).** In 1963, George P. Miller (D-CA), Chairman of the House Committee on Science and Astronautics, convinced his colleagues that, because of the increasing size and complexity of the Federal research system, the House should establish a mechanism to permit a more continuous, in-depth oversight of the system than had previously been necessary (U.S. House of Representatives 1980, 127–62). Accordingly, the Subcommittee on Science, Research, and Development, chaired by Emilio Q. Daddario (D-CT), was created on August 23, 1963. Among the subcommittee's first actions were to organize a series of periodic special seminars and panels with the objective of providing opportunities for members of Congress to meet and interact with members of the science and engineering communities; to request a detailed study from the Legislative Reference Service of the Library of Congress on the aids and tools available to Congress in the area of science and technology; and to send to the House floor legislation to create a Science Policy Research Division within the Library of Congress, which was enacted in 1964. In December 1965, the subcommittee received from this new unit a report titled *The National Science Foundation—Its Present and Its Future*, which provided the basis for a series of hearings designed to revise, update, and broaden the National Science Foundation Act of 1950. These hearings demonstrated widespread support for the Foundation, but also suggested that the agency had become a sufficiently significant component of the U.S. science and engineering enterprise to play a more active role than had been the case up to that time. Legislation enacted on July 18, 1968, amended the 1950 Act by requiring annual authorization for the agency; elevating its deputy director to the status of a presidential appointee; including the social sciences explicitly among those qualifying for National Science Foundation support; requiring that National Science Foundation analyze rather than simply gather and disseminate data on the condition of the science and engineering enterprise; and requiring that the National Science Board submit an annual report to the Congress through the President. (See "Congressional and Presidential Directives.")

In November–December 1969, the Subcommittee held a series of hearings that resulted, in 1972, in an Act to create the Office of Technology Assessment. Daddario was subsequently selected as the Office of Technology Assessment's first director.

♦ **Review of Federal policy and organization for science and technology (1973–76).** The Presidential Science Advisory System, established by President Eisenhower with the creation of the President's Science Advisory Committee and the appointment of James Killian as his full-time science advisor, and expanded with President Kennedy's creation of the Office of Science and Technology within the Executive Office of the President, enjoyed broad support in the Congress. After the President's Science Advisory Council and the Office of Science and Technology were abolished in January 1973, the House Subcommittee on Science, Research, and Development convened hearings, beginning in July of that year, on Federal policy and organization for science and technology.* Expanded hearings were held before the full parent Committee on Science and Technology in June–July 1975.** A majority of witnesses, including six former presidential science advisors, urged that Congress enact legislation to reestablish some type of presidential science advisory system. Parallel hearings leading to a similar conclusion were also held by the Subcommittee on the National Science Foundation of the Senate Committee on Labor and Public Welfare, chaired by Senator Edward M. Kennedy (D-MA). Gerald R. Ford, who became President following the resignation of Richard M. Nixon on August 8, 1975, was sympathetic to recreating such a system and directed Vice President Nelson A. Rockefeller to negotiate the matter with the Senate and House. These negotiations led to enactment, on May 11, 1976, of legislation creating the Office of Science and Technology Policy within the Executive Office of the President and articulating for the first time the consensus of Congress on the principles and elements of an adequate national science policy.***

♦ **House Science Policy Task Force study (1985–86).** In 1984, Congressman Don Fuqua (D-FL), Chairman of the House Science and Technology Committee, noted that Congress had not organized a broad review of national science policy since the Daddario Subcommittee hearings 20 years earlier. In July of that year, he convinced his colleagues to establish an *ad hoc* Science Policy Task Force within the Committee, which he also agreed to chair. During 1985 and 1986, the Fuqua task force held hearings on the entire range of science policy issues, including Federal support for research, research facilities in universities and Federal laboratories, science education, university–industry cooperation, the role of the public in setting the national research agenda, and international scientific cooperation, with an emphasis on cooperation in "big science." The task force also commissioned several special studies, including a collection of articles entitled *Reader on Expertise and Democratic Decision Making* and *A History of Science Policy in the United States, 1940–85*. The results of the two-year task force study were published in a multivolume set.

♦ **House Science Committee study (1997–98).** In February 1997, the Speaker of the House of Representatives requested that the House Science Committee,**** Chaired by James Sensenbrenner (R-WI), conduct a study to outline "a framework for an updated national science policy that can serve as a policy guide to the Committee, Congress, and the Nation." (See "Current Visions/Key Policy Documents.") Hearings and special meetings during the next two years under the guidance of Vernon Ehlers (R-MI) led, on September 24, 1998, to the release of a report entitled *Unlocking Our Future* (U.S. House of Representatives Science Committee 1998). Consisting of 51 pages of text, including four pages of summary recommendations, in addition to a four-page list of sources, the Ehlers report grouped its findings under four major headings: (I) Ensuring the Flow of New Ideas, (II) The Private Sector's Role in the Scientific Enterprise, (III) Ensuring that Technical Decisions Made by Government Bodies Are Founded in Sound Science, and (IV) Sustaining the Research Enterprise—The Importance of Education. In presentations to several scientific society meetings, Congressman Ehlers expressed the hope that the report would be only a first step in an ongoing process in which Congress would focus more actively on science policy, perhaps reviewing it every five years.

**U.S. Code Congressional and Administrative News, 94th Congress, Second Session*, vol. I, pp. 882–903.

**The Committee on Science and Astronautics was renamed the Committee on Science and Technology in January 1975.

***National Science and Technology Policy, Organization, and Priorities Act of 1976. Public Law 94-282, enacted May 11, 1976.

****The House Science and Technology Committee was renamed the House Science Committee in January 1995.

Unlocking Our Future also recognized the indispensable and increasingly important role of private industry both as supporter and performer of research. However, both reports emphasized the centrality of universities to the entire U.S. research enterprise. *Science in the National Interest* asserted that:

> A significant fraction of research, particularly fundamental research, is performed at academic institutions. This has multiple benefits. Research and education are linked in an extremely productive way. The intellectual freedom afforded academic researchers and the constant renewal brought by successive generations of inquisitive young minds stimulate the research enterprise (Clinton and Gore 1994, 7).

The increasing importance of multidisciplinary research, particularly as a basis for addressing national goals, was also emphasized by both reports.

Human Resources for Science and Engineering

Both reports assigned a high priority to human resources as an integral element of science policy. *Science in the National Interest* stated that "The challenges of the twenty-first century will place a high premium on sustained excellence in scientific research and education. We approach the future with a strong foundation" (Clinton and Gore 1994, 2). An adequate education for the 21st century requires greater flexibility, particularly at the graduate school level. *Unlocking Our Future* asserted that "While continuing to train scientists and engineers of unsurpassed quality, the higher education process should allow for better preparation of students who plan to seek careers outside of academia by increasing flexibility in graduate training programs" (U.S. House of Representatives Science Committee 1998, 42).

Both reports agreed that science education at all levels, including adequate science education for nonspecialists, was essential to the national interest. According to *Unlocking Our Future*, "Not only must we ensure that we continue to produce world-class scientists and engineers, we must also provide every citizen with an adequate grounding in science and math if we are to give them an opportunity to succeed in the technology-based world of tomorrow—a lifelong learning proposition" (U.S. House of Representatives Science Committee 1998, 5).

Partnerships

Preparation of both reports involved the active participation of individuals and groups with interests in the U.S. science and engineering enterprise. Appropriately, then, both emphasized the importance of partnerships in maintaining the vitality of the enterprise and strengthening its links with society. *Unlocking Our Future* took special note of the fact that:

> The science policy described herein outlines not only possible roles for Federal entities such as Congress and the Executive branch, but also implicit responsibilities of other important players in the research enterprise, such as States, universities and industry. We believe such a comprehensive approach is warranted given the highly interconnected relationships among the various players in the science and technology enterprise (U.S. House of Representatives Science Committee 1998, 11).

More broadly,

> Each member of society plays an important part in the scientific enterprise. Whether a chemist or a first-grade teacher, an aerospace engineer or machine shop worker, a patent lawyer or medical patient, we all should possess some degree of knowledge about, or familiarity with, science and technology if we are to exercise our individual roles effectively (U.S. House of Representatives Science Committee 1998, 36).

Science in the National Interest noted that:

> Science advances the national interest and improves our quality of life only as part of a larger enterprise. Today's science and technology enterprise is more like an ecosystem than a production line. Fundamental science and technological advances are interdependent, and the steps from fundamental science to the marketplace or to the clinic require healthy institutions and entrepreneurial spirit across society (Clinton and Gore 1994, 8).

Accountability

Because the overall objective of both reports was to examine the changing character of science and engineering in a rapidly changing social, economic, and political context, both laid considerable emphasis on public accountability. *Science in the National Interest* asserted the accountability theme simply and concisely at the outset: "The principal sponsors and beneficiaries of our scientific enterprise are the American people. Their continued support, rooted in the recognition of science as the foundation of a modern knowledge-based technological society, is essential" (Clinton and Gore 1994, 1). However, obtaining and maintaining broad public support, as *Unlocking Our Future* emphasized, requires the active engagement of individuals from several types of institution:

> Whether through better communication among scientists, journalists, and the public, increased recognition of the importance of mission-directed research, or methods to ensure that, by setting priorities, we reap ever greater returns on the research investment, strong ties between science and society are paramount. Re-forging those ties with the American people is perhaps the single most important challenge facing science and engineering in the near future (U.S. House of Representatives Science Committee 1998, 5).

International Dimensions

Both reports emphasized that cognizance of the international dimensions of research would be essential in formulating an adequate national science policy for the 21st century. *Unlocking Our Future* recognized that international collaborations are among the many types of partnership that individual scientists and engineers require to work effectively: "Although science is believed by many to be a largely individual endeavor, it is in fact often a collaborative effort. In forging collaborations, scientists often work without concern for international boundaries. Most international scientific collaborations take place on the level of individual scientists or laboratories" (U.S. House of Representatives Science Committee 1998, 21).

Science in the National Interest emphasized the importance of the international dimensions of science both to the

U.S. research enterprise and to U.S. national interests more broadly:

> The nature of science is international, and the free flow of people, ideas, and data is essential to the health of our scientific enterprise. Many of the scientific challenges, for example in health, environment, and food, are global in scope and require on-site cooperation in many other countries. In addition to scientific benefits, collaborative scientific and engineering projects bring Nations together thereby contributing to international understanding, good will, and sound decision-making worldwide (Clinton and Gore 1994, 8).

Advances in Science and Engineering

NSF funding of basic research across a broad range of disciplines as well as funding from other government agencies, industry, and academia in the United States and abroad has lead to many advances. Science and engineering breakthroughs have contributed to new capabilities in equipment that subsequently have enabled newer discoveries. It is not possible to review them all. The following discussion will be only illustrative in nature and will point to other ongoing efforts to identify and document such advances.

Central to the vision of the first transition period was the desirability of encouraging and facilitating partnerships among the three primary sectors of the U.S. research community: academia, industry, and government. Although the relationships among these sectors have changed considerably since that time, these partnerships have been essential to the major advances in all fields of science and engineering that have taken place during the past 50 years. These advances have led us to a better understanding of ourselves and the world around us. Increased understanding has, in turn, underlain the development of new products and processes, which have changed our everyday lives and the way we live them. Deeper understanding of specific aspects of the natural and human-influenced world has also demonstrated how little we know in many cases and suggested the need for new approaches to address important scientific and engineering problems. This finding has led to increased multidisciplinary research, international and intersectoral cooperation, and the creation of disciplines and whole industries (for example, information technology and biotechnology industries) that did not exist during the first transition period. Such advances have changed our lives, our economy, and our society in important and sometimes profound ways.[46]

The View by *Indicators*

Earlier editions of *Science and Engineering Indicators* reports have discussed important discoveries and advances. For example, the "Advances in Science and Engineering" chapter of *Science and Engineering Indicators – 1980* covered the following areas:

- Black Holes,
- Gravity Waves,
- The Sun,
- Cognitive Science in Mathematics and Education,
- Information Flow in Biological Systems,
- Catalysts and Chemical Engineering, and
- Communications and Electronics.

The *Science and Engineering Indicators – 1982* "Advances in Science and Engineering" chapter covered the following areas:

- Prime Numbers: Keys to the Code,
- The Pursuit of Fundamentality and Unity,
- The Science of Surfaces,
- Manmade Baskets for Artificial Enzymes,
- Opiate Peptides and Receptors,
- Helping Plants Fight Disease, and
- Exploring the Ocean Floor.

The *Science and Engineering Indicators – 1985* chapter entitled "Advances in Science and Engineering: The Role of Instrumentation" covered five case studies illustrating the important and synergistic roles that refinements in measuring and computing technologies play in undergirding and linking advances in science and engineering, as well as in developing new fields, processes, and products in academia and industry. The chapter highlighted the following areas:

- *Spectroscopy*—including a discussion of optical spectroscopy, mass spectroscopy, and nuclear magnetic resonance spectroscopy;
- *Lasers*—including discussions of applications in chemistry, measurement of fundamental standards, commercial applications, and biomedical applications;
- *Superconductivity*—including discussions of the fundamental process, the search for superconductors, applications, and ultra-high-field magnets;
- *Monoclonal Antibodies*—including the discovery of the technology, production of pure biochemical regents, studies of cell development, potential medical applications, and engineered monoclonal antibodies; and
- *Advanced Scientific Computing*—assisting scientists and engineers to test ideas on the forces moving the Earth's plates, track the path an electron takes within the magnetic fields of a neutron star, link a fragment of viral DNA to a human gene, watch plasmas undulating within fusion reactors yet to be built, form and reform digital clouds and monitor the formation of tornadoes, see galaxies born and watch their spiral arms take shape, set the clock at the (almost) very beginning and recreate the universe, begin

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[46] See "100 Years of Innovation: A Photographic Journey," *Business Week*, Summer Special Issue 1999 for a remarkable essay of how science, technology, and innovation have changed our lives.

to think about confirming and denying the root theories of proton and neutron structure in order to test our ideas of the nature of matter, and predict how a spacecraft will glide through the atmosphere of Jupiter.

Some of the cutting-edge problems discussed in these earlier chapters remain current. Others have long since been resolved and are now regarded as commonplace. This illustrates the rapidly changing nature of discoveries in science and engineering as well as the difficulties in predicting what new advances will occur and when.

Contributions from the Past and Toward the Future

The basis for some of the advances of the past 50 years occurred during the first transition period. For example, the transistor was invented in 1947, ultimately leading to the invention of microchips in the 1960s. The Electronic Numerical Integrator and Computer, developed by University of Pennsylvania engineers, first became operational in 1948 and was the progenitor of several generations of computers, including the personal computer, first introduced in the 1970s. Information technologies resulted from the fusion of computer and communications technologies. Through information technologies, advances in materials science and physics have led, in turn, to new industries (see NRC 1999 and Huttner 1999), streamlined processes in traditional industries, and expanded scientific capabilities. (See chapter 9 for a discussion of the significance of information technologies.)

Scientists and engineers from all over the globe have joined together to explore space and our universe. Based on accomplishments over time from many countries, the United States was able to send a man to the moon and back in 1969 and a tiny Sojourner rover to Mars in 1997; both captured our imaginations and enhanced our understanding of our universe. Construction of an international space station is now under way with men and women contributing to its development and its associated missions.

The bases for many of the significant advances that have occurred since the late 1940s have been consistent with the importance of developing partnerships as well as the importance of encouraging individual researchers to pursue new and innovative ideas. In the area of medicine, the polio vaccine was developed in the 1950s by physician Jonas Salk, and microbiologist Albert Sabin later developed an oral vaccine. The first heart transplant was performed in 1967. Today many organs are being transplanted or replaced with artificial parts or organs, and researchers are making use of fundamental knowledge to investigate the role of genetics in preventative treatment for some diseases.

The double helical structure of the DNA molecule was discovered in the 1950s, and recombinant DNA techniques (or gene splicing) occurred in the early 1970s, leading to many additional advances. Researchers around the world are striving to complete the human genome project. Advances in a variety of subfields of the biosciences have resulted in vast amounts of new data, leading to the problem of how to store, interpret, and make these data available to researchers in other subfields. Researchers in computer sciences and biological sciences have addressed this problem by creating the entirely new field of biological informatics, which applies advances in information technology to make possible further understanding of biological systems.

In plant biology, researchers currently apply genetic engineering to develop crops resistant to disease and insects. It is now known that all flowering plants derive from a common ancestry and share a common set of biochemical pathways. This knowledge has led plant biologists to direct their coordinated research efforts toward developing a complete understanding of a small, relatively simple flowering plant, *Arabidopsis,* that serves as a model organism. Scientist around the globe, in a multiagency, multinational project, are mapping and identifying the function and location of all the genes in *Arabidopsis.* New fundamental discoveries from this initiative have already led to significant improvements in several crop plants and may possibly result in totally new crops in the future. The *Arabidopsis* project is also providing information that can be used to study genes from a variety of more complex organisms, ranging from corn and wheat to mice and humans.

Breakthroughs are not without controversy. The cloning of Dolly the sheep, the first mammal to be cloned from an adult cell, has been a triumph and a concern. It is an example of the importance of dialogue with the public and better understanding of societal concerns. Findings in Chapter 8 on public attitudes and understanding of science and technology show that the public greatly appreciates scientific discoveries, although they do not always fully understand them. Also a large majority believe that in general the benefits of scientific research outweigh harmful results. Nonetheless, when asked about genetic engineering, the U.S. public's answers are more evenly divided.

Over the past half-century, discoveries associated with NSF funding[47] include materials science discoveries by engineers, chemists, physicists, biologists, metallurgists, computer scientists, and other researchers. These advances have led to increased data storage capacity of computer systems, advances in semiconductor lasers, improvements in compact disc players and laser printers, new medical applications, and major breakthroughs in synthetic polymers which are found today in products from clothing to automobiles.

Because of the complex nature of both research itself and its links to possible useful products and processes, there is often a delay between the dissemination of fundamental knowledge and its eventual outcome or effect on products or processes. Therefore it is not always easy to trace back to the precise origins of all discoveries. Nevertheless, a number of studies have accomplished this goal. For example, an early study contracted for by NSF, entitled *Technology in*

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[47] See *America's Investment in the Future,* an NSF publication in press, for an engaging and broad-ranging discussion of important discoveries made by researchers funded by NSF.

Retrospect and Critical Events in Science (Illinois Institute of Technology 1968; commonly known as the “Traces” study) chronicled and traced the development of important innovations such as magnetic ferrites, videotape recorders, the oral contraceptive pill, the electron microscope, and matrix isolation, an example of a scientific technique used in certain chemical processing industries. In most cases, the traces emphasized the importance of nonmission research and contributions from all sectors and their interplay. The study pointed out the importance of interaction between science and technology and interdisciplinary communication as well as demonstrated the long-term, sometimes serendipitous, nature of innovation. This social science study was a precursor to many of today’s efforts to trace innovations and conduct accountability studies such as called for under the Government Performance and Review Act (see chapter 2 for more explanation of this Act). Current studies and different approaches also demonstrate the close nature of science and technology to new products and processes (NSB 1998b; Narin, Hamilton, and Olivastro 1997).

A more traditional way of acknowledging important scientific discoveries and breakthroughs is with awards. The most famous scientific award is the Nobel Prize. Appendix table 1-1 lists the various Nobel Prizes since the 1950s and the accomplishments that they celebrate. An examination of the discoveries listed provides a glimpse into the progress in several fields.

Research is increasingly collaborative and interdisciplinary in nature. Findings from one country, discipline, or sector can build on those developed in others, highlighting the importance of alliances and partnerships. Chapters 2 and 6 show how such collaborative activities have increased over the past decade. As one important example of interdisciplinary research, computer scientists, mathematicians, and cognitive scientists have joined forces with scholars in the humanities to conduct research on modeling and visualization techniques to address a variety of problems from modeling the human heart or brain to modeling traffic patterns. Nanotechnology is another important emerging interdisciplinary field that has many potentially valuable applications. International cooperation has also increased considerably during the past 50 years, with many large-scale scientific projects planned and financed internationally from the outset.

With the help of ever more powerful instruments—be it the Hubble telescope or the new Gemini telescopes—astronomers and astrophysicists are increasing understanding of our solar system and even reaching beyond to discover planets outside of our solar system. An important recent example is the Gemini project, to construct and operate a pair of identical, state-of-the-art, 8-meter optical telescopes in the Northern and Southern Hemisphere (at Mauna Kea, Hawaii, and Cerro Pachon, Chile). Project Gemini is an international project involving the United States, the United Kingdom, Canada, Argentina, Australia, Brazil, and Chile. Gemini North has been dedicated and has provided some of the sharpest infrared images ever obtained by a ground-based telescope. These first high-resolution images from Gemini North reveal the remarkable power of the telescope’s technologies, which minimize distortions that have blurred astronomical images since Galileo first pointed a telescope skyward almost 400 years ago. The clarity of these images is equivalent to resolving the separation between a set of automobile headlights at a distance of 2,000 miles.

Large-scale physics facilities such as Centre Europénne pour la Recherche Nucléaire and its Large Hadron Collider are also investigating the structure of our universe from the atomic to the cosmic scale in a fascinating and different fashion. The work of astronomers and physicists have created new knowledge about the infinite vastness and smallness of our marvelous universe. *Physics in the Twentieth Century* by Curt Suplee (1999) documents many of the important breakthroughs in physics, and the May 1999 issue of *Physics Today* heralds many of the triumphs in astronomy over the past 100 years.

Discoveries in the geosciences and engineering have enabled us to better prepare for and predict disasters such as earthquakes and to mitigate economic and social effects of long-term weather phenomenon such as El Niño. New discoveries related to plate tectonics and discoveries from interdisciplinary polar science research have increased our understanding of our world, its structure, and its atmosphere.

Advances in the social and behavioral sciences cannot be ignored and are key to solving and understanding some of our Nation’s and world’s most complex problems. Better understanding of economics and game theory, risk assessment, and cognitive science have made important contributions to our economy and well-being.

The Importance of Human Resource Development: The NSF Class of 1952

None of these advances could have been accomplished without the hard work of numerous talented scientists and engineers and their students. From the beginning, NSF recognized the importance of educating and training young people in science and engineering fields; improving and linking education and research continue to be a major priority and contribution of NSF. Of the $3.5 million appropriated by Congress for the new Foundation’s first full fiscal year (from July 1, 1951, through June 30, 1952), NSF expended approximately $1.07 million for 97 research grants and approximately $1.53 million to award 535 predoctoral and 38 postdoctoral fellowships.

The new fellows were informed of their awards during the first week of April 1952. Among the predoctoral fellowship recipients, 154 were listed as first-year students, that is, college seniors intending to enroll in graduate school in the fall; 165 were completing their first year as graduate students, and 216 had completed two years or more. Arguably, these 573 fellowships, awarded to aspiring scientists and engineers in 47 states and the District of Columbia, composed the first widely visible indication that NSF was open and ready for business.

The first recipients of NSF fellowships made important contributions from many fields and sectors—both within science and engineering fields and outside of these disciplines. A short historical reprise of what the NSF fellowship meant to these first recipients shows that it helped many to decide to go into science, assisted in bolstering confidence, and made a significant difference in being able to choose their own areas of study. The first fellows included many who would later become prominent, such as Nobel Prize Winners Burton Richter and James Cronin, and Maxine Singer, a co-discoverer of recombinant DNA, now President of the Carnegie Institution of Washington and the 1999 recipient of the NSB's Vannevar Bush award. Also they included many who, although less prominent, have contributed to their fields; to government, industry, and academia; and to their communities.

The following excerpts are from a survey and report of the first fellows by William A. Blanpied, summarized in "The National Science Foundation Class of 1952" (Blanpied 1999). These excerpts give a flavor of the times as well as what the NSF fellowship meant to the careers and lives of these then young people—approximately 100 members of the NSF Class of '52 who responded to a personal letter. This group of scientists and engineers have had professional careers approximately spanning the lifetime of the Foundation, and their recollections of their fellowship years and the impacts of those years on their subsequent professional life provide insights into the personal impacts as well as societal impacts of supporting bright young scientists and engineers. The birth years of these respondents range from 1917 through 1932, the median year being 1929. Many experienced military service in World War II and noted that their undergraduate education had been made possible, at least in part, by benefits received from the GI bill of rights,[48] which had been enacted in June 1944. U.S. higher education was becoming democratized during their undergraduate years.

Peter von Hippel, among the youngest of the Class of '52, recalled classmates who were "given the GI bill of rights, often considerably older and more mature." Peter von Hippel was then in his last year of a five-year combined bachelor's/master's in science program in biophysics at MIT which he believes was the first undergraduate biophysics program in the country. Von Hippel is now the American Cancer Society Research Professor of Chemistry at the Institute of Molecular Biology at the University of Oregon.

Edward O. Wilson, now Pellegrino University Research Professor at Harvard and then a student in Harvard's Department of Biology, recounted the thrill of getting the news of the fellowship. "The announcements of the first NSF predoctoral fellowships fell like a shower of gold on several of my fellow students in Harvard's Department of Biology on a Friday morning in the spring of 1952. I was a bit let down because I wasn't among them, but then lifted up again when I received the same good news the following Monday (my letter was late)."

Joseph Hull, a geology major at Columbia, recalled, "I knew that there were political implications when Senator Mike Monroney of my home state, Oklahoma, wrote me a congratulatory letter reminding me that he had voted for the bill. I was also aware that supplying geographical diversity by being from Oklahoma gave me an edge in the selection. No matter. I was exhilarated. Being an NSF Fellow carried a lot of prestige." Hull received his doctorate from Columbia in 1955 and then pursued a career with the petroleum industry.

Richard Lewontin, Professor of Biology at Harvard, had even earlier knowledge of NSF. "When I was a high school senior in 1946," he wrote,

> I was in the first wave of Westinghouse Science Talent Search winners. One of the things that the group did when we went to Washington was to testify before a congressional committee that was considering the National Science Foundation legislation. As bright high school students, it was our task to tell a somewhat reluctant congressional committee that the Federal support of science through a National Science Foundation would be a good thing. I do not know if that testimony had any influence, but you may well imagine that I remember the occasion very well.

Josephine Raskind, later Peter von Hippel's wife, was a classmate of Lewontin's at Forest Hills High School and a co-Westinghouse finalist. She recalls meeting President Truman and physicist Lise Meitner, among others, on that 1946 trip to Washington.

At least three other members of the NSF Class of '52 had also been Westinghouse finalists. One was Alan J. Goldman, currently in the Mathematical Sciences Department of the Whiting School of Engineering at The Johns Hopkins University, who wrote that the multiday trip to Washington for the finalists was the first time he had been away from his family even overnight. Another was Andrew Sessler, now Distinguished Senior Scientist at the Lawrence Berkeley laboratory. The third was Barbara Wolff Searle, who reported that she was the "top girl" in that group in 1947. Searle was also among 32 women who received NSF fellowships in 1952. Remarkably, 5 of those 32 were seniors at Swarthmore College. "The men who took the exam were not slouches," Searle recalled," but whatever the test tested, we (the women) did better at." Two other members of the Swarthmore-5 also responded to the November 1998 letter: Vivienne Nachmias, recently retired as Professor in the Department of Cellular and Developmental Biology at the University of Pennsylvania School of Medicine, and Maxine Singer, President of the Carnegie Institution of Washington. Searle herself recently retired from the staff of the World Bank, where she served for several years as an education specialist.

Joseph Berkowitz, who was working in the nuclear reactor program at Brookhaven National Laboratory when he received the fellowship that allowed him to pursue graduate work in chemistry at Harvard, had graduated from New York University as a member of the Class of 1951. "The opportunity to attend graduate school at Harvard opened entirely new

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[48] An Act to Provide Federal Government Aid for the Readjustment in Civilian Life of Returning World War II Veterans. Public Law 78-346, enacted June 22, 1944.

vistas for me," he recalled. "My fellow students were quite different from the ones I encountered as an engineering student. I discovered the addiction to basic research. I had the opportunity to attend lectures by future Nobel Prize winners. It launched me on a life-long career in basic research, which I didn't know was possible in my youth. It's probably no exaggeration to say that the NSF predoctoral fellowship changed the direction of my life." Berkowitz, who spent much of his career at Argonne National Laboratory, is now an Emeritus Senior Scientist at that facility.

Several respondents also noted that their fellowships allowed them to change their research directions. Burton Richter, Director Emeritus of SLAC and a Nobel Laureate in Physics, recalled that, as a student at MIT, he was working …

> on an experiment [at the National Magnet Laboratory] to determine the hyperfine structure of the radioactive mercury isotopes. My job was to make the radioactive mercury isotopes, which I did by a kind of inverse alchemy turning gold into mercury using the MIT cyclotron. I began to find myself more interested in what was going on at the cyclotron laboratory than in what was going on with my experiment. As my interest grew, I decided that perhaps I should change fields. I went off to spend three months at Brookhaven seeing what particle physics was like. I found I loved it and on return transferred to the synchrotron laboratory and began working in the direction that I have pursued ever since. It may be that I could have done all of this with a normal graduate research assistantship but it would certainly have been more difficult. I would have had to find a professor who was willing to spend his own research money to give a young student an opportunity to try out some different area.

Robert M. Mazo, a senior chemistry major at Harvard in the spring of 1952 and now Professor Emeritus in the Department of Chemistry and Institute of Theoretical Science at the University of Oregon, suggested that there were …

> two primary classes of people affected by the fellowship program. There were those like me, already intellectually committed to a career in science, but uncertain about practical ways and means [of financing their graduate education]. Then there were those, many with great abilities, which were unsure about their career aims. The existence of a fellowship program temporarily freeing them from financial stress tipped the balance in favor of a career in science for many.

"My NSF year," as Swarthmore graduate Vivianne T. Nachmias recalled,

> was primarily a year that allowed me to try things out, to search, to take more graduate studies, and so to narrow my field of interest. I had the fixed idea that the only thing to study was the brain. But how? After my year with NSF support [in the Harvard Department of Chemistry], I went across the river to Harvard Medical School and there in the first year, I encountered cells, in my histology course with Helen Padykula as instructor. I did my first successful project with her (on muscle cells) and from then on I was as interested in cells as in the brain.

Nachmias went on to earn a medical degree from the University of Rochester in 1957 and subsequently pursued a career in biomedical research. She conjectured that another reason for her decision to pursue a medical degree rather than a doctorate may have been that "at that time there was only, to my knowledge, one woman professor at Harvard, and she, a very successful astronomer, was from Russia.[49] One indeed might conclude that there was not much chance of success along traditional graduate lines. On the other hand, one did see practicing physicians, though admittedly not many. The current scene is one of women succeeding in biology all over the place."

A few of the first fellows reported that, although they had entered graduate school intending to pursue careers in industry, their fellowship years convinced them to turn to academic careers instead. In contrast, George W. Parshall recalled that:

> the academic progress and the financial freedom afforded by the fellowship gave me the liberty to explore a career in industry through summer employment. With the concurrence of my advisor, I accepted an offer from the Chemical Department of the DuPont Company to spend the summer of 1953 at their Experimental Station in Wilmington, Delaware. That summer was an eye-opener! I was assigned to work with a team of chemists who were exploring the chemistry of a newly discovered compound, dicyclopentadienyliron, later dubbed ferrocene.

That experience also convinced Parshall to pursue a research career with DuPont after receiving his doctorate from the University of Illinois in 1954.

Certainly many of the recipients benefited personally, and most continue to be grateful for the opportunity given them almost one-half century ago. Harry R. Powers, Jr., who received his doctorate in plant pathology from North Carolina University in 1953 and has recently retired after his career with the U.S. Forest Service, recalled that, in the spring of 1952,

> I was in the second year of my Ph.D. program. However, my family had quite a few medical bills that year, and as was usually the case, we had no medical insurance. I could see no way out except to leave school and get a job. Fortunately, our department head had encouraged all of the graduate students to take the test, a hard 8 hours as I recall [the Graduate Record Examination, the primary basis for the selection of fellows during the first year]. When the telegram came saying that I had received the award, I canceled plans to drop out of school since the fellowship provided more than I had been getting.

Responses from several members of the Class of '52 expressed gratitude to NSF for having helped them launch their careers in science and engineering, a few regretting that they had not done so years earlier. Daniel Lednicer, who received his doctorate in chemistry from Ohio State University in 1954 and went on to pursue a career as a research chemist at the National Cancer Institute, was among those who decided not to wait—and to go straight to the top at that. "Sometime in the spring of 1954," as he recalled,

> renewal of the NSF fellowship for a third year came through. I was wakened bright and early on the morning following the

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[49] Nachmias was probably referring to Ceceilia Helene Payne-Gaposchkin, originally from the United Kingdom and a protege of Harlow Shapley; her husband Serge was a White Russian immigrant who worked at the Harvard College Observatory as an astronomer also.

> party to celebrate the event by a reporter from the *Columbus Dispatch*. I must have been less than sharp in answering his questions. That renewal did make me realize that it would be appropriate to thank someone for this generous support of my graduate studies. The man who had proposed NSF and steered the bill through Congress was none other than the immediate past President, Harry S Truman, a man whom I admired even back in 1954. So a letter expressing my appreciation went off to him that summer. A letter in an expensive looking envelope with a Kansas City return address arrived in early October.

Lednicer made available a copy of that letter, whose tone is quintessentially Trumanesque:

> *October 2, 1954*
>
> *Dear Mr. Lednicer:*
>
> *Your good letter of September 21 was very much appreciated.*
>
> *I always knew that the Science Foundation would do a great amount of good for the country and for the world. It took a terrific fight and three years to get it through the Congress, and some smart fellows who thought they knew more than the President of the United States tried to fix it so it would not work.*
>
> *It is a great pleasure to hear that it is working and I know it will grow into one of our greatest educational foundations.*
>
> *Sincerely yours,*
>
> */s/ Harry S Truman*

One thing that is obvious is that the past 50 years' investments in research and education have been an excellent investment in people, ideas, and tools. It is hoped that the next 50 years will be equally as productive and exciting.

Enduring Themes: Continuity and Change

The 1948 and 1998 speeches delivered by Presidents Truman and Clinton, compared and contrasted in an earlier section, qualify as significant indicators of the science policy priorities of those respective presidents. But presidential addresses are rare and subject to time constraints. As a result, only the most essential of their priorities can be presented in public forums.

A comparison of other documents from the 1940s and the current time of transition reinforce a conclusion reached in comparing the speeches made by President Truman and by President Clinton 50 years later: namely, that whereas there is an enduring quality to the science policy themes articulated a half-century ago, changes have also occurred within those overarching themes. In some cases, issues associated with a particular theme have not changed a great deal. In other cases, the character of the issues are very different, reflecting the largely unpredictable changes that have occurred both as a result of advances in science and engineering, and in the social, political, and economic contexts in which science and engineering activities take place.

Examples of the enduring character of many science policy themes, along with changes in emphasis, can be discerned by comparing some of the principal themes presented in *Science—The Endless Frontier* and *Science and Public Policy* with those presented in *Science in the National Interest* and *Unlocking Our Future,* in addition to those discussed in greater detail in subsequent chapters of *Science and Engineering Indicators – 2000.*

Support and Performance of R&D

National R&D Expenditures

Science and Public Policy included data on estimated U.S. R&D expenditures for 1947 (Steelman 1947, vol. I, 12, table II). (See text table 1-3.) The approximately $1.2 billion expended during that year was a record high. Nevertheless, the report argued that a national research program that would be adequate to address the Nation's needs would require that those expenditures double by 1957 so that they would then constitute 1 percent of national income (that is, GDP).

Today, total national R&D expenditures for 1998 were estimated at $220.6 billion, or 2.61 percent of GDP.[50] (See chapter 2.)

Sources of R&D Expenditures

Science—The Endless Frontier included pre-World War II data on sources of national R&D expenditures (Bush 1945a, 86), and *Science and Public Policy* included similar data for 1947 (Steelman 1947, vol. I, 12). According to the former, industry accounted for almost 68 percent of total national R&D expenditures in 1940, with the Federal Government accounting for about 19 percent, universities for 9 percent, and other sources for about 4 percent. (See text table 1-3 and figure 1-2.) During World War II, the Federal Government became the dominant supporter of R&D, a condition that continued during the early postwar years. In 1947, according to the Steelman report, the Federal Government accounted for approximately 54 percent of national R&D investments and industry for about 40 percent, with universities and other sources each contributing less than 4 percent. (See text table 1-3.)

After the end of World War II in 1945, industrial R&D investments increased, while Federal expenditures declined so that by the end of the decade industry was once again the leading supporter of R&D in the country. The Korean War, which began on June 25, 1950, a few days before the start of FY 1951, led to a rapid increase in defense R&D expenditures so that, beginning in 1951, Federal contributions exceeded those of industry. That situation continued until 1980, when industrial R&D investments equaled and then began to exceed those of the Federal Government. (See text table 1-3 and figure 1-2.) Since 1990, Federal R&D expenditures measured in constant dollars have declined, while those of industry, universities and colleges, and other sources have continued to increase. In 1998, industry accounted for 65.1 percent of

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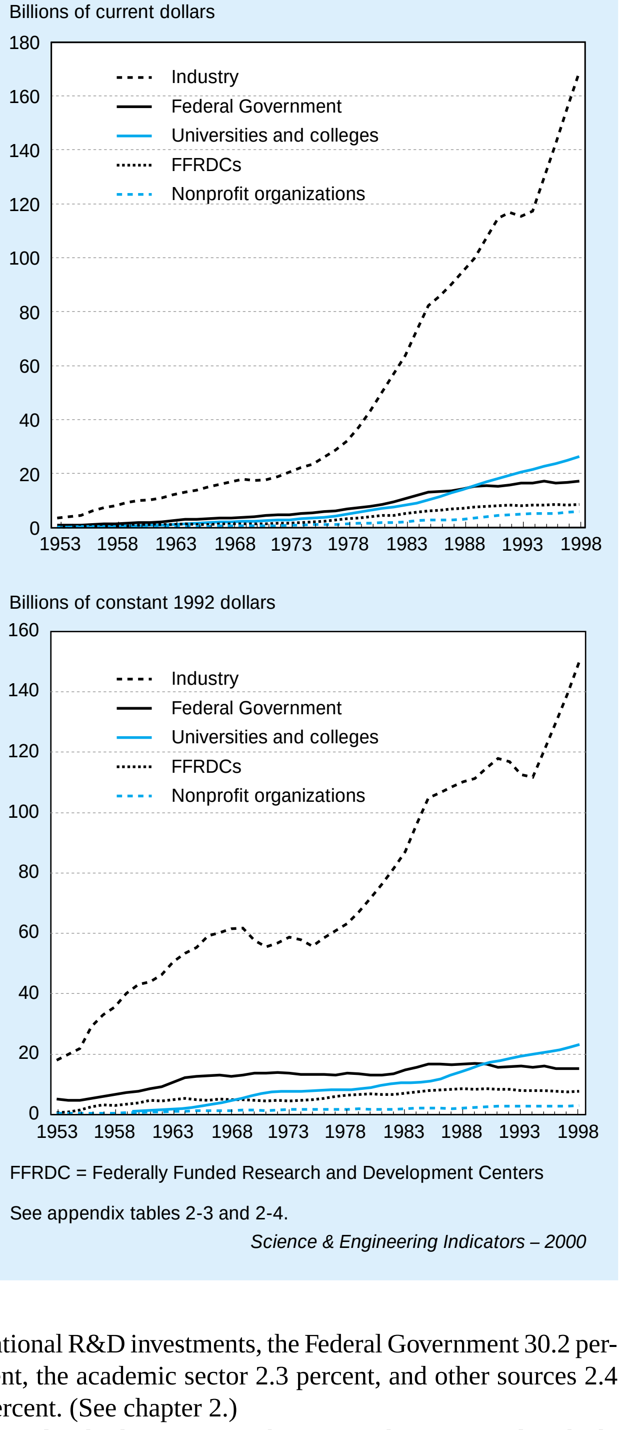
[50] Because U.S. Government accounting conventions changed during the early 1950s, precise comparisons of current R&D expenditure levels with those in the 1940s and earlier are difficult to make. (See footnote 43.)

Figure 1-2.
National R&D performance, by type of performer: 1953–1998



FFRDC = Federally Funded Research and Development Centers

See appendix tables 2-3 and 2-4.

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national R&D investments, the Federal Government 30.2 percent, the academic sector 2.3 percent, and other sources 2.4 percent. (See chapter 2.)

Today, both *Science in the National Interest* and *Unlocking Our Future* emphasized that Federal Government R&D expenditures will remain constrained during the foreseeable future and that industry will continue to be the dominant funder of R&D. Both also noted the importance of the complementary support roles of government and industry in maintaining the vitality of the total national science and engineering system.

Role of Nonprofit Organizations

A unique aspect of the U.S. system is the role that nonprofit organizations play in the support and conduct of research. One of the four committee reports appended to *Science—The Endless Frontier* included pre-World War II expenditure estimates for research support by nonprofit organizations (Bush 1945a, 86). In 1940, these amounted to approximately $4.5 million, compared with an estimated $31.5 million expended by universities for their research. *Science and Public Policy* acknowledged that, although nonprofit organizations had played important roles in supporting basic research, their expenditures were unlikely to increase significantly (Steelman 1947, vol. I, 27). This assertion provided one basis for the argument that a stronger Federal role in basic research support was essential.

Today, nonprofit organizations accounted for an estimated $3.4 billion in R&D expenditures in 1998, compared with the approximately $5.0 billion expended for R&D by universities and colleges from their own sources. Research facilities operated by nonprofit organizations received an estimated $2.9 billion in Federal support for their research during that same year. These facilities occupy a unique, important niche in the national research system. After having been eclipsed as significant sources of research support, nonprofit organizations and their strategic roles are again being recognized—particularly in technology development and health-related research. For this reason, NSF is currently conducting a substantial study that aims to determine in more detail the current roles of nonprofit organizations in the U.S. science and engineering enterprise. (See chapter 2.)

Defense R&D

The importance of scientific research and engineering development to national security has been among the most enduring science policy themes. *Science—The Endless Frontier* recommended that a Division of Defense Research should be established within the proposed National Research Foundation and allocated approximately 30 percent of its budget during the first year, decreasing in relative terms to about 16 percent by the fifth year (Bush 1945a, 40). (See text table 1-5.) This division would have been authorized to support defense-related research in civilian institutions without recourse to, or approval by, any military authority.

By contrast, *Science and Public Policy* argued that Federal R&D allocations were distorted, with defense-related expenditures too large relative to nondefense components. In 1947, the combined R&D budgets of the War and Navy departments accounted for 80 percent of all Federal R&D expenditures. (See text table 1-4.) The report recognized that the absolute level of defense R&D was probably appropriate and that there was no short-term prospect for any significant reduction (Steelman 1947, vol. I, 21–3). Therefore, it recommended that, over the long term, greater emphasis should be placed on increasing other components of the Federal R&D budget so that by 1957, defense R&D would account for 22 percent of the total.

Today, both defense and nondefense R&D expenditures have grown to levels vastly higher than envisaged 50 years

Text table 1-5.
Proposed National Research Foundation budget
In millions of U.S. dollars

Activity (by division)	First year 1945 current	 1998 constant	 Percent	Fifth year 1945 current	 1998 constant	 Percent
Medical research	5.0	41.3	14.9	20.0	165.4	16.3
Natural sciences	10.0	82.7	29.9	50.0	413.4	40.8
National defense	10.0	82.7	29.9	20.0	165.4	16.3
Scientific personnel and education	7.0	57.9	20.9	29.0	239.8	23.7
Publications and collaboration	0.5	4.1	1.5	1.0	8.3	0.8
Administration	1.0	8.3	3.0	2.5	20.7	2.0
Total	33.5	277.0	100.0	122.5	1,012.9	100.0

NOTE: Details may not sum to totals because of rounding.

SOURCE: Vannevar Bush, *Science—The Endless Frontier: A Report to the President on a Program for Postwar Scientific Research* (1945a). Reprinted by NSF (Washington, DC: 1990).

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ago, each responding to changing needs and opportunities.[51] During the Strategic Defense Initiative era of the 1980s, defense R&D expenditures accounted for almost 80 percent of the total Federal R&D budget. But that situation has changed. The fraction of defense R&D in the Federal R&D budget, which by 1989 had declined to approximately 61 percent of all Federal R&D expenditures, continued to decline to 48.5 percent in 1997. The Clinton Administration's budget for fiscal year 2000 proposed expending $35.1 billion for defense R&D, or 44.5 percent of the $78.2 billion proposed for total Federal R&D expenditures.[52] (See chapter 2.)

Health-Related Research

Among the unique characteristics of the U.S. system is the high level of support that the Federal R&D budget allocates to health-related research. But this was not the case in the late 1940s. One of the four committee reports appended to *Science—The Endless Frontier* dealt exclusively with health research and laid particular emphasis on the need to increase support for basic research underlying medical advances (Bush 1945a, 46–69). The body of the report recommended that a Division of Medical Research should be established within its proposed National Research Foundation and allocated 15 to 16 percent of its total budget (Bush 1945a, 40). (See text table 1-5.) *Science and Public Policy* argued that Federal investments in health-related research were inadequate. It recommended that these investments should be tripled during the next 10 years so that they would then constitute 14 percent of the Federal R&D budget (Steelman 1947, vol. I, 28).

Today, health-related R&D accounts for the largest fraction of the Federal nondefense R&D budget. In FY 1999, the R&D budget of the Department of Health and Human Services was $15.8 billion—almost 20 percent of total Federal R&D budget, and slightly less than 38 percent of Federal nondefense R&D (NSF 1998). *Science in the National Interest* assigned a high priority to health as a core element of the national interest, emphasizing that a wide range of scientific disciplines, including the physical, social, and behavioral sciences, in addition to the biomedical sciences, make essential contributions (Clinton and Gore 1994, 3). (See chapter 2.)

Centrality of the University System

Support for University Research

Science—The Endless Frontier's recommendation that the Federal Government should assume major responsibility for supporting research in universities was, of course, its most novel feature; the proposed National Research Foundation was to be the principal means for discharging this new function. Bush proposed that the budget for the new agency should be $33.5 million for the first year, rising to a steady state level of $122.5 by the fifth year (Bush 1945a, 40). (See text table 1-5.) These amounts were to be allocated to research in all fields of science, including defense and medical research (but excluding the social sciences) and to a scholarship and fellowship program.

Science and Public Policy also emphasized the Federal role in supporting university research. Following Bush, it recommended the creation of a National Science Foundation, but excluded the defense research support function proposed by Bush, while explicitly including support for the social sciences.[53] The report recommended that the initial budget of the proposed National Science Foundation should be $50 mil-

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[51] Compare this with Office of Science and Technology Policy (1995). This policy document, based on a White House Forum held at NAS March 29–30, 1995, considered environmental and economic security issues as well as military security.

[52] *Budget of the United States Government for Fiscal Year 2000*, Executive Summary, p. 107, table 7-1.

[53] See Steelman (1947, vol. I, 31–2). Section 3(a)(2) of the National Science Foundation Act of 1950 "directed and authorized" the Foundation to support research in the "mathematical, physical, medical, biological, engineering, and other sciences." The 1968 Daddario Amendments to the National Science Foundation Act added the social sciences to this enumeration.

lion, rising to $250 million after 10 years when it should account for 20 percent of the total Federal R&D budget.

Today, because recommendations from these key policy documents of the early transition period were taken seriously, universities have come to occupy the vital center of the U.S. national research system, a situation which is unique to the United States. Both *Science in the National Interest* and *Unlocking Our Future* explicitly recognize their central roles, and there is a widespread consensus about the need to provide adequate support for university research. Issues now have to do with the balance of support for academic research among fields and disciplines. The significance of interdisciplinary research to address national objectives is increasingly stressed, as is the importance of research in the social and behavioral sciences.[54] (See chapter 6.)

Support for University Research Facilities

One of the four committee reports appended to *Science—The Endless Frontier* included pre-World War II data on capital expenditures for university research (Bush 1945a, 87). *Science and Public Policy* emphasized that "additional libraries, laboratory space and equipment are urgently needed, not only in terms of the [report's] contemplated program of basic research, but to train scientists for research and development programs in the future" (Steelman 1947, vol. I, 37). It urged that provision be made for Federal aid to educational institutions for the construction of facilities and the purchase of expensive equipment.

Today, there is still concern about the adequacy of academic research facilities. As evidence of the bipartisan character of its interest, Congress requires NSF to issue a periodic report on the state of academic facilities for basic research. (See chapter 6.)

Human Resources for Science and Engineering

Supply and Demand for Scientists and Engineers

The deficit of trained scientists and engineers resulting from World War II was one of the primary concerns of both *Science—The Endless Frontier* and *Science and Public Policy.* The Bush report included a section on this problem, entitled "Renewing our Scientific Talent" (Bush 1945a, 23–7). A chapter on human resources in volume I of the Steelman report estimated that there was at that time (1947) a deficit of 90,000 scientists at the bachelor's level and 5,000 at the doctoral level (Steelman 1947, vol. I, 15–23). It went on to estimate, on the basis of demographic data, that it would require 10 years before the numbers of scientists at these two levels would reach the numbers that might have reasonably been expected if World War II had not intervened. By the mid-1950s these deficits had largely been alleviated, thanks in part to educational support provided to returning veterans by the GI bill of rights and, beginning in the early 1950s, to Federal Government predoctoral and postdoctoral fellowship programs.[55]

Today, demand for scientists and engineers continues to be high, although there is considerable variation by field and sector. Unemployment rates for this population are consistently lower than for persons trained at similar levels in other fields, while employment in the science and engineering sector is projected to increase at more than three times the rate for all occupations. (See chapter 3.)

Research by Academic Faculty

Science and Public Policy paid particular attention to human resources in the academic sector. It emphasized the importance of the links between research and teaching responsibilities of faculty in U.S. colleges and universities that had both research and teaching responsibilities, but the conditions then prevailing in those institutions frequently did not permit faculty to exercise those responsibilities effectively (Steelman 1947, vol. I, 19–20). Teaching loads had increased significantly since the end of World War II as a result of the doubling of the number of science and engineering students—many of them returning veterans—over prewar levels. One result was a diminished capacity for research in the academic sector. The report estimated that it would take 15,000 additional qualified science and engineering instructors to restore the prewar student–teacher ratio in U.S. colleges and universities.

Today, tenure track positions in colleges and universities are highly competitive. This has led to considerable demoralization among younger scientists, owing to diminishing opportunities to obtain positions either in academia or industry where they can continue to pursue the type of basic research they performed as graduate students. The amount of research experience required to qualify for a tenure track position has continued to increase. As a result, a large percentage of recent Ph.D.s aspiring to academic careers hold postdoctoral positions, which were relatively rare in the 1940s. There is widespread concern that academia is "overproducing" Ph.D.s—particularly for academic positions. After years of relative neglect, establishing effective links between research and education has reemerged as a salient policy issue. (See chapter 3.)

Science and Engineering Education at the Undergraduate and Graduate Levels

Science and Public Policy pointed out that the above-noted shortages of qualified science and engineering instructors in U.S. colleges and universities, coupled with increasing enrollments, was also undermining the quality of undergraduate science and engineering education (Steelman 1947, vol. I, 16–20). Neither *Science—The Endless Frontier* nor *Science and Public Policy* considered details of graduate study curricula explicitly. However, the latter included a report commissioned from AAAS on "The Present Effectiveness of Our Schools in the Training of Scientists," which discussed the

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[54] NSF created a Directorate for Social, Behavioral, and Economic Sciences in January 1992.

[55] The first NSF fellowships, consisting of 535 predoctoral and 38 postdoctoral awards, were made in the spring of 1952 at a total cost of $1.53 million, or approximately $8.7 million in constant 1998 dollars (NSF 1952, 55, 75).

recruitment, retention, and support of graduate students in science and engineering (Steelman 1947, vol. IV, 131–40).

Today, after several years of rapid expansion, enrollments in higher education in the United States have leveled off. Issues associated with graduate education in science and engineering remain salient, particularly the retention, training, and support of graduate students.[56] (See chapter 4.)

Foreign Students in U.S. Universities

Science and Public Policy recommended that foreign students should be encouraged to attend U.S. colleges and universities, noting that it might be some time before most of the first-rate European institutions would recover completely from the devastation of World War II (Steelman 1947, vol. I, 39–40). It conceded that the crowded conditions then prevailing at many of these institutions might make it difficult for them to accept too many foreign students. On the other hand, it suggested such a program, which it noted might be supported through the recently established Fulbright Program for International Educational Exchange, would be an important contribution to international goodwill.[57]

Today, foreign-born students are a significant presence in U.S. universities, particularly in science and engineering programs at the graduate level. Asian students predominate. There is some concern about the fact that the number of foreign students in some disciplines is larger (in some cases far larger) than the number of U.S. students. (See chapter 4.)

Elementary and Secondary Education

Both *Science—The Endless Frontier* and *Science and Public Policy* recognized the importance of elementary and secondary education. The former report emphasized that “improvement in the teaching of science is imperative, for students of latent scientific ability are particularly vulnerable to high school teaching, which fails to awaken interest or to provide adequate instruction. To enlarge the group of specially qualified men and women it is necessary to increase the number who go to college” (Bush 1945a, 26). One of its four appended committee reports included a section entitled “The Education Pyramid: Studies Concerning Able Students Lost to Higher Education” (Bush 1945a, 166–76). Although data specific to mathematics and science education were not included, the section urged that improvements in instruction in all subjects were essential if a greater proportion of qualified students were to go on to higher education.

Volume IV of *Science and Public Policy*, which was devoted entirely to human resources for science and engineering, included an extensive survey and analysis of the condition of mathematics, science, and engineering education from the primary through the undergraduate–graduate levels (Steelman 1947, vol. IV, 47–162). This analysis pointed to a number of deficiencies in mathematics and science instruction at the elementary and secondary levels and made specific recommendations for remedial action.

Today, student achievement, curriculum and instruction, and teacher preparation have become issues of national importance. Repeated studies during the past three decades indicate that U.S. students do not perform as well in mathematics or science as do their peers in many other nations. More recent studies point to a far less challenging curriculum and less demanding instructional practices as key factors in that performance. Minority students and women tend to perform less well and to take fewer demanding mathematics and science courses. (See chapter 5.)

Significance of Industrial R&D

R&D and Economic Growth

Both *Science—The Endless Frontier* and *Science and Public Policy* emphasized the importance of R&D to economic growth. The former dealt with the theme in terms of science, technology, and job creation noting that,

> one of our hopes is that after the war there will be full employment, and that the production of goods and services will serve to raise our standard of living. There must be a stream of new scientific knowledge to turn the wheels of private and public enterprise. There must be plenty of men and women trained in science and technology for upon them depend both the creation of new knowledge and its application to practical purposes (Bush 1945a, 6).

Science and Public Policy approached the economic growth theme in terms of U.S. leadership stressing that, “if we are to remain a bulwark of democracy in the world, we must continually strengthen and expand our domestic economy and our foreign trade. A principal means to this end is through the constant advancement of scientific knowledge and the consequent steady improvement of our technology” (Steelman 1947, vol. I, 3–4).

Today, the importance of science-related and high-technology industries in terms of both job creation and international standing is widely recognized. (See chapter 7.) *Science in the National Interest* emphasized prosperity as a core element of the national interest, stating that “Prosperity requires technological innovation. Basic scientific and engineering research is essential for training innovative scientists and engineers, for many technology improvements, and for achieving the revolutionary advances that create new industries” (Clinton and Gore 1994, 4).

Domestic Competition

Science and Public Policy gave several reasons for the impressive increase in industrial R&D expenditures during the two years since the end of World War II. In particular, it noted that “competition, in many instances, is forcing a rapid exploitation of scientific advances” (Steelman 1947, vol. I, 22).

Today, successful competition in the domestic market relies heavily on industrial R&D investments. *Unlocking Our Future* noted that:

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[56] See, for example, NSB (1997).

[57] An Act To Amend the Surplus Property Act of 1944 To Designate the Department of State as the Disposal Agency for Surplus Property Outside the United States. Public Law 79-584, enacted August 1, 1946. Senator William J. Fulbright of Arkansas introduced provisions in this legislation to permit the use of U.S.-owned foreign currency for educational exchanges.

> Today's technology-driven company must bridge the research gap between basic science and product development if it wants to remain on the cutting edge of the industry. This research is typically necessary to develop basic research results into an emerging technology and then into a marketable product (U.S. House of Representatives Science Committee 1998, 24).

Increasing competition has led to a fundamental structural change in the character of industrial research. Formerly, a good deal of that research, including a reasonable amount of basic research, was conducted in centralized corporate laboratories. However, most of that research has been divested to individual business units on the grounds that research results can thereby be captured more immediately and effectively for commercial developments. The decline of corporate research laboratories as performers of basic research has increased the importance of university basic research to industry, indicating the need for effective partnerships between these two sectors. (See chapter 7.)

International Competition

Science and Public Policy emphasized that the economic and technological supremacy that the United States enjoyed in 1947 was a partial result of the wartime devastation that other industrialized countries had experienced. It went on to warn that,

> the future is certain to confront us with competition from other national economies of a sort we have not hitherto had to meet. Many of these will be state-directed in the interest of national policies. Many will be supported by new, highly efficient industrial plant and equipment—by the most modern technology. The destructiveness of the recent war makes it inevitable that much of Europe, in rebuilding its factories, will soon possess an industrial plant more modern than ours today (Steelman 1947, vol. I, 4).

Today, high-technology exports are a critical contributor to the U.S. balance of trade. The United States is dominant in the export of technology. However, in some vital areas of technology, the capabilities of Japan or one or more European countries are at least on a par with those of the United States, and in a few cases may actually exceed those of this country. High-technology competition from several emerging economies is also increasing. (See chapter 7.)

The Federal Role

Support for Science and Engineering Students

Both *Science—The Endless Frontier* and *Science and Public Policy* recommended that the Federal Government should establish undergraduate scholarship and graduate fellowship programs as a means to alleviate the wartime deficit of scientists and engineers (Bush 1945a, 26–7; Steelman 1947, vol. I, 7). Both emphasized that, in addition to helping relieve the deficits, an undergraduate scholarship program would make it possible for all qualified students to obtain a college education even if their families lacked the requisite financial resources. For that reason, both recommended that the scholarship program should encompass fields other than science and engineering. The recommended undergraduate scholarship programs were never implemented in the form recommended by the two reports. However, Title II of the Servicemen's Readjustment Act of 1944, commonly known as the GI bill of rights, provided support for returning veterans to attend college and led to the results that both reports had hoped would occur—namely, the democratization of U.S. higher education.[58]

Today, the democratization of higher education has improved, in the sense that more qualified students are able to obtain an education at the undergraduate level. Nonetheless, there are serious concerns about unevenness in demographic representation in science and engineering fields, particularly for women and for racial and ethnic minorities. (See chapter 4.) Additionally, there are continuing problems with and differences in the quality of K–12 education throughout the Nation, a factor influencing access to higher education. (See chapter 5.)

Federal Role Vis-à-Vis Industrial Research

Then as now, the appropriate role of the Federal Government *vis-à-vis* the industrial research sector was an issue of primary importance. *Science—The Endless Frontier* took the position that the Federal Government should not provide direct financial support for nondefense research in industry, nor interfere in any way with industry's prerogative to determine its own research priorities and directions. It asserted that "the simplest and most effective" way that government could assist industry would be to support basic research in universities and help ensure that there would be an adequate number of trained scientists and engineers. The report also recommended clarification of the tax code on the matter of the deductibility of R&D expenditures and a simplification of the patent system to reduce the cost of patent filing, in part because filing costs often discouraged businesses from investing in R&D (Bush 1945a, 21).

While agreeing that industry should determine its own research priorities, *Science and Public Policy* was more flexible on the matter of Federal support. In fact, it argued that Federal Government expenditures for nondefense development were too small relative to its defense expenditures. The report noted that, of the estimated $625 million expended by the Federal Government for R&D in contracts to industrial and university laboratories in 1947, $500 million was accounted for by the Departments of War and Navy.[59] (See text table 1-4.) In addition to increasing support for university research by a factor of four by 1957, it recommended doubling support for nondefense development so that it would constitute 44 percent of the Federal R&D budget by that same year (Steelman 1947, vol. I, 28).

Today, both *Science in the National Interest* and *Unlocking Our Future* emphasized intersectoral partnerships and alliances as key elements in a vital national research system. The importance and legitimacy of the Federal role in cata-

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[58] Public Law 78-346, enacted June 22, 1944.

[59] The Departments of War and Navy were combined into the Department of Defense in 1947.

lyzing and facilitating partnerships and alliances is widely accepted. In addition, there are also a few relatively modest Federal programs to provide partial support for particularly risky research in industry. (See chapter 7.)

Coordination of Federal Research Policy and Programs

Volume II of *Science and Public Policy* was devoted entirely to "The Federal Research Program," while volume III dealt with "Administration for Research." The principal conclusions of these volumes were summarized in a chapter in the first, summary volume titled "Federal Organization for Science" (Steelman 1947, 61–7). This chapter recommended that "(1) An Interdepartmental Committee for Scientific Research should be created; (2) The Bureau of the Budget should set up a unit for reviewing Federal scientific research and development programs; and (3) The President should designate a member of the White House staff for scientific liaison."

Today, all of these recommendations have been implemented. The functions of the Interdepartmental Committee for Scientific Research and Development, which was created in December 1947 and became the Federal Coordinating Committee for Science and Technology in November 1957, were later expanded and subsumed by the FCCSET, which was established in 1976 by the same Act of Congress that created the OSTP.[60] In 1993, FCCSET was subsumed in turn into the NSTC, which is chaired by the President and includes the heads of all Federal agencies and bureaus with significant science and technology responsibilities, as well as other Federal Government officials—most prominently the President's Assistant for Science and Technology (commonly known as the President's Science Advisor) and the director of the Office of Management and Budget. These two officials have been working together closely for several years to develop a coherent Federal R&D budget aimed at addressing administration science and technology priorities. At the beginning of each annual budget cycle, they co-sign a letter to the heads of all relevant agencies that contains instructions relevant to the preparation of budget proposals in specific categories related to the priorities and strategic goals of the Administration. The Congress also remains concerned with the problem of ensuring that the Federal Government's science and technology programs effectively address significant national issues, as evidenced most recently in *Unlocking Our Future* (U.S. House of Representatives Science Committee 1998).

International Considerations

International Aspects of U.S. Science Policy

Science and Public Policy recommended that, as part of the Marshall Plan proposed by Secretary of State George C. Marshall at the June 5, 1947, Harvard University commencement, "every effort [should] be made to assist in the reconstruction of European laboratories" (Steelman 1947, vol. I, 7). It also recommended that scientific missions should be established in U.S. embassies in scientifically important countries and that foreign students should be encouraged to study in U.S. universities (Steelman 1947, vol. I, 38–40). *Science—The Endless Frontier* emphasized the importance of international exchange of scientific information to the U.S. research enterprise (Bush 1945a, 22). It recommended Federal Government support for (1) American scientists to attend international scientific meetings abroad, (2) visits to the United States by prominent foreign scientists, (3) international fellowships for U.S. scientists, and (4) translation services.

Today, the global character of science and technology is evident from R&D investments in other countries which, particularly among a majority of the G-7 countries (Canada, France, Germany, Italy, Japan, and the United Kingdom, in addition to the United States), include substantial industrial as well as government components. (See chapter 2.) The substantial research and educational resources and science and engineering talent existing in countries throughout the world has enhanced opportunities for mutually beneficial international cooperation involving university and industry researchers, including research experience for graduate students and postdoctoral researchers.[61]

Beginning in the early 1950s, *Science and Public Policy*'s recommendation that scientific missions should be established in important U.S. embassies abroad began to be implemented with the appointment of Science and Technology Counselors in many of these missions. However, the number of these positions has declined considerably during the 1990s, as has the importance accorded science and technology as elements of U.S. foreign policy.[62]

Research in the Soviet Union/Russia

Science and Public Policy pointed to the Soviet Union as the principal scientific competitor of the United States, noting that its 1947 R&D budget reportedly had increased to $1.2 billion as compared with outlays of $900 million in 1946 (Bush 1945a, 5–6). It also remarked that the country had embarked upon a five-year program of stepped-up training for scientists and engineers.

Today, the Soviet Union no longer exists as a political entity. R&D expenditures in Russia (which contained the major concentration of the Soviet Union's scientific resources) have declined sharply from an estimated 2.03 percent of GDP in 1989 to about 0.73 percent in 1995. Knowledgeable U.S. observers continue to regard Russia as a scientifically and technologically significant country, noting its substantial and important past contributions to research in many disciplines. Yet they also emphasize that the country must resolve formidable economic problems before it can once again make sub-

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[60] Public Law 94-282.

[61] Several NSF programs facilitate research experiences abroad at the graduate and postdoctoral and, to some extent, the undergraduate level as well. NSF's overseas offices in Tokyo and Paris issue frequent reports on research opportunities in Japan and Europe.

[62] Compare this with the Carnegie Commission on Science, Technology, and Government (1992); Watkins (1997, 650–1); U.S. House of Representatives Science Committee (1998, 22–4).

stantial contributions to the global science and technology enterprise. (See chapter 2.)

Significance of Developing Countries

The Steelman report pointed to India as a country where progress was being made in the construction of new scientific research laboratories and in the training of first-rate researchers (Steelman 1947, vol. I, 41). It predicted that similar developments could be anticipated in China and in Latin America.

Today, the developed countries (primarily the United States and Canada, Western Europe, and Japan) still account for by far the largest fraction of the world's R&D expenditures, with the United States, Japan, Germany, France, and the United Kingdom expending more than 2 percent of GDP for these purposes. By contrast, the R&D expenditures of China, India, and Brazil, for example, are estimated to be somewhat less than 1 percent of their GDPs. Despite their relatively modest R&D investments, all three countries have produced world-class scientists and engineers and have developed impressive, competitive capabilities in several important areas. Many scientists and engineers from the United States and other developed countries have enjoyed cooperative working relations with colleagues from these and other developing countries for several years. (See chapters 2, 4, 6, and 7.)

Public Attitudes and Understanding of Science and Technology

Although the analysis of mathematics and science education by AAAS included in *Science and Public Policy* dealt primarily with the production of professional scientists and engineers, a section entitled "Science and General Culture" also emphasized the importance of science education for nonspecialists. It suggested that "maintenance of the crucially necessary supply of research talent, and integration of the sciences into a sound ethical structure of society without which civilization cannot survive, are both dependent upon adequate representation of science in our educational system"(Steelman 1947, vol. IV, 113).

Today, both *Science in the National Interest* and *Unlocking Our Future* emphasized the importance of public attitudes and understanding both to the vitality of the science and engineering enterprise and to the Nation, particularly since understanding many significant national issues requires some familiarity with science and technology. It has also been recognized that the level of public understanding of adults is strongly correlated with the adequacy of the science and mathematics education they receive at the primary and secondary school levels.[63] Bipartisan support is evidenced by the consistently high level of NSF's annual education and human resources appropriations, $689 million in FY 1999. (See chapter 8.)

Impacts of Information Technology

Had the term "information technology" been in use in the 1940s, it might well have referred to developments in communications technology—namely, radio and perhaps even television—that had been successfully demonstrated immediately before the outbreak of World War II but were not commercialized until a few years later. *Science—The Endless Frontier* did cite radio as one of several technologies whose widespread commercialization occurred after the end of World War I. It did so to suggest, by inference, that new and at that time (1945) unimagined technologies would almost certainly result from the applications of post-World War II research. However, neither the Bush nor the Steelman reports speculated about what those future technologies might be.

But on a personal level, Vannevar Bush foresaw the development of what is now called the digital library. In an article published in the Atlantic Monthly in July 1945 (the same month that *Science—The Endless Frontier* was delivered to President Truman), Bush invited his readers to …

> Consider a future device for individual use, which is a sort of mechanized private file and library. It needs a name, and to coin one at random, "memex" will do. A memex is a device in which an individual stores all his books, records, and communications, and which is mechanized so that it may be consulted with exceeding speed and flexibility. It is an enlarged intimate supplement to his memory (Bush 1945b).

Today, information technology, based on a merging of computer and communications technologies, has become ubiquitous. Information technology has had an impact on virtually all sectors of our economy and society, including the conduct of research, as well as on our daily lives. The digital libraries that Bush foresaw more than a half-century ago are becoming a reality, even though based on very different technologies than he envisioned. Nor did he foresee the possibilities that digital libraries separated by great spatial distances could be linked electronically and accessed from other distant locations. (See chapter 9.)

Current Emerging Themes

As discussed in "A Program for the National Science Foundation," the NSB determined during its first year that one of its major responsibilities would be to ensure that the condition of the U.S. (and global) science and technology enterprise would be monitored. Since 1972, its *Indicators* reports have been the most visible manifestation of that determination. The NSB published a strategic plan in November 1998 that emphasized its commitment to *Science and Engineering Indicators* as an instrument for assessing the overall health of the enterprise and for providing a robust basis for decisionmaking in national science and engineering policy, as well as its determination to continually improve this instrument to serve these objectives (NSB 1998c). These reports have also provided the Board with opportunities to point to both emerging themes and to emphasize transmutations in the more traditional themes that began to be evident 50 years ago.

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[63] The widespread consensus about the importance of science and mathematics education at the primary, secondary, and undergraduate levels is suggested by the fact that NSF's annual budget for education and human resource development currently exceeds $600 million.

Among the emerging themes that the Board has identified (NSB 1998c) as important in the first decade of the 21st century are:

- globalization of research and education,
- access to and impacts of information technologies,
- environmental research and education,
- knowledge-based economy,
- partnerships and linkages,
- adequacy of the supply of well-trained scientists, engineers, and science teachers,
- education as a key determinant of social and economic progress,
- special significance of K through 12 education,
- public understanding of science and technology, and
- accountability.

Plans to address these themes are laid out in the NSB Strategic Plan (NSB 1998c). Additionally, several of these themes have been addressed by previous NSB Statements and Occasional Papers; for example:

- "Science in the International Setting" (NSB 1982),
- "In Support of Basic Research" (NSB 1993a),
- "Federal Investments in Science and Engineering" (NSB 1995),
- U.S. Science and Engineering in a Changing World (NSB 1996b),
- The Federal Role in Science and Engineering Graduate and Postdoctoral Education (NSB 1997),
- "Failing Our Children: Implications of the Third International Mathematics and Science Study" (NSB 1998a),
- "Industry Trends in Research Support and Links to Public Research" (NSB 1998b), and
- "Revised Interim Report: NSB Environmental Science and Engineering for the 21st Century" (NSB 1999a).

The Board plans to issue additional occasional papers on several of these issues during the next few years.

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Chapter 2

U.S. and International Research and Development: Funds and Alliances

Contents

Highlights

National Trends in R&D Expenditures

- **Total annual research and development (R&D) expenditures in the United States were $227 billion in 1998 by current estimates.** This level of R&D expenditure represents a 6.5 percent increase, after adjusting for inflation, over the $211 billion spent in 1997. In turn, the 1997 estimate represents a 5.5 percent increase over the 1996 level after adjusting for inflation.

- **The entire economy of the United States, as measured by gross domestic product (GDP), was estimated to reach $8,509 billion in 1998.** Adjusted for inflation, GDP increased by 3.9 percent per year in 1997 and 1998. Such growth in GDP is exceptionally high, yet it is slower than the growth of R&D. R&D has generally been outpacing the overall growth of the economy since 1994. As a result, R&D as a proportion of GDP has been on the rise as well—from 2.43 percent in 1994 to 2.67 percent in 1998.

- **Despite this recent increase, the R&D share of GDP (2.67 percent in 1998) is still below levels reached in the early 1990s** (e.g., 2.72 percent in 1991). Since 1957, the highest R&D/GDP ratio was 2.88 percent in 1964; the low was 2.13 percent in 1978.

- **Since 1980, industry has provided the largest share of financial support for R&D. Industry's share of funding for R&D was projected to reach $150 billion in 1998, or 66 percent of the total.**

- **Industrial R&D performance—predominately "development"—grew by only 0.7 percent per year in inflation-adjusted ("real") terms from 1985 to 1994.** From 1994 to 1998, that growth rate increased to 7.6 percent annually in real terms.

- **The most striking change in industrial R&D performance during the past two decades may be the nonmanufacturing sector's increased prominence.** Prior to 1983, nonmanufacturing industries accounted for less than 5 percent of the industry R&D total. By 1993, this percentage had risen to an all-time high of 26 percent. It has fallen only slightly since then and has remained above 22 percent.

- **Federal R&D support in 1998 reached $67 billion, as reported by performers doing the work.** The Federal Government once was the main provider of the Nation's R&D funds—accounting for as much as 67 percent in 1964. Its share of support first fell below 50 percent in 1979, and it remained between 45 and 47 percent from 1980 to 1988. Since 1988 it has fallen steadily to 29.5 percent in 1998—the lowest ever recorded in the National Science Foundation's (NSF) data series (which began in 1953).

- **The provision of Federal R&D obligations is concentrated from several agencies.** Six Federal agencies had R&D obligations of more than $1 billion in FY 1998, out of the total Federal R&D obligations of $72.1 billion. These six agencies are, in descending order of R&D obligations, the Department of Defense (DOD) (with a 48.3 percent share of the total), the Department of Health and Human Services (HHS) (19 percent), the National Aeronautics and Space Administration (NASA) (13.7 percent), the Department of Energy (DOE) (8.1 percent), NSF (3.3 percent), and the Department of Agriculture (USDA) (2.0 percent).

- **In contrast to total R&D obligations, only three agencies had intramural R&D expenditures that exceeded $1 billion in 1998, including costs associated with planning and administering extramural R&D programs:** DOD, HHS (which includes the National Institutes of Health), and NASA. These three agencies together accounted for 81 percent of all Federal R&D obligations for 1998 and 77 percent of Federal intramural R&D.

- **State governments also provide funding for R&D activities.** In 1995 (the most recent year for which these data are available), almost 25 percent of the $244 million state-funded, state-performed R&D was health related. Between 1965 and 1995, total state R&D spending increased at an inflation-adjusted average annual rate of 3.3 percent, compared with nationwide R&D spending growth of 2.5 percent per year over the same period.

- **Between 1953 and 1969, R&D expenditures grew at a real annual rate of 8.2 percent.** Starting in 1969 and for nearly a decade thereafter, however, 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 1 percent per year as business and government tended to deemphasize research programs. Between 1975 and 1985, R&D expenditures picked up again, averaging 5.6 percent real growth per year. That rate then slowed to 1.1 percent in 1985–94. In 1994–98, R&D expenditures rose sharply again, averaging 5.8 percent real growth per year. Almost all of the recent growth in national R&D expenditures is the result of a resurgence of industrial R&D.

- **R&D is substantially concentrated in a small number of states.** In 1997, California had the highest level of R&D expenditures—$41.7 billion, representing approximately one-fifth of the $199.1 billion U.S. total that could be attributed to individual states. The six states with the highest levels of R&D expenditures—California, Michigan, New York, New Jersey, Massachusetts, and Texas—accounted for approximately one-half of the entire national effort. The top 10 states—adding, in descending order, Pennsylvania, Illinois, Washington, and Maryland—accounted for approximately two-thirds of the national effort.

- **The United States spent $37.9 billion on the performance of basic research in 1998, $51.2 billion on applied research, and $138.1 billion on development, by current estimates.** These totals are the result of continuous increases over several years. They reflect a 4.7 percent annual increase, in real terms, for basic research; 3.9 percent for applied research; and 3.4 percent for development since 1980. As a share of all 1998 R&D performance expenditures, basic research represented 16.7 percent, applied research 22.5 percent, and development 60.8 percent. These shares have not changed very much over time.
- **R&D in the broad area of the life sciences is characterized by strong and fairly continuous real growth.** Federal obligations for research in the life sciences rose from $8 billion in 1985 (in constant 1992 dollars) to $11 billion in 1996. Company-funded R&D in drugs and medicines grew dramatically in real terms, from $4 billion in 1985 to $10 billion in 1997. Likewise, academic R&D (not Federally funded) in the life sciences and bioengineering/biomedical engineering grew continuously, from $3 billion in 1985 (in constant 1992 dollars) to $5 billion in 1996.
- **Growth in collaborative research is an important trend in R&D activities as a means of synergizing R&D investments.** By the end of 1998, 741 research joint ventures (RJVs) associated with NCRA and the National Cooperative Research and Production Act had been registered. By 1998, however, the number of new RJV filings had fallen sharply to 31 per year, after having reached a peak of 115 in 1996.
- **Cooperative research and development agreements (CRADAs) between Federal agencies and other sectors grew in number geometrically, from 34 in 1987 to 3,688 in 1996 (averaging 68 percent growth per year).** Between 1996 and 1997, however, the number of active CRADAs declined to 3,239.

International Comparisons of National R&D Trends

- **The United States accounts for roughly 43 percent of the industrial world's R&D expenditure total.** U.S. R&D investments continue to outdistance, by more than 2 to 1, R&D investments made by Japan, the second largest performer. Not only did the United States spend more money on R&D activities in 1997 than did any other country, it also spent as much by itself as the other "group of seven" (G-7) countries—Canada, France, Germany, Italy, Japan, and the United Kingdom—combined. In terms of nondefense R&D spending, however, combined expenditures in those six countries exceeded nondefense R&D spending in the United States by 17 percent in 1996.
- **Relative to shares reported in other G-7 countries, U.S basic research spending (17 percent of its R&D total) is less than the shares reported for Germany, France, and Italy (each at 21–22 percent) but higher than the basic research share in Japan (12 percent of its R&D total).** Basic research accounts for 18 percent of Russia's R&D total.
- **There was a worldwide slowing in R&D spending in large and small countries in the early 1990s.** In fact, inflation-adjusted R&D spending fell for three consecutive years (1992, 1993, and 1994) in the United States, Japan, Germany, and Italy. R&D spending has since recovered in these countries but has remained stagnant in France and the United Kingdom. Most of the recent R&D growth results from rebounding industrial nondefense spending.
- **The most notable trend among G-7 and other Organisation for Economic Co-operation and Development (OECD) countries has been the relative decline in government R&D funding.** In 1997, roughly one-third of all OECD R&D funds derived from government sources—down considerably from the 45 percent share reported 16 years earlier. Much of this change reflects a decline in industrial reliance on government funds for R&D performance. In 1981, government provided 23 percent of the funds used by industry in the conduct of R&D within OECD countries. By 1997, government's share of the industry R&D total had fallen by more than one-half, to 10 percent of the total.
- **Even with the recovery in R&D spending in many G-7 countries, their R&D/GDP ratios generally are no higher now than they were at the start of the 1990s.** The U.S. R&D/GDP ratio inched back up to 2.7 percent in 1998 from its 16-year low of 2.4 percent in 1994. The United States ranked sixth among OECD countries in terms of reported R&D/GDP ratios for 1995–97. Sweden leads all countries with a R&D/GDP ratio of 3.9 percent, followed by Japan and South Korea (2.9 percent), Finland (2.8 percent), and Switzerland (2.7 percent).
- **R&D spending in the Russian Federation remains considerably below levels in place prior to the introduction of a market economy.** R&D downsizing and restructuring of obsolete, state-owned (generally military-oriented) enterprises were undertaken to establish viable commercial and scientific R&D infrastructures. In 1997, inflation-adjusted R&D spending was 74 percent below the level reported for 1990, and the number of scientists and engineers employed in research was less than half the number estimated to be employed in 1990.
- **Worldwide changes in the R&D landscape are presenting governments with a variety of new challenges and**

opportunities. Defense R&D has been substantially reduced not only in the United States but also in the United Kingdom and France, where the national defense share of the government R&D total declined from 44 percent to 38 percent and from 40 percent to 28 percent, respectively, during the 1990–97 period.

- **Among nondefense functions, U.S. government R&D spending for health is far greater than for any other activity.** Health accounts for about 19 percent of government R&D, making it second only to defense R&D activities. In the United Kingdom, 15 percent of the government's R&D support is health related. Several additional nondefense functions are emphasized to different degrees among other G-7 countries. Relatively large shares of government R&D support are devoted to energy in Japan; to space in France and the United States; and to industrial development in Canada, Germany, and Italy.
- **Many countries have put fiscal incentives into place to increase the overall level of R&D spending and to stimulate industrial innovation.** Almost all industrialized countries (including the United States) allow industry R&D expenditures to be 100 percent expensed (written off as costs in expense statements) in the year they are incurred, and about half of these countries (including the United States) provide some type of additional R&D tax credit or incentive. In fiscal year 1998, U.S. industry received an estimated $3.2 billion through tax credits on incremental research and experimentation expenditures. About 15 states in the United States offer additional R&D tax credits. Most countries (including the United States) provide preferential R&D programs for small businesses.
- **International partnerships have become a pillar in the global R&D landscape.** In many countries, the rapid rise in international cooperation has spawned activities that now account for more than 10 percent of government R&D expenditures. According to a 1999 study, seven agencies of the U.S. government participated in 575 international science and technology agreements in FY 1997 with 57 countries, 8 international organizations, and 10 groups of organizations or countries.
- **Industrial firms increasingly have used global research partnerships to strengthen core competencies and expand into technology fields critical for maintaining market share.** Since 1990, companies worldwide have entered into more than 5,100 known multifirm R&D alliances involving strategic high-technology activities. About one-third of these alliances were between U.S. firms and European or Japanese firms. Alliances were created most often to develop and share information technologies.
- **Worldwide, an increasing share of industrial R&D performance is financed by foreign (generally industry) sources.** U.S. companies make substantial R&D investments overseas ($13.1 billion in 1997). From 1985 to 1996, U.S. firms' investment in overseas R&D increased almost three times faster than company-funded R&D performed domestically (9.7 percent versus 3.4 percent average annual constant-dollar growth). Equivalent to about 6 percent of industry's total (domestic plus overseas) R&D funding in 1985, overseas R&D represented 10.4 percent of U.S. industry's R&D funding in 1996. In 1997, strong growth in companies' domestic financing for research (up 10 percent) coupled with a 7 percent decline in industry's overseas R&D spending reduced the overseas share to 8.9 percent of companies' R&D total.
- **More than two-thirds of U.S.-funded R&D abroad was performed in Europe—primarily in Germany, the United Kingdom, and France.** The current European share of U.S. industry's offshore R&D activity, however, is less than the 75 percent share reported for 1982. Overall, U.S. R&D investments abroad have generally shifted from the larger European countries and Canada toward Japan, several of the smaller European countries (notably Sweden and the Netherlands), Australia, and Brazil. Pharmaceutical companies accounted for the largest industry share (18 percent of U.S. 1997 overseas R&D), which was equivalent to 21 percent of their domestically financed R&D. Much of this pharmaceutical R&D took place in the United Kingdom.
- **U.S. firms are known to have established at least 186 R&D facilities in other countries by 1997.** Japan leads all countries as the site of overseas U.S. R&D facilities (43), followed by the United Kingdom, Canada, France, and Germany. Most U.S.-owned foreign facilities support the automotive (32 facilities), drugs and biotechnology (28), computers (25), and chemicals and rubber (23) industries.
- **Substantial R&D investments are made by foreign firms in the United States.** From 1987 to 1996, inflation-adjusted R&D growth from majority-owned U.S. affiliates of foreign firms averaged 10.9 percent per year. This growth contrasts favorably with the 3.9 percent average annual rate of increase in U.S. firms' domestic R&D funding. R&D expenditures in the United States by foreign companies are now roughly equivalent to U.S. companies' R&D investment abroad. Affiliates of firms headquartered in Germany, Switzerland, the United Kingdom, France, Japan, and Canada collectively account for 81 percent of this foreign funding.
- **Foreign-funded R&D in the United States in 1996 was concentrated in drugs and medicines (mostly from Swiss, German, and British firms), industrial chemicals (funded predominantly by German and Dutch firms), and electrical equipment (one-third of which came from French affiliates).** More than 700 R&D facilities run by 375 foreign-owned companies from 24 different countries are located in the United States.

Introduction

Chapter Overview

The U.S. economy approaches the end of the 20th century with unprecedented real growth, miniscule inflation, low unemployment, and strong consumer and investor confidence. Economists have dubbed it the "Cinderella economy." The reasons for this success are many and varied. However, it can be argued that technological change has been behind the economic boom of the late 1990s.

Technological change has three general effects on the economy. First, it reduces the costs of producing goods and providing services. That is, technological change allows for the consumption of greater amounts of goods and services, without the use of greater amounts of human labor, physical capital, or natural resources. Second, technological change is responsible for the creation of new and improved goods and services. Although the relative value of any new product is subjectively determined by each individual, the spending patterns of consumers overall often reveal the preferability of these new products over their predecessors. Ironically, the third factor—what technological change has not yet done, but is expected to do—may have made the greatest contribution to the recent economic boom. Technological change is expected to continue to transform many aspects of economic production, distribution, and consumption. Such changes include, for example, further development of Internet commerce (e.g., banking and retail operations), additional advances in biotechnology (e.g., "designer" drugs), greater automation in production (e.g., advanced robotic systems), new forms of household entertainment (e.g., digital video disc entertainment systems), and new ways of conducting scientific research itself (e.g., the creation of virtual laboratories). Investors and public planners have continued to devote new resources to preparing for these changes, thereby stimulating economic investment and expansion. Thus, much of the current investment-led economic growth is only a prelude to future advances. In this sense, our present is being influenced largely by our future—a future that will owe much of its character to technological change.

Of course, innovation—and the technological change that results from it—does not just happen. It has to be paid for—through expenditures on research and development (R&D). How R&D funds are spent helps determine how scientific knowledge will accumulate and how technological change will be manifested. Thus, R&D decisionmaking—how much different organizations spend and on what areas of science or engineering—is critical to the future of the U.S. economy and national well-being. This factor explains why the United States and many other nations collect extensive R&D expenditures data and disseminate the information worldwide for study by analysts in a wide variety of fields.

In addition to indicating the directions of technological change, R&D expenditure data also measure the level of economic purchasing power that has been devoted to R&D projects as opposed to other economic activities. Industrial (private sector) funding of R&D, for example—which represents most of R&D expenditure in the United States—may be interpreted as an economic metric of how important R&D is to U.S. companies, which could have easily devoted those same funds to any number of other business activities. Likewise, government support for R&D reflects government and society's commitment to scientific and engineering advancement, which is an objective that must compete for dollars against other functions served by discretionary government spending. The same basic notion holds for other sectors that fund R&D, such as colleges and universities 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, it would not be R&D), the amount they devote is based on their perception, rather than their absolute knowledge, of R&D's value. Such information about R&D's perceived relative value is also extremely useful for economic decisionmaking. For example, increased R&D in a particular field of study may reflect an increase in demand for scientists and engineers to study and work in that field. An increase in R&D in a particular industrial sector could be among the first signs that the sector is about to expand with new lines of products or services. 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 may well be an important input into such analysis. This chapter therefore presents information that will provide a broad understanding of the nature of R&D expenditures and the implications of these data for science and technology policy.

Chapter Organization

This chapter has two major parts, both of which examine trends in R&D expenditures. The first part looks into R&D performed in the U.S. alone; the second compares R&D trends across nations. The first part contains sections on economic measures of R&D; trends in financial support for R&D; trends in R&D performance; industrial R&D performance; R&D performance by geographic location, character of work, and field of science; and intersector and intrasector R&D partnerships and alliances. The second part 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; the character of R&D efforts (or R&D efforts separated into basic research, applied research, and development components); international comparisons of government R&D priorities; comparisons of government R&D tax policies; the growth in public- and private-sector international R&D agreements and alliances; the United States' international R&D investment balance; and patterns in overseas R&D and foreign R&D performed in the United States, in terms of both expenditures and facility placement.

Economic Measures of R&D

Latest Developments in U.S. National R&D

The United States is spending more money on R&D than ever before, even when the amounts are adjusted for inflation. In 1998 (the most recent year for which R&D expenditure data are available at this writing), total R&D expenditures in the United States reached $227.2 billion.[1] Moreover, the rate at which R&D has been increasing in recent years has been impressive. The $227.2 billion total for 1998 reflects a nominal growth rate (without accounting for inflation) of 7.5 percent over the 1997 level of $211.3 billion, or a real growth rate (after adjusting for inflation) of 6.5 percent.[2] Similar growth occurred in 1997: The 1997 level of R&D reflects a 7.5 percent nominal growth over the $196.5 billion spent in 1996, or 5.5 percent real growth.

By comparison, the U.S. GDP,[3] the main measure of the nation’s total economic activity, grew in real terms by 3.9 percent per year in 1997 and 1998. Such growth in the GDP is exceptionally high, yet it is slower than the growth of R&D. R&D has generally been outpacing the overall growth of the economy since 1994. As a result, R&D as a proportion of GDP has been on the rise as well—from 2.43 percent in 1994 to 2.67 percent in 1998.

Organizations that conduct R&D often receive outside funding; likewise, organizations that fund R&D often do not perform as much R&D as the amount of money they devote to it. Therefore, any discussion of the nation’s R&D must always be careful to distinguish between where the money comes from originally and where the R&D is actually performed. That is, R&D expenditures can be categorized, respectively, by source of funds or by performer.

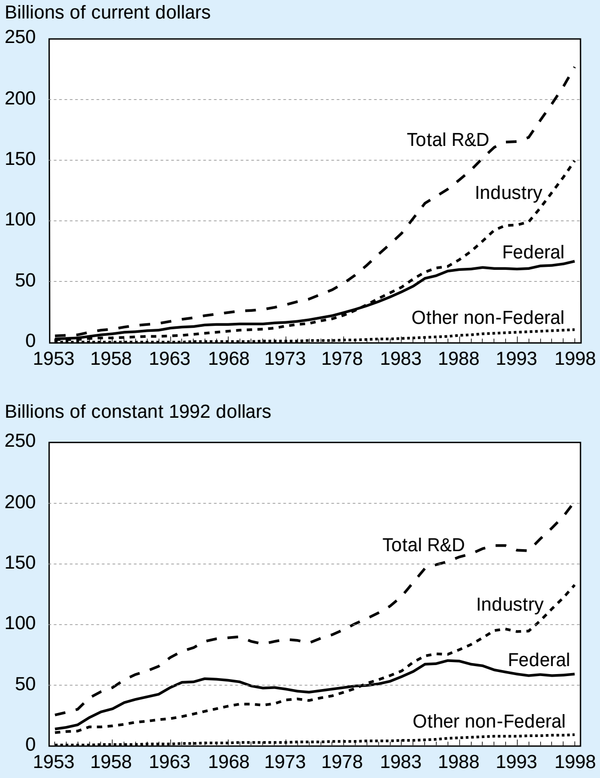
By source of funds, most of the nation’s R&D is paid for by private industry, which provided 65.9 percent ($149.7 billion) of total R&D funding in 1998. Nearly all of these funds (98 percent) were used by private industry itself in the performance of its own R&D, and most of these funds (70 percent) were for the development of products and services rather than for research. In 1998, the Federal Government provided the next largest share of R&D funding—29.5 percent ($66.9 billion dollars)—and the other sectors of the economy (state governments, universities and colleges, and nonprofit institutions) contributed the remaining 4.7 percent ($10.6 billion). (See figures 2-1, 2-2, and 2-3 and text table 2-1.)

By performer, industry in 1998 accounted for an even larger share of the total—74.4 percent; universities and colleges accounted for 11.6 percent, and the Federal Government accounted for 7.6 percent. Federally Funded Research and Development Centers (FFRDCs)—which are administered by various industrial, academic, and nonprofit institutions—accounted for an additional 3.8 percent, and other nonprofit organizations accounted for 2.6 percent. (See figures 2-2 and 2-3.)[4]

R&D Growth Trends

Between 1953 and 1969 R&D expenditures grew at a real annual rate of 8.2 percent.[5] Starting in 1969, however, 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 1 percent per year as business and government tended to deemphasize research programs. (See figure 2-1.)

Figure 2-1.
National R&D funding, by source: 1953–1998



See appendix tables 2-5 and 2-6.

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[1] Projections for 1998 and preliminary tabulations for 1997 were based in part on time-series modeling techniques. Except for discussions of the Federal budget authority, which refer to fiscal years, other references to years in this chapter refer to calendar years, not fiscal years (even in discussions of academic and Federal intramural performance). Other chapters in this report and other NSF reports on academic or Federal expenditures alone, however, often refer to fiscal years because those institutions operate on a fiscal year basis. Calendar years are used in this chapter and in the NSF reports *National Patterns of R&D Resources* and *Research and Development in Industry*, however, for consistency with industry data, which represent three-fourths of U.S. R&D expenditure, and for consistency with the vast majority of all other national economic statistics provided by Federal statistical agencies.

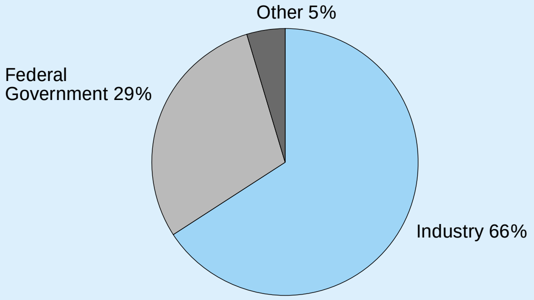
[2] For a discussion of how dollar amounts are adjusted for inflation, see “Appendix A: Controlling for Inflation and Foreign Currency,” in NSF (1999c).

[3] For historical data on the GDP, see appendix table 2-1.

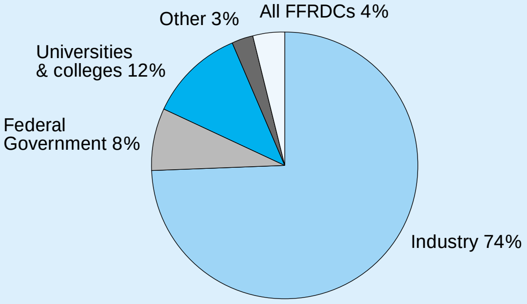
[4] In some of the statistics provided below, FFRDCs are included as part of the sector that administers them. In particular, statistics on the industrial sector often include industry-administered FFRDCs as part of that sector because some of these statistics from the NSF Industry R&D Survey cannot be separated with regard to the FFRDC component. Whenever a sector is mentioned in this chapter, the wording used will specify whether FFRDCs are included.

[5] For additional background on U.S. R&D in the 1950s, see chapter 1.

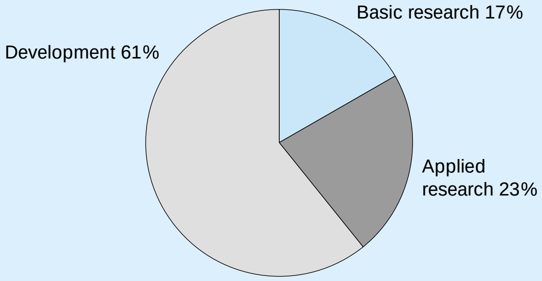
Figure 2-2.
National R&D expenditures: 1998



By source of funds



By performing sector



By character of work

FFRDCs = Federally Funded Research and Development Centers

NOTE: Data labels rounded to nearest whole number.

See appendix tables 2-3, 2-5, 2-7, 2-11, and 2-15.

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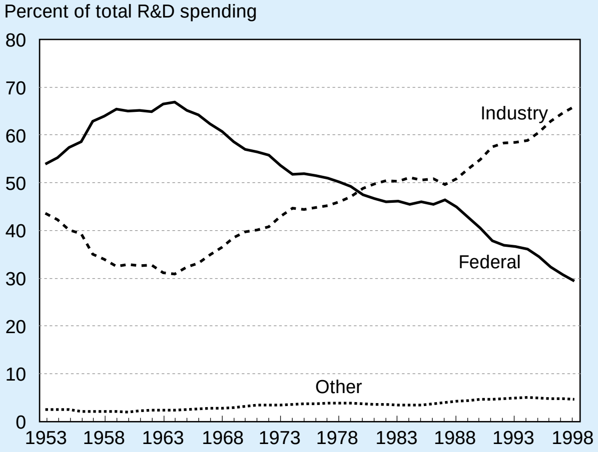
Federal funding in particular fell 19 percent in real terms during this period; this decrease was felt in defense- and nondefense-related programs (as discussed in greater detail below).

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 72 percent from 1975 to 1985 (5.6 percent per year), compared with a 37 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 Federal and non-Federal sources. In particular, 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.

Figure 2-3.
National R&D expenditures, by source of funds



See appendix table 2-5. *Science & Engineering Indicators – 2000*

Overall, the 1975–80 R&D recovery witnessed an average growth rate of 4.4 percent per year. That annual rate remained between 4 and 5 percent through 1982, though 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 8.2 percent over 1982–85. Such rapid growth had not been seen since the post-Sputnik era of the early 1960s.

On average, R&D spending increased 6.8 percent per year in real terms in the first half of the 1980s. The situation then changed abruptly again. From 1985 to 1994, average annual R&D growth after inflation slowed to 1.1 percent, compared with a 2.4 percent annual real growth in GDP. Reductions in Federal and non-Federal funding of R&D as a proportion of GDP had contributed to this slowing. However, the decline in real Federal R&D funding was the primary factor in the slow growth of R&D in the early 1990s.[6]

This downward trend reversed again in 1994, as a result of substantial increases in industrial R&D.[7] R&D in the United

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[6] 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 (Federal labs, industry, universities, and other nonprofit organizations), on the other hand. For a discussion of this divergence in R&D totals, see sidebar, "Accounting for Defense R&D: Gap Between Performer- and Source-Reported Expenditures."

[7] For a detailed discussion of this upturn, see Jankowski (1999).

Text table 2-1.
U.S. R&D expenditures, by performing sector, source of funds, and character of work: 1998
(Millions of U.S. dollars)

	Performer						
Character of work/ sources of funds	Federal Government	Industry[a]	Universities and colleges	U&C associated FFRDCs[b]	Other nonprofit institutions[a]	Total	Percent distribution by sources
TOTAL R&D							
Federal Government	17,189	24,589	15,558	5,517	4,077	66,930	29.5%
Industry	..	146,706	1,896	..	1,051	149,653	65.9%
Universities and colleges	..	..	7,049	..	..	7,049	3.1%
Other nonprofit institutions	..	..	1,840	..	1,702	3,541	1.6%
Total.	17,189	171,295	26,343	5,517	6,830	227,173	100.0%
Percent distribution, performers	7.6%	75.4%	11.6%	2.4%	3.0%	100.0%	
BASIC RESEARCH							
Federal Government	2,920	1,816	11,248	2,721	1,531	20,235	53.4%
Industry	..	9,625	1,205	..	483	11,313	29.9%
Universities and colleges	..	..	4,479	..	..	4,479	11.8%
Other nonprofit institutions	..	..	1,169	..	681	1,850	4.9%
Total.	2,920	11,441	18,100	2,721	2,695	37,877	100.0%
Percent distribution, performers	7.7%	30.2%	47.8%	7.2%	7.1%	100.0%	
APPLIED RESEARCH							
Federal Government	5,421	3,087	3,130	1,545	1,144	14,326	28.0%
Industry	..	32,701	567	..	357	33,625	65.6%
Universities and colleges	..	..	2,107	..	..	2,107	4.1%
Other nonprofit institutions	..	..	550	..	613	1,163	2.3%
Total.	5,421	35,788	6,354	1,545	2,114	51,221	100.0%
Percent distribution, performers	10.6%	69.9%	12.4%	3.0%	4.1%	100.0%	
DEVELOPMENT							
Federal Government	8,848	19,686	1,181	1,251	1,403	32,369	23.4%
Industry	..	104,380	124	..	210	104,715	75.8%
Universities and colleges	..	..	463	..	..	463	0.3%
Other nonprofit institutions	..	..	121	..	408	529	0.4%
Total.	8,848	124,066	1,888	1,251	2,021	138,075	100.0%
Percent distribution, performers	6.4%	89.9%	1.4%	0.9%	1.5%	100.0%	

FFRDC = Federally Funded Research and Development Center

NOTE: State and local government funds are included in industry funds reported to industry performers, and in university and college funds reported to university and college performers. Details may not add to totals because of rounding.

[a] Expenditures for FFRDCs administered by both industry and nonprofit institutions are included in the totals of their respective sectors. They are estimated to account for less than 2 percent and 12 percent, respectively, of the industry and nonprofit institutions performance totals. FFRDCs are organizations exclusively or substantially financed by the Federal Government to meet a particular requirement or to provide major facilities for research and training purposes.

[b] FFRDCs administered by individual universities and colleges and by university consortia.

See appendix tables 2-3 , 2-7, 2-11, and 2-15.

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States grew in real terms by 5.8 percent per year between 1994 and 1998, in spite of virtually no real growth (0.6 percent per year) in Federal R&D support. Over the same period, industrial support for R&D grew at a real annual rate of 8.9 percent. Much of this increase might be explained by the favorable economic conditions that generally existed during the period.

Trends in Financial Support for R&D

Federal Support by National Objective

Federal Funding Trends

In recent years the Federal Government has contributed smaller shares of the Nation's R&D funding. The Federal Government once was the main provider of the Nation's R&D funds—accounting for 54 percent in 1953 and as much as 67 percent in 1964. The Federal share of R&D funding first fell below 50 percent in 1979, and it remained between 45 and 47 percent from 1980 to 1988. Since then it has fallen steadily, to 29.5 percent in 1998—the lowest ever recorded in the National Science Foundation's (NSF) data series (which began in 1953).[8] This decline in the Federal share, however, should not be misinterpreted as a decline in the actual amount funded. Federal support in 1998 ($66.9 billion), for example, actually reflects a 2.1 percent increase in real terms over the 1997 level. Because industrial funding increased much faster (see above), however, Federal support as a proportion of the total has continued to decline.

Although the Federal share of total R&D expenditures continued to fall, Federal R&D funding, in absolute terms, actually expanded between 1980 and 1998 (from $30.0 billion to $66.9 billion)—which, after inflation, amounted to a small, real growth rate of 1.0 percent per year. This rate was not uniform across the period, however. From 1980 to 1985, Federal R&D funding grew an average of 6.2 percent in real terms annually. Nearly all of the rise in Federal R&D funding during the early 1980s resulted from large increases in defense spending—as evidenced by figures on the Federal budget authority. (See figure 2-4.) For example, defense activities of the Department of Defense (DOD) and the Department of Energy (DOE) accounted for roughly half of the total Federal R&D budget authorizations in 1980.[9] By 1986, such defense-related activities peaked at 69 percent of the Federal R&D budget authority.

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 mandated that new spending increases be offset with specific spending cuts).

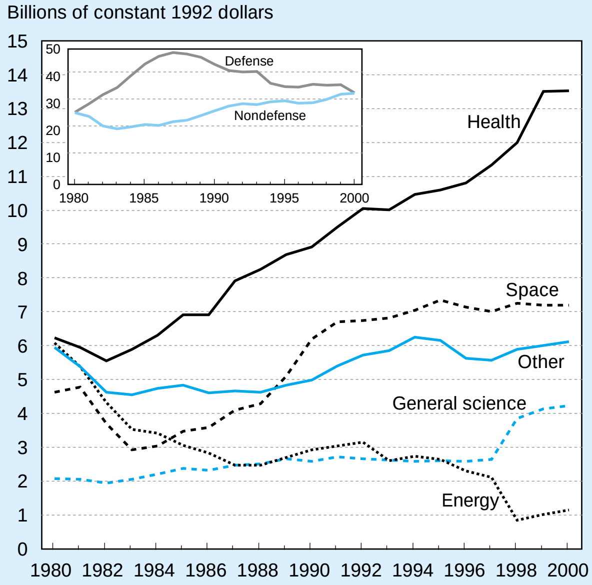
Federal Support by Budget Function

In 1980, the Federal budget authority for defense-related R&D was roughly equal to that for nondefense R&D. As a result of modifications in U.S. security measures in an evolving international arena, defense-related R&D expanded in the early and mid-1980s, coinciding with a decline in nondefense-R&D spending. 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 steadily increasing since 1983. For the year 2000, the budget authority for defense R&D and nondefense R&D are roughly equal again, but they are now 28 percent and 29 percent higher in real terms than their respective 1980 levels.

Since 1986, Federal budget authority for civilian-related R&D has grown faster than defense-related R&D. In particular, the budget allocation for health- and space-related R&D increased substantially between FY 1986 and FY 2000, with average real annual growth rates of 4.9 and 5.1 percent, respectively. (Most of the growth in the budget authority for space-related R&D occurred between FY 1986 and FY 1991.) (See figure 2-4.) The budget allocation for defense programs declined by an average real annual rate of 2.5 percent during the same period.

R&D (most of which is development) accounts for 13 percent of all money authorized to be spent by the Federal Government on defense activities in 2000, according to the Federal budget authority. In contrast, R&D accounts for only 3 percent of the Federal nondefense budget authority, though many nondefense functions have much higher proportions. (See text table 2-2.) With regard to nondefense objectives (or "budget functions"), R&D accounts for 73 percent of the funds for general science—nearly all of which (95 percent) is devoted to basic research. (See text table 2-3.) R&D accounts for 67 percent of the funds for space research and technology, most of which (78 percent) is devoted to applied research and development. Among funds for health, R&D represents 10 percent, most of which (54 percent) is devoted to basic research and nearly all of which is directed toward NIH programs.

Figure 2-4.
Federal R&D funding, by budget function



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 2-23. *Science & Engineering Indicators – 2000*

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[8] The sample design for estimating industry R&D expenditures was revised for 1991 and later years. The effect of the change in industry's sample design was to reduce the Federal share of the national R&D total to 38 percent in 1991, down from the 41 percent share previously published for 1991. For more information on these survey changes and their effects on R&D estimates, see Appendix A in NSF (1999c).

[9] These percentage share calculations of defense-related R&D activities are based on Federal budget authorization totals, not on data reported by the performers of R&D. Although funding is designated in the budget authority, it is actually provided through appropriations, not authorizations. In congressional terminology, authorizations are only guidelines, suggestions, or ceilings for appropriations and do not result in any money actually being spent. Only appropriations can provide money.

21st Century Research Fund and Earlier Concepts

The discussion and statistics on Federal funding of R&D provided in this chapter are based on two economic measures of R&D that have significant historical precedence: the Federal “budget authority” for R&D and accounts of “Federal funds” for R&D. Statistics on the R&D budget authority are provided in the Budget of the United States Government, though more detailed information on the budget authority for R&D is acquired through the NSF survey *Federal R&D Funding by Budget Function.* Statistics on Federal funds for R&D are acquired through the NSF survey *Federal Funds for Research and Development.* These two Federal surveys, along with other NSF surveys of the academic, industrial, and nonprofit sectors, provide the statistical information on R&D levels presented in this chapter.

The budget authority and Federal funds differ in definition. The budget authority is the primary source of legal authorization to enter into financial obligations that will result in outlays. Budget authority is most commonly granted in the form of appropriations laws enacted by Congress with the approval of the President. In contrast, Federal funds are measured in the form of obligations, which represent the amounts for orders placed, contracts awarded, services received, and similar transactions during a given period, regardless of when the funds were appropriated or when future payments are required.

In recent years, however, 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 (NAS 1995), members of a National Academy of Sciences 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. (This concept was discussed in *Science & Engineering Indicators—1998.*) The FS&T concept differed from Federal funds for research in a variety of ways: It was never defined in precise terms; unlike Federal funds, it did not include major systems development supported by DOD and DOE; and it contained not only research but also some development and some R&D plant.*

In the FY 1999 budget, a new concept—the “Research Fund for America” (RFA)—was introduced, which reflected the Administration’s interest in addressing the FS&T concept previously proposed by the Academy. Unlike the FS&T budget, however—which was constructed from components of the R&D budget—the RFA was constructed out of easily-trackable programs and included some non-R&D programs, such as NSF education programs and staff salaries at the National Institutes of Health (NIH) 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. With regard to specific Federal agencies, the RFA included R&D supported by the Department of Health and Human Services (HHS), NSF, DOE, the Department of the Interior (DOI), the Environmental Protection Agency (EPA), and the Department of Veterans Affairs; R&D supported by various offices under the Department of Agriculture (USDA), the Department of Commerce (DOC), the National Aeronautics and Space Administration (NASA), and the Department of Education; and R&D associated with the “Climate Change Technology Initiative” interagency project. Not included under the RFA concept was R&D supported by DOD, the Department of Housing and Urban Development (HUD) (not otherwise included in the climate change technology initiative), the Department of Justice (DOJ), the Department of Labor (DOL), and the Department of Transportation (DOT).

The FY 2000 Budget refers to the concept “21st Century Research Fund,” which is a slight modification of the RFA. It expands the RFA to include basic and applied research in defense, adds certain programs in transportation, and removes the HUD portion of the climate change technology initiative. Thus, the 21st Century Research Fund includes research supported by HHS, NSF, DOE, NASA, DOD, USDA, DOC, DOI, EPA, the Department of Veterans Affairs, the Department of Education, and DOT but does not include research supported by HUD, DOJ, DOL, the Treasury Department, the Smithsonian Institution, and other agencies with relatively low levels of research support.

The 21st Century Fund’s estimated total budget authority for FY 1998, according to the 2000 Budget of the United States Government, is $33.8 billion. It captures approximately 95 percent of total basic research and 75 percent of total applied research. Like the RFA, the 21st Century Fund includes some development funds, as well as the same non-R&D programs as the RFA. Consequently, it is not comparable to total research funding as defined and reported in this chapter.

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*For additional discussion on the differences between R&D, FS&T, and the programs in the 21st Century Fund, see Chapter 6 of AAAS (1999b).

At first glance, the R&D budget authority for energy appears to have declined rapidly in recent years—in particular, from $2.4 billion in 1997 to only $0.9 billion in 1998. (See figure 2-4.) This effect, however, was the result of reclassification, not an actual decline in economic resources devoted to energy R&D. Beginning in FY 1998, several DOE programs were reclassified from “energy” to “general science,” so the decline from $2.4 billion to $0.9 billion in energy R&D was offset by an increase in general science from $2.9 billion to $4.4 billion. (See appendix table 2-23.)

Federal Support by Functional Categories

Defense-related R&D, as a proportion of the Nation’s total R&D, has undergone substantial shifts. From 1953 to 1959, defense-related R&D rose from 48 percent to 54 percent; it then declined to a relative low of 24 percent in 1980. From 1980 to 1987, it climbed again to 31.8 percent, but then it declined again to a low of 16 percent in 1998.[10] (See figure 2-5.)

Text table 2–2.
R&D as a percentage of Federal budget authority, by function: FY 2000

Budget function	Millions of dollars: R&D total (preliminary 2000)	Millions of dollars: Federal total	Percent: R&D share
Total	75,415	1,781,050	4.2
On-budget	75,415	1,441,914	5.2
National defense	37,710	280,800	13.4
Nondefense (on-budget)	37,704	1,161,114	3.2
Health	15,824	155,483	10.2
Space research and technology	8,422	12,509	67.3
Energy[a]	1,348	(2,260)	NA
General science	4,951	6,771	73.1
Natural resources and environment	1,944	23,952	8.1
Transportation	1,840	53,423	3.4
Agriculture	1,522	14,148	10.8
All other	1,853	897,088	0.2

NA = Not applicable

NOTES: Because of rounding, components may not add to totals shown. Data are derived from the Administration’s 1999 budget proposal. On-budget totals are for all Federal Government transactions except those of the Social Security trust funds (Federal Old-Age and Survivors Insurance and Federal Disability Insurance Trust Funds) and the Postal Service.

[a] The budget authority for Energy is negative because of offsetting receipts from sales of the Strategic Petroleum Reserve.

SOURCES: National Science Foundation, Division of Science Resources Studies, and Office of Management and Budget, *The Budget for Fiscal Year 2000*, Historical Tables, and National Science Foundation/Division of Science Resources Studies, *Federal R&D Funding by Budget Function: Fiscal Years 1998–2000*.

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Text table 2–3.
Budget authority for R&D by function and character of work: Anticipated levels for FY 2000
(Millions of dollars)

Budget function	Basic research	Applied research and development	R&D total
Total	18,101	57,314	75,415
National defense	1,152	36,559	37,710
Nondefense (total)	16,949	20,755	37,704
Health	8,590	7,234	15,824
Space research and technology	1,841	6,581	8,422
Energy	46	1,302	1,348
General science	4,710	241	4,951
Natural resources and environment	175	1,769	1,944
Transportation	634	1,206	1,840
Agriculture	736	786	1,522
All other	218	1,636	1,853

NOTE: Because of rounding, components may not add to totals shown.

SOURCES: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Federal R&D Funding by Budget Function: Fiscal Years 1998–2000*, and unpublished tabulations.

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Space-related R&D funding, as a percentage of total R&D funding, reached a peak of 22 percent in 1965, during the height of U.S. efforts to surpass the Soviet Union in space travel. It declined after that, to a low of 3 percent in 1984 and 1986. By 1990 it was back up to 4 percent, and it has remained between 4 and 5 percent since. Federal support for nondefense/nonspace R&D programs, as a percentage of total U.S. R&D, has been declining steadily since 1994, when it was 12 percent. It was 10 percent in 1998—the lowest since 1961 (when it was 9 percent).

R&D by Federal Agency

According to preliminary data provided by Federal agencies, in FY 1999 DOD was the source of 75 percent of all Federal R&D obligations to industry, excluding industry-administered FFRDCs. (See appendix table 2-38.) Nearly all (94 percent) of these funds supported development work. Two other agencies—NASA and DOE—provide most of the other Federal R&D funds that industry receives.

HHS accounted for 59 percent of all Federal R&D obligations to universities and colleges, excluding university-administered FFRDCs, in FY 1999. Most of HHS’s R&D support (56 percent) is directed toward academia; 21 percent is spent internally, mostly in NIH laboratories. HHS also accounts for 67 percent of all Federal R&D obligations for nonprofit organizations in 1999. Approximately 5 percent of HHS R&D obligations go to industrial firms.

NSF and DOD are the other leading supporters of R&D conducted in academic facilities. Eighty-one percent of NSF’s

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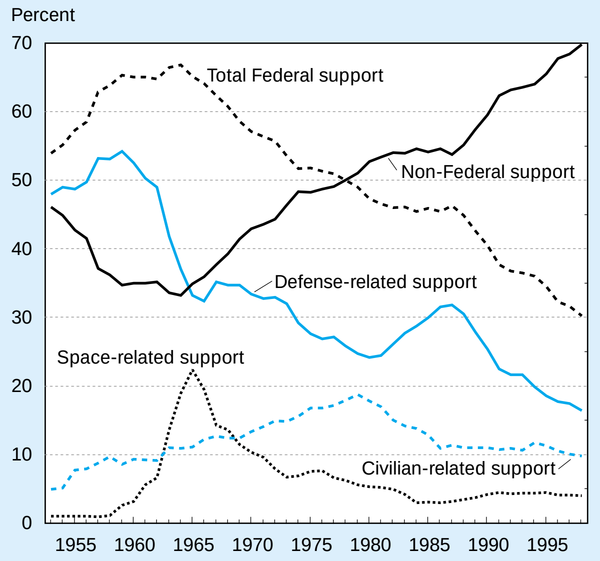
[10] These shares by national objective represent a distribution of performer-reported R&D data. They are distinct from the budget authority shares reported above, which are based on the functional categories that constitute the Federal budget.

Figure 2-5.
Trends in Federal and non-Federal R&D expenditures as a percentage of total R&D: 1953–98



See appendix table 2-19. *Science & Engineering Indicators – 2000*

R&D budget supports projects at universities and colleges. Most of the remainder is divided among other nonprofit organizations (7 percent), university-administered FFRDCs (6 percent), and industry (5 percent). DOD provides only 4 percent of its R&D support to universities and colleges; it provides 70 percent to industry and 23 percent to Federal intramural activities. In contrast, DOE provides 9 percent of its support to universities, 22 percent to industry, 12 percent to Federal intramural activities, and 37 percent to FFRDCs administered by universities and colleges.

Of all Federal obligations to FFRDCs in FY 1999, DOE accounted for 61 percent, NASA accounted for 18 percent, and DOD accounted for 14 percent. More than half (56 percent) of DOE's R&D support is directed to FFRDCs.

Unlike all other Federal agencies, USDA, DOC, and DOI spend most of their R&D obligations internally. Most of the R&D supported by these agencies is mission-oriented and is conducted in laboratories run by the Agricultural Research Service, the National Institute for Standards and Technology (NIST), and the U.S. Geological Survey (USGS).

Federal R&D obligations are concentrated in a small number of agencies. Six Federal agencies had R&D obligations of more than $1 billion in FY 1998 (out of total Federal R&D obligations of $72 billion). These agencies, in descending order of R&D obligations, are DOD (48.3 percent of the total), HHS (19.02 percent), NASA (13.7 percent), DOE (8.1 percent), NSF (3.3 percent), and USDA (2.0 percent). (See figure 2-6 and text table 2-4.)

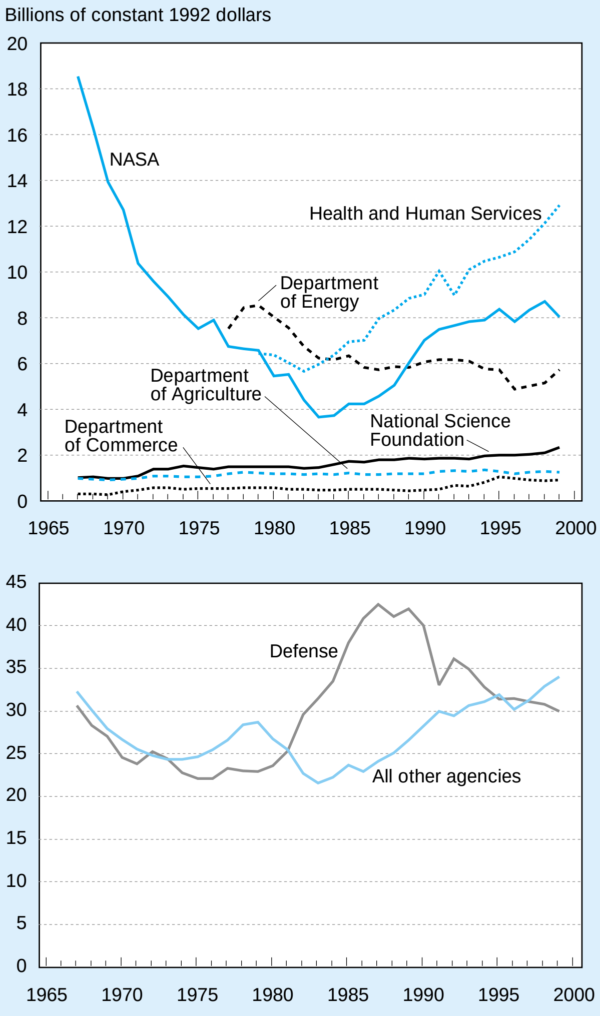
In contrast to total R&D obligations, only three agencies had intramural R&D expenditures that exceeded $1 billion in 1998, including costs associated with planning and administering extramural R&D programs: DOD, HHS (which includes NIH), and NASA. These three agencies together accounted for 81 percent of all Federal R&D obligations for 1998 and 77 percent of Federal intramural R&D.

All agencies, including those that fund R&D, are subject to evaluation and scrutiny according to the Government Performance and Results Act (GPRA) of 1993. (See sidebar, "GPRA and Federal Support for R&D.")

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 59 percent, and it has remained between 59 and 60 percent since. Although this share of funding has not changed much in recent years, the actual amount of funding, in real terms, grew an average of 4.8 percent per year between 1985 and 1994 and 2.8 percent between 1994 and 1998. (For more information on academic R&D, see chapter 6.)

Figure 2-6.
National R&D obligations, by selected agency



See appendix table 2-26. *Science & Engineering Indicators – 2000*

GPRA and Federal Support for R&D

In response to the Clinton Administration's effort to move toward a government that works better and costs less, Congress passed the Government Performance and Results Act (GPRA) of 1993. GPRA aims to shift the focus of Federal agencies away from traditional concerns such as staffing and the level of services provided and toward results. Specifically, GPRA seeks to improve Federal planning and management, increase accountability for and assessment of results, and provide better information for congressional and agency decisionmaking. To accomplish these and related goals, GPRA requires every Federal agency to prepare detailed, multiyear strategic plans, annual performance plans, and annual performance reports. These documents give agencies formal tools with which to set forth goals, to prepare plans to meet those goals, and to assess and measure progress and accomplishments on a regular and systematic basis.

GPRA poses a particular challenge for agencies that must assess the scientific research programs they fund. In fact, the General Accounting Office (GAO) has found that measuring the discrete contribution of a Federal initiative to a specific program result is particularly challenging for regulatory programs; scientific research programs; and programs that deliver services to taxpayers through third parties, such as state and local governments (GAO 1997a). Regarding research programs, GAO points out that the amount of money spent on R&D has been used as the primary indicator of how much research is being performed in a given area—but that such an input indicator does not provide a good indication of the outcomes (results) of the research. In a recent report, GAO notes:

> Experiences in research measurement have tried for years to develop indicators that would provide a measure of the results of R&D. However, the very nature of the innovative process makes measuring the performance of science-related projects difficult. For example, a wide range of factors determine if and when a particular R&D project will result in commercial or other benefits. It can also take many years for a research project to achieve results…Experiences from pilot efforts made under the Government Performance and Results Act have reinforced the finding that output measures are highly specific to the management and mission of each Federal agency and that no single indicator exists to measure the results of the research (GAO 1997b, 2–3).

The Committee on Science, Engineering, and Public Policy (COSEPUP)—a joint committee of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine—wrote a report titled *Evaluating Federal Research Programs*: *Research and the Government Performance and Results Act* (COSEPUP 1999). As the title suggests, the report addressed how Federally supported research should be evaluated for its compliance with GPRA requirements. According to the report, "Agencies are required to develop a strategic plan that sets goals and objectives for at least a 5-year period, an annual performance plan that translates the goals of the strategic plan into annual targets, and an annual performance report that demonstrates whether targets are met" (COSEPUP 1999, 1).

Through its expert analysis of the nature of Federal research support and its understanding of GPRA requirements, COSEPUP reached the following conclusions:

- Both applied research and basic research…can be evaluated meaningfully on a regular basis.
- Agencies must evaluate their research programs by using measurements that match the character of research.
- The most effective means of evaluating Federally funded research programs is expert review.
- Agencies must pay increased attention to their human-resource requirements in terms of training and educating young scientists and engineers and in terms of providing an adequate supply of scientists and engineers to academe, industry, and Federal laboratories.
- Mechanisms for coordinating research programs in multiple agencies whose fields or subject matters overlap are insufficient.
- The development of effective methods for evaluating and reporting performance requires the participation of the scientific and engineering community, whose members will necessarily be involved in expert review (COSEPUP 1999, 4–8).

In accordance with these findings, COSEPUP made the following recommendations:

- Research programs should be described in strategic and performance plans and evaluated in performance reports.
- For applied research programs, agencies should measure progress toward practical outcomes. For basic research programs, agencies should measure quality, relevance, and leadership.
- Federal agencies should use expert review to assess the quality of research they support, the relevance of that research to their mission, and the leadership of that research.
- Both research and mission agencies should describe in their strategic and performance plans the goal of developing and maintaining adequate human resources in fields critical to their missions both at the national level and in their agencies.
- Although GPRA is conducted agency-by-agency, a formal process should be established to identify and coordinate areas of research that are supported by multiple agencies. A lead agency should be identified for each field of research and that agency should be responsible for assuring that coordination occurs among the agencies.
- The science and engineering community can and should play an important role in GPRA implementation (COSEPUP 1999, 8–11).

Text table 2–4.
Federal R&D obligations, total and intramural by agency: FY 1998

Agency	Total R&D obligations (millions of current dollars)	Total R&D obligations as a share of Federal total (percent)	Intramural R&D (millions of current dollars)	Percent of agency R&D obligations that are intramural[a]	Percent change in real intramural R&D from previous year[b]
Department of Defense	34,832.6	48.30	7,750.6	22.25	–6.1
Dept of Health & Human Services, total	13,717.8	19.02	2,957.2	21.56	9.3
National Aeronautics & Space Admin	9,850.7	13.66	2,462.7	25.00	4.4
Department of Energy	5,833.1	8.09	535.1	9.17	24.3
National Science Foundation	2,356.9	3.27	14.4	0.61	3.9
Department of Agriculture, total	1,441.9	2.00	954.9	66.23	3.0
Department of Commerce, total	978.7	1.36	695.1	71.02	3.4
Department of Transportation, total	664.7	0.92	265.8	39.99	36.8
Department of the Interior, total	613.3	0.85	541.9	88.36	3.3
Environmental Protection Agency	606.0	0.84	289.3	47.74	11.1
Department of Veterans Affairs	299.3	0.42	299.3	100.00	17.0
Department of Education	211.8	0.29	9.8	4.63	5.3
Agency for International Development	183.9	0.26	21.0	11.42	–7.8
Smithsonian Institution	134.0	0.19	134.0	100.00	1.9
Department of Justice, total	102.9	0.14	42.2	41.01	0.2
Department of the Treasury, total	74.2	0.10	45.3	61.05	15.7
Social Security Administration	56.1	0.08	6.3	11.23	24.5
Nuclear Regulatory Commission	50.7	0.07	14.0	27.61	-9.0
Department of Labor, total	46.8	0.06	16.8	35.90	25.8
Dept of Housing & Urban Development	39.6	0.05	25.0	63.13	16.5
U.S. International Trade Commission	5.8	0.01	5.8	100.00	0.5
Tennessee Valley Authority	2.9	0.00	2.9	100.00	–67.8
Library of Congress	2.5	0.00	2.5	100.00	–11.8
Department of State	1.0	0.00	0.3	30.00	–1.2
Other Agencies[c]	6.9	0.01	5.4	78.26	11.2
Entire Federal Government[d]	72,114.1	100.00	17,097.6	23.71	1.0

[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 for 1997 and 1998. (See appendix table 2-1.)

[c] Includes: Appalachian Regional Commission, Consumer Product Safety Commission, Federal Communications Commission, Federal Trade Commission, National Archives and Records Administration, U.S. Arms Control and Disarmament Agency, and U.S. Information Agency.

[d] Numbers do not total exactly, due to rounding.

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Survey of Federal Funds for Research and Development: Fiscal Years 1997, 1998, and 1999.*

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R&D performance in 1998 by university-administered FFRDCs was $5.5 billion, or approximately 2.4 percent of the national R&D effort. These FFRDCs accounted for 17.3 percent of total 1998 academic R&D performance (universities and colleges plus academically administered FFRDCs). From 1974 to 1980, R&D at academically administered FFRDCs grew by 8.5 percent per year in real terms. This increase largely mirrored the Federal emphasis on energy programs. Since 1980, the Federal shift away from energy concerns has resulted in much slower growth in academically administered FFRDC R&D performance—only 1.2 percent per year in real terms.

Federal Funding to Other Sectors

Trends in Federal funding to industry, FFRDCs, and other nonprofit organizations have varied considerably over time. (See figure 2-7.) The greatest fluctuation has been Federal funds to industry (excluding industry-administered FFRDCs), which rose from a low of $7.1 billion (in constant 1992 dollars) in 1953 (at the beginning of a time series)[11] to $31.1 billion in 1966, fell to $18.7 billion in 1975, rose sharply

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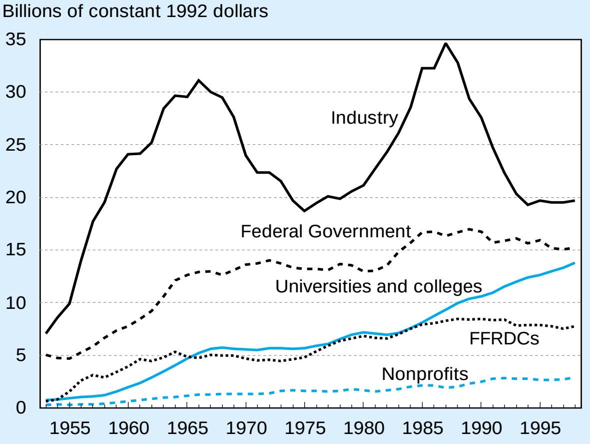
[11] The 1953 value is actually an overestimate because the 1953 and 1954 figures for Federal support to industry include support to industry-administered FFRDCs, whereas the figures for subsequent years do not. (See appendix table 2-6.)

Figure 2-7.
Federal R&D support, by performing sector



See appendix tables 2-6 and 2-7.

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thereafter to $34.6 billion in 1987, and then fell sharply again to $19.3 billion in 1994. From 1994 to 1998, however, Federal support to industry has been relatively unchanged—ranging from $19.3 to $19.7 billion (in constant 1992 dollars). These trends reflect the historical shifts in Federal priorities on defense-, space-, heath-, and energy-related R&D. (See sidebar, "FY 1998 is Final Year for Tracking of Independent Research and Development Defense Spending.")

Federal funding to FFRDCs and nonprofit organizations has undergone much less fluctuation since 1953. Federal support to nonprofit organizations displayed steady growth overall for the 1953–98 period. Support to FFRDCs grew substantially in real terms between 1955 and 1963, experienced almost no real growth between 1963 and 1981, grew substantially again between 1981 and 1985, and has since experienced a gradual decline in real funding. (See figure 2-7.)

Federal financing for industrial R&D, including industry FFRDCs, has varied markedly across time and across different industries. The Federal Government provided $23.9 billion for industry R&D in 1997 (the most recent year for which detailed data by industrial category are available). Aerospace companies (or the industrial sector "aircraft and missiles") alone received 44 percent of all Federal R&D funds provided to all industries. Consequently, 65 percent of the aerospace industry's R&D dollars came from Federal sources; the remaining 35 percent came from those companies' own funds. In comparison, the drugs and medicines sector in 1997 financed 100 percent of its R&D from company funds; machinery financed 99 percent of its R&D from company funds, professional and scientific instruments financed 67 percent from company funds, transportation equipment other than aircraft and missiles financed 90 percent from company funds, business services financed 97 percent from company funds, and engineering and management services financed 64 percent from company funds.[12]

Federal funding of R&D in aircraft and missiles has declined between 1985 and 1997, both as a percentage of total Federal support to all industries and as a percentage of the aircraft and missiles sector's total R&D. (See figure 2-8.) Nevertheless, the aircraft and missiles sector has continued to receive more Federal support than any other industrial sector in actual dollars. The exact amounts, however, seem somewhat in question. Classifying and tracking Federal support for defense-related industrial R&D appears to be extremely difficult. (See "Accounting for Defense R&D: Gap Between Performer- and Source-Reported Expenditures.")

Federal R&D support for professional and scientific instruments rose sharply between 1988 and 1997—from 0.6 percent of all Federal support to industry to 19 percent of all Federal support. Likewise, Federal support in this area grew from only 3 percent of the sector's total R&D performance in 1988 to 33 percent 1997. (See figure 2-8.)

Interestingly, Federal funds devoted to the nonmanufacturing sector grew from 9 to 17 percent between 1985 and 1997. Because total Federal support to industry declined in real terms over this period, however, Federal support to R&D in nonmanufacturing as a percentage of all R&D in nonmanufacturing declined markedly over the same period—from 34 percent in 1985 to 11 percent in 1997.

Also declining over this period—both as a percentage of the Federal contribution and as a percentage of each of the sectors' total R&D performance—was Federal support for R&D in electrical equipment, transportation equipment other than aircraft and missiles, and machinery. (See figure 2-8.)

Federal Support for Small Business R&D

In addition to traditional government procurement for R&D that tends to be performed by large companies, Federal R&D support is also provided through its Small Business Innovation Research (SBIR) Program. Created in 1982 to strengthen the role of small firms in Federally supported R&D, the SBIR Program presently consists of 10 independently administered Federal agency programs; it is the country's largest merit-based competitive grants program available to small businesses. Through FY 1997, the SBIR Program had directed nearly 46,000 awards worth more than $7.5 billion in R&D support to thousands of qualified small high-technology companies on a competitive basis. Under this program—which is coordinated by the Small Business Administration (SBA) and is in effect until the year 2000—when an agency's external R&D obligations (those exclusive of in-house R&D performance) exceed $100 million, the agency must set aside a fixed percentage of such obligations for SBIR projects. This per-

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[12] The 100 percent company funding for the drugs and medicines sector does not include the benefits this sector receives from R&D financed by NIH.

FY 1998 is Final Year for Tracking of Independent Research and Development Defense Spending

In addition to the Federal R&D obligations discussed in this chapter, DOD's Independent Research and Development (IR&D) Program enables industry to obtain Federal funding for R&D conducted in anticipation of government defense and space needs. Because private contractors initiate IR&D themselves, IR&D is distinct from R&D performed under contract to government agencies for specific purposes. IR&D allows contractors to recover a portion of their in-house R&D costs through overhead payments on Federal contracts on the same basis as general and administrative expenses.*

Until 1992, all reimbursable IR&D projects were to have "potential military relevance." Because of the concern that defense cutbacks would reduce civilian R&D—not only in the level of commercial spillovers from weapons research but, more important, in dramatically reduced DOD procurement from which IR&D is funded—the rules for reimbursement have been successively eased and the eligibility criteria broadened. Reimbursement is now permissible for a variety of IR&D projects of interest to DOD, including those intended to enhance industrial competitiveness, develop or promote dual-use technologies, or provide technologies that address environmental concerns. DOD reimbursed $1.6 billion in 1998. (NASA also reimburses firms for IR&D costs, but those amounts are significantly less—about 5 to 10 percent of the DOD reimbursements.) As an equivalent proportion of DOD's direct industrial R&D support, IR&D fell from 12 percent in 1984 to less than 7 percent in 1998, although the latter figure is undoubtedly on the low side as a result of accounting and statistical changes. (See appendix table 2-43.) Prior to 1993, contractors with auditable costs of $40 million or more were included in the IR&D statistics. Since then, the threshold has included only firms with auditable costs of more than $70 million. As a result of auditing and reimbursement policy changes that allow practically all of industry's IR&D claims, future collection of IR&D data is not expected.

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*In national statistics on R&D performance and funding, industrial firms are requested to report IR&D expenditures as industry-funded, industry-performed R&D. Ultimately, firms expect to be reimbursed for most—but not all—of these expenditures. Federal agencies do not include IR&D obligations in their reported R&D totals. For example, IR&D reimbursements to industry are paid out of DOD's procurement accounts, not its research, development, test, and evaluation (RDT&E) accounts.

centage initially was set at 1.25 percent, but under the Small Business Research and Development Enhancement Act of 1992, it rose incrementally to 2.5 percent by 1997.

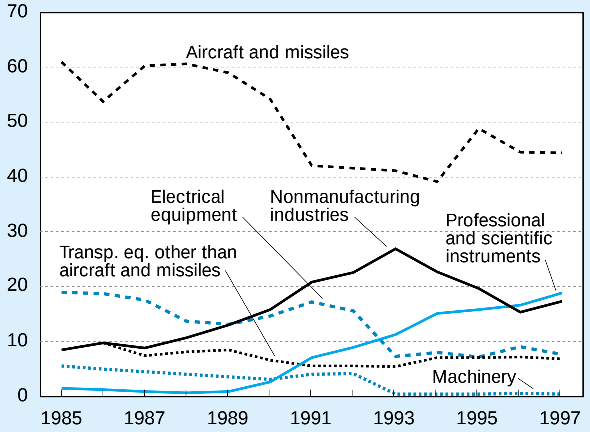
To obtain funding, a company applies for a Phase I SBIR grant. The proposed project must meet an agency's research needs and have commercial potential. If approved, grants of up to $100,000 are made to allow evaluation of the scientific and technical merit and feasibility of an idea. If the concept shows potential, the company can receive a Phase II grant of up to $750,000 to develop the idea further. 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.

Ten Federal agencies participated in the SBIR Program in 1997, making awards totaling $1.1 billion—an amount equivalent to 1.6 percent of all government R&D obligations (2 percent of Federally funded R&D performed outside of government labs). The total amount obligated for SBIR awards in 1997 was 20 percent more than in 1996—a result of legislatively required increases in R&D amounts agencies must earmark for SBIR. Since 1992, SBIR funding has more than doubled, while total Federal R&D funding has increased by just 5 percent. In FY 1997, 74 percent of total SBIR funds were disbursed through Phase II grants, although 71 percent of the grants awarded were Phase I grants (3,371 of 4,775 awards). Approximately 51 percent of all SBIR obligations were provided by DOD, mirroring this agency's share of the Federal R&D extramural funding total. (See appendix table 2-44.)

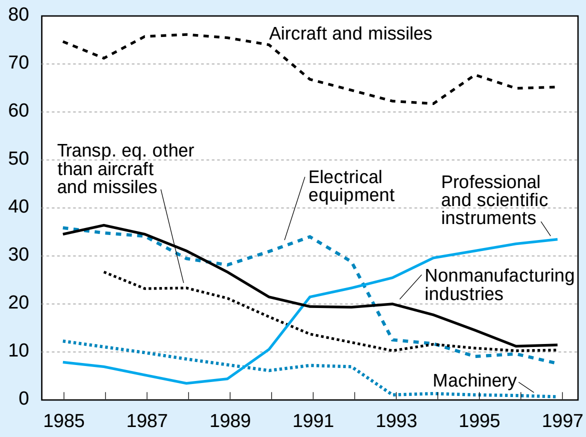
Except for evaluations undertaken by GAO, there have been few independent assessments of the overall effectiveness of the SBIR Program. Where such assessments do exist, however, there is general agreement that the quality of funded research proposals is high and that the value of the program in fostering small business technology-led economic growth is apparent. (See, for example, GAO 1997a and 1998.) In a recent assessment of program administrators' perspectives on SBIR strengths and weaknesses, Federal and state partners agreed that SBIR is invaluable as an effective catalyst for the development of technological innovations by small businesses. Indicative of this viewpoint, all but two states—Kentucky and Pennsylvania—currently have some structured SBIR promotion or assistance effort underway (SSTI 1999b). Most state initiatives focus on the early stages of the SBIR process—for example, creating awareness of the program and supporting pre-Phase 1 activities. (See text table 2-5.)

SBA classifies SBIR awards into various technology areas. In terms of all SBIR awards made during the 1983–97 period, the fine technology areas receiving the largest (value) share of awards were advanced materials, electronics device performance, electromagnetic radiation, and computer communications systems. More broadly, more than one-fourth of all awards made from 1983 to 1997 were electronics-related, and roughly one-sixth involved computers. (See figure 2-9.) Computer- and electronics-related projects received more than 70 percent of their support from DOD and NASA. One-seventh of all SBIR awards went to life sci-

Figure 2-8.
Federal support for R&D in selected industries as a percentage of all Federal support to industrial R&D



Federal support for R&D in selected industries as a percentage of all total R&D performed in those industries



See appendix tables 2-53, 2-54, and 2-55.

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ences research; the bulk of this funding was provided by HHS (SBA 1998).

U.S. Federal and State R&D Tax Credits

Federal R&D Tax Credits

The U.S. government has tried various policy instruments in addition to direct financial R&D support to indirectly stimulate corporate research spending. Proponents of such measures commonly note that, especially as Federal discretionary spending for R&D is squeezed, incentives must be used to invigorate U.S. investment in private-sector innovation to expand U.S. global leadership in high technology. The most notable of these efforts have been tax credits on incremental

Text table 2–5.
Number of states offering different types of SBIR assistance and services: 1998

Stage in the SBIR Program	Service or Activity	Number
Awareness	Outreach conference	45
	Information clearinghouse	37
	Website	35
	Proactive topic match	18
	Marketing & press release	17
	SBIR newsletter	10
Phase 0	Proposal writing workshops	37
	Proposal assistance	31
	Proposal critique	30
	Reactive topic match	22
	Project team assembly	21
	Literature searches	16
	Phase 0 grants	11
	Marketing topics to agencies	10
Phase I	Trouble shooting for winners	20
	Mentor networks	16
	Winner recognition	11
	Local focus groups	6
	Phase 1 matching funds	5
Pre-Phase II	Strategic alliances	28
	Bridge financing	8
Phase II and beyond	Commercialization assistance	25
	Technology transfer	19
	Phase III investments	5
	Phase II matching funds	2

SOURCE: State Science and Technology Institute (SSTI), *State and Federal Perspectives on the SBIR Program*, Westerville, OH: SSTI, 1999.

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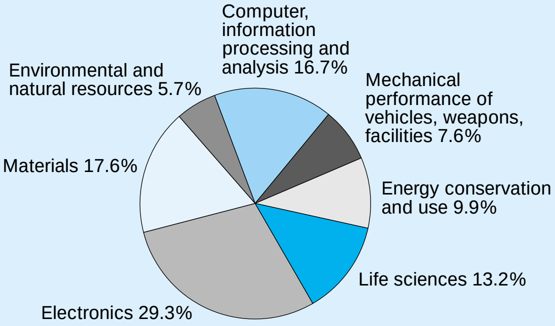
Figure 2-9.
Small business innovation research awards, by technology area: 1983–97



SOURCE: Small Business Administration, Annual Report–FY 1997.

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research and experimentation (R&E) expenditures.[13] The credit was first put in place in 1981; it has been renewed nine times, most recently through the end of June 1999.[14] Although the computations are complicated, the tax code provides for a 20 percent credit for a company's qualified R&D amount that exceeds a certain threshold.[15] Since 1986, companies have been allowed to claim a similar credit for basic research grants to universities and other qualifying nonprofit institutions, although otherwise deductible R&E expenditures are reduced by the amount of the basic research credit. This basic research provision generally has gone unutilized.[16]

According to a report prepared for the Joint Economic Committee of the U.S. Congress (based on information from the Internal Revenue Service Statistics of Income publications), more than 12,000 firms use the tax credit (Whang 1998b). From tax years 1991 through 1995 (the latest year of available data), an average of 12,472 firms filed claims totaling $1.85 billion each year, although not all claims are allowed and not all of the allowed credits can be taken immediately. (Thus, the dollar value of R&E tax credits actually received by firms is unknown.) In dollar terms, the largest credits are claimed by large manufacturers—especially pharmaceuticals, motor vehicles, aircraft, electronics and computer firms. Companies with more than $250 million in assets account for three-quarters of the dollar value of all credit claims. On the other hand, three-quarters of credit claimants have assets of $25 million or less, and many claims are filed by medium-sized manufacturers and service providers.

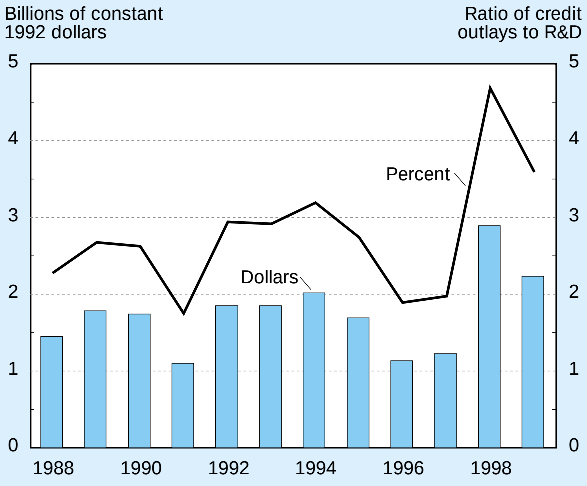
Budget Impact of Federal Tax Credits

To determine the budgetary effect of the credit, the Treasury Department annually calculates estimates of foregone tax revenue (tax expenditures) resulting from preferential tax provisions, including the R&E tax credit. As one such measure, Treasury provides outlay-equivalent[17] figures that allow a comparison of the cost of this tax expenditure with the cost of a direct Federal R&D outlay. Between fiscal years 1981 and 1998, an outlay-equivalent of more than $32 billion was provided to industry through this indirect means. For FY 1998 alone, Treasury calculates an outlay-equivalent of $3.3 billion from the R&D tax credit. Consequently, these credits were equivalent to about 3.2 percent of direct Federal R&D support for the entire 1981–98 period and a record 4.7 percent of direct Federal obligations in FY 1998. (See figure 2-10 and appendix table 2-45.)

State R&D Tax Credits

The Federal Government is not the only source of fiscal incentives for increasing research. According to a survey of the State Science and Technology Institute (SSTI 1997a), 35 states offered some type of incentive for R&D activity in 1996. Many states offered an income tax credit modeled after the Federal R&E credit guidelines. Fifteen states applied the Federal research tax credit concepts of qualified expenditures or base years to their own incentive programs, although they frequently specified that the credit could be applied only to expenditures for activities taking place within the state. Other types of R&D incentives included sales and use tax credits and property tax credits.

Figure 2-10.
Budgetary impact of Federal research and experimentation tax credit: FYs 1988-99



See appendix table 2-45.

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[13] Not all R&D expenditures are eligible for such credit, which is limited to expenditures on laboratory or experimental R&D.

[14] Simply knowing whether the tax credit is in effect is a formidable challenge. Annual extensions have become the norm, and credits are often reinstated retroactively one or two months after the credit expires. At this writing, provision for the tax credit had once again lapsed, but congressional indications were that the credit would be renewed again, retroactively to July 1, 1999, and perhaps with a five-year extension.

[15] The complex base structure for calculating qualified R&D spending was put in place by the Omnibus Reconciliation Act of 1989. With various exceptions, a company's qualifying threshold is the product of a fixed-base percentage multiplied by the average amount of the company's gross receipts for the four preceding years. The fixed-base percentage is the ratio of R&E expenses to gross receipts for the increasingly distant 1984–88 period. Special provisions cover startup firms. An alternative credit was established in 1996 that is not dependent on a firm's incremental R&D. Instead, a 1.65 percent to 2.74 percent credit is awarded for all research expenses exceeding 1 percent of sales. The marginal value of this credit has provided minimal incentive for firms (Whang 1998a).

[16] In 1992 (the latest year for which any such data exist), firms applying for the R&E credit spent about $1 billion on research performed by educational and scientific organizations. After accounting for various qualification restrictions, the basic research credit contributed less than $200 million toward the R&E tax credit (OTA 1995; Whang 1998a).

[17] Specifically, the "outlay-equivalent" measure is the amount of outlay that would be required to provide the taxpayer the same after-tax income as would be received through the tax preference. These amounts tend to be greater than estimates of Federal "revenue losses" from the credit because the outlay program increases the taxpayer's pre-tax income.

State Government Support for R&D

The pivotal role of state governments in expanding regional economic growth through science and technology (S&T) development is a widely recognized, albeit relatively recent, phenomenon. Almost all states have established lead S&T offices; the existence of most of these offices can be traced only to the mid- to late 1980s (NSB 1991). During the 1990s, states increasingly have included an S&T component in their economic development plans. Many states have adopted statewide S&T strategic initiatives of varying levels of sophistication and complexity (SSTI 1997b). A review of "State of the State" speeches, inaugural addresses, and budget messages delivered by most governors in the early part of 1999 indicates a continuing high level of interest in S&T-based economic development (SSTI 1999a). Common to these plans is the acknowledged importance of:

- Maintaining and strengthening the R&D capacity of the states' colleges and universities;
- Encouraging "home grown" businesses by providing support to entrepreneurs and small technology-based firms; and
- Facilitating the incorporation of new technology into processes and products.

States have become particularly adept at leveraging funds and fostering university-industry partnerships.

NSF has sponsored intermittent surveys of state governments' R&D expenditures dating to the mid-1960s. Over the past 30 years, growth in state R&D support is readily apparent; it generally has been proportionate to changes in other R&D indicators. (See text table 2-6.) Between 1965 and 1995, total state R&D spending increased at an inflation-adjusted average annual rate of 3.3 percent, compared with nationwide R&D spending growth of 2.5 percent per year (NSF 1999d). State sources of state R&D spending grew by 3.4 percent annually, from $732 million (1992 dollars) in 1965 to $2.010 billion (1992 dollars) in 1995. Most of the remaining funds derived from Federal agency support to state agencies. In 1995, state sources for R&D expenditures were equivalent to 1.18 percent of total R&D spending in the United States—a figure similar to the percentages estimated for 1987 and 1977 (1.20 and 1.21 percent, respectively) and somewhat higher than the 1965 estimate (of 0.9 percent). As a percentage of GDP, state sources for R&D have ranged narrowly between 0.025 and 0.032 percent during the 1965–95 period for which there are data. These data also show that universities historically have received the lion's share of state-funded R&D. In 1995, 80 percent of all state R&D funds from state sources supported university activities—only slightly higher than their estimated 78 percent share in 1965.

According to a report by Battelle and the State Science and Technology Institute (Battelle/SSTI 1998), 45 percent of all R&D funds from state sources ($2.431 billion) in 1995 were in support of the "science and technology base" ($1.088 billion), which includes research capacity building. (See text table 2-7.) These funds were spent predominately in support of university-based research. The only functional categories other than "science and technology base" to receive 10 percent or more of states' R&D funds were "food, fiber, agriculture" ($305 million) and "health" ($244 million). Universities

Text table 2–6.
Trends in state government R&D expenditures
(Billions of constant 1992 dollars[a])

	1965	1977	1987	1995
Total state R&D spending[b]	0.884	1.451	2.093	2.336
State sources	0.732	1.112	1.830	2.010
Federal sources	0.144	0.299	0.242	0.240
Non-government sources[c]	0.008	0.040	0.020	0.086
State R&D indicators (percent)				
State R&D/U.S. R&D	1.09	1.58	1.37	1.37
State sources/U.S. R&D	0.90	1.21	1.20	1.18
State R&D/U.S. GDP	0.031	0.034	0.037	0.035
State sources/U.S. GDP	0.025	0.026	0.032	0.030

NOTE: Because of rounding, details may not add to totals. Excludes expenditures on R&D plant. Annual survey data in this table were adjusted data to permit direct comparisons.

[a] GDP implicit price deflators used to convert current dollars to constant dollars.

[b] Includes all funds under state government control. These include state sources such as direct appropriations and funds generated from state bonds, funds from the Federal Government that pass through state agencies, and leveraged funds from industry and other non-government sources.

[c] Non-government sources include industry and other non-state, non-Federal sources such as donations, endowments, and gifts from private individuals or foundations.

SOURCE: National Science Foundation, Division of Science Resources Studies, *What is the State Government Role in the R&D Enterprise?* Arlington, VA: 1999.

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Text table 2–7.
State sources of R&D expenditures, by functional purpose: FY 1995

	($ millions)	Percent
Total	2,431.1	100.0
Science & technology base	1,087.7	44.7
Food, fibre, agriculture	305.4	12.6
Health	243.7	10.0
Economic development	192.1	7.9
Other functions, n.e.c.	158.4	6.5
Environment	110.1	4.5
Education	101.9	4.2
Transportation	80.9	3.3
Natural resources	78.7	3.2
Energy	44.1	1.8
Community development	16.8	0.7
Income security/social services	9.4	0.4
Crime prevention/control	1.9	0.1

SOURCE: Battelle Memorial Institute and State Science and Technology Institute, *Survey of State Research and Development Expenditures FY 1995*. Columbus, OH: Battelle/SSTI, 1998.

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were the primary recipients for funding in both of these categories. "Health" was the single largest functional focus of R&D performed by state agencies; almost 25 percent of the $244 million state-funded state-performed R&D was health-related. R&D explicitly related to "economic development" accounted for 8 percent ($192 million) of total state R&D funding in 1995. Reflecting recent trends to use R&D in support of local business and economic growth, however, "economic development" accounted for 38 percent of state R&D funds to industry ($33 million of the $87 million provided) and 53 percent of state R&D funds to nonprofit organizations ($55 million of $105 million). By comparison, the functionally equivalent category of "economic growth and productivity" accounted for only 5 percent of state funding for R&D to all performers in 1987 and for 2.2 percent of total in 1977 (NSF 1999d).

Historical Trends in Non-Federal Support

R&D financing from non-Federal sources grew by 5.9 percent per year (controlling for inflation) between 1953 and 1980. Between 1980 and 1985, concurrent with gains in Federal R&D spending, it grew at an even faster rate of 7.4 percent per year in real terms. It then slowed to 4.1 percent between 1985 and 1990 and 2.9 percent between 1990 and 1995, but it was back up to 8.4 percent for the 1995–98 period.

Most non-Federal R&D support is provided by industry. Of the 1998 non-Federal support total ($160.2 billion), 93.4 percent ($149.7 billion) was company funded, representing a 8.7 percent increase over its 1997 level in real terms. Industry's share of national R&D funding first surpassed that of the Federal Government in 1980; 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 7.6 percent. This growth was maintained through the mild 1980 recession and the more severe 1982 recession. (See figure 2-1.) Key factors behind increases in industrial R&D have 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 2.8 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 2.4 percent. In contrast, from 1994 to 1998, industrial R&D support grew in real terms by 8.9 percent per year, compared with a 3.4 percent growth rate for the economy overall.

As one might expect, however, growth of industrial R&D varied significantly among different industrial sectors.[18] The largest sectors in recent years have been chemicals and allied products, electrical equipment, machinery, nonmanufacturing, and transportation equipment. (See appendix tables 2-53 and 2-54.) Between 1985 and 1997, the industrial sectors with the highest rates of annual growth in real R&D performance, from non-Federal sources, have been nonmanufacturing (14.7 percent); paper and allied products (4.9 percent); electrical equipment (4.7 percent); and lumber, wood products, and furniture (4.3 percent). Industries experiencing the greatest annual declines (or negative growth) in R&D over the same period were stone, clay, and glass products (–5.3 percent); petroleum refining and extraction (–5.3 percent); primary metals (–2.5 percent); and food, kindred, and tobacco products (–0.9 percent). (See appendix table 2-54.)

R&D funding from other non-Federal sectors—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 5.2 percent between 1980 and 1985, 8.2 percent between 1985 and 1990, 2.3 percent between 1990 and 1995, and 3.9 percent between 1995 and 1998. The level of $10.6 billion in funding in 1998 was 4.8 percent higher in real terms than the 1997 level. Most of these funds have been used for research performed within the academic sector.

Trends in R&D Performance

U.S. R&D/GDP Ratio

Growth in R&D expenditure 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, 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

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[18] For studies of patterns of technological change among different industrial sectors, see, for example, Nelson (1995); Pavitt (1984); Utterback (1979).

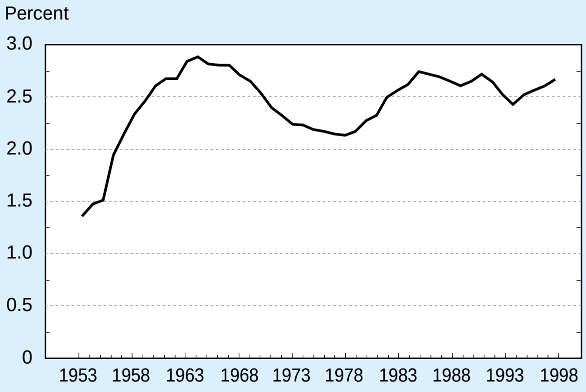
of 2.88 percent in 1964, followed by a gradual decline to 2.13 percent in 1978. (See figure 2-11.) R&D expenditures rose steadily again to a peak of 2.74 percent of GDP in 1985 and did not fall below 2.6 percent until 1993. In 1994, the ratio dropped to 2.43 percent—the lowest it had been since 1981. Starting in 1994, however, R&D/GDP has been on an upward trend as investments in R&D have outpaced growth on the general economy. As a result, the current ratio of 2.67 for 1998 is the highest since 1991.

The initial drop in the R&D/GDP ratio from its peak in 1964 largely reflected 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 at around 2.2 percent. (See figure 2-11.) Over the entire 1965–78 period, the annual percentage increase in real R&D was less than the annual percentage increase in real GDP. In years 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 as much a result of a slowdown in GDP growth as 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 broader economic measures.

R&D/GDP decreased from 2.74 percent in 1985 to 2.61 percent in 1989 but rose to 2.72 percent by 1991. (See figure 2-11.) Again, the ratio tended to fall when GDP experienced relatively fast real growth and rise when it experienced relatively slow real growth. Nevertheless, R&D itself was also affected. The share of R&D that was defense related dropped from 31.1 percent in 1985 to 22.6 percent in 1991. Commensurate with this change was the sharp fall in the share of R&D that was Federally funded—from 46.0 percent in 1985 to 37.8 percent in 1991. (See figure 2-3.) This decline in Federal funding was counterbalanced by increased non-Federal funding.

Figure 2-11.
Historical pattern of R&D as a percentage of GDP: 1953–98



See appendix tables 2-1 and 2-3.

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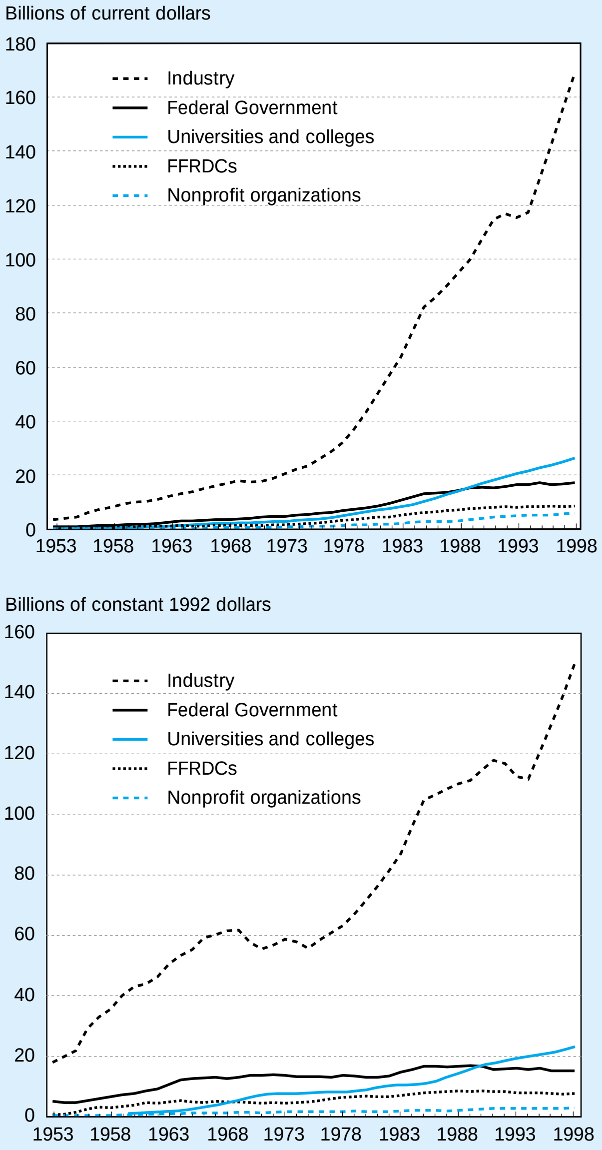
Rates of Growth Among Sectors

The sectoral shares of U.S. R&D performance, measured in terms of expenditures, have shifted significantly since the early 1980s. (See figure 2-12.) 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 performed 12.4 percent, and the nonprofit sector (including nonprofit-administered FFRDCs) performed 3.4 percent. As industry’s defense-related R&D efforts

Figure 2-12.
National R&D performance, by type of performer: 1953–1998



FFRDC = Federally Funded Research and Development Centers

See appendix tables 2-3 and 2-4.

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accelerated in the early 1980s, its share of the performance total rose to 73.4 percent in 1985.

From 1985 to 1994, R&D performance grew by only 1.1 percent per year in real terms for all sectors combined. This growth was not evenly balanced across sectors, however. R&D performance at universities and colleges (including their FFRDCs) grew by 4.1 percent per year in real terms, compared with 0.7 percent real annual growth for industry, a decline of 0.7 percent per year for Federal intramural performance, and growth of 2.9 percent per year for nonprofit organizations (including their FFRDCs).

The period from 1994 to 1998 witnessed dramatic changes in these growth rates. Total R&D performance, in real terms, averaged 5.8 percent growth per year—substantially higher than in the earlier sluggish period. Yet R&D performance at universities and colleges (including their FFRDCs) grew by only 2.5 percent per year in real terms. Industry R&D performance (including their FFRDCs) grew at a remarkable rate of 7.6 percent in real terms. (See figure 2-7.) Federal intramural performance declined by 0.6 percent per year in real terms. Nonprofit organizations (including their FFRDCs), according to current estimates, saw their R&D increase by only 2.0 percent per year in real terms over the same four-year period.

According to preliminary estimates, in 1998 academia (including FFRDCs) accounted for 14.0 percent of total U.S. R&D performance, Federal intramural activities 7.6 percent, other nonprofit organizations (including FFRDCS) 3.0 percent, and private industry (including FFRDCS) 75.4 percent. (See text table 2-1.)

Federal R&D Performance

The Federal Government, excluding FFRDCs, performed $17.2 billion of total U.S. R&D in 1998. This figure was slightly higher than the level for 1997 ($16.8 billion), which reflected only 1.2 percent growth after adjusting for inflation. Federal agencies accounted for 7.6 percent of the 1998 national R&D performance effort—continuing the gradual decline, since 1972, of Federal performance as a percentage of total R&D.

DOD has continued to perform more Federal intramural R&D than any other Federal agency; in fact, in 1998 it performed more than twice as much R&D as the next-largest R&D- performing agency, HHS (whose intramural R&D is performed primarily by NIH). (See text table 2-4.) DOD's intramural R&D performance has grown by less than 1 percent per year in real terms since FY 1980, however, reaching a level of $7.8 billion in FY 1998. Furthermore, an undetermined amount of DOD's intramural R&D ultimately appears to be contracted out to extramural performers. NASA's intramural R&D has grown by 1.7 percent per year in real terms since 1980, to $2.5 billion in FY 1998, while HHS intramural performance has grown by 3.7 percent, to $3.0 billion.[19] Together, these three agencies accounted for 77 percent of all Federal intramural R&D in FY 1998. (See text table 2-4.)

Total R&D performed by industrial, academic, and nonprofit FFRDCs combined reached $8.7 billion in 1998, which is essentially the same as its level of $8.4 billion in 1997 after adjusting for inflation. R&D at FFRDCs in 1998 represented 3.8 percent of the national R&D effort; most of this R&D ($5.5 billion in 1998) was performed by university- and college-administered FFRDCs.

Industrial R&D Performance

Recent Growth in Industrial R&D

R&D performance by private industry reached $171.3 billion in 1998, including $2.4 billion spent by FFRDCs administered by industrial firms. This total represented a 7.6 percent increase over the 1997 level of $157.5 billion—which, in turn, reflected a smaller, though still notable, real gain of 6.9 percent over 1996.

In 1998, R&D performed by industry that was not Federally financed rose 8.7 percent in real terms above its 1997 level. Overall, private companies (excluding industry-administered FFRDCs) funded 86.8 percent ($146.7 billion) of their 1998 R&D performance, with the Federal Government funding nearly all of the rest ($22.2 billion, or 13.2 percent of the total). Between 1997 and 1998, there was little or no change, in real terms, in Federal funds for these industrial R&D activities. As recently as 1987, the Federal funding share of industry's performance total (excluding FFRDCs) was 31.9 percent; however, the Federal share of industry's performance has been steadily declining since its peak of 56.7 percent in 1959. Much of that decline can be attributed to declines in Federal funding to industry for defense-related R&D activities.

R&D in Manufacturing Versus Nonmanufacturing Industries

The tendency for R&D to be performed more by large firms than small firms is greater in the manufacturing sector than in the nonmanufacturing sector. However, within each of these two sectors there is considerable variation in this regard, depending on the type of industry. Among industrial categories, those in which most of the R&D is conducted by large firms include aircraft and missiles, electrical equipment, professional and scientific instruments, transportation equipment (not including aircraft and missiles), and transportation and utilities (which is in the nonmanufacturing sector). (See text table 2-10.) In these sectors, however, much of the economic activity overall is carried out by large firms; consequently, the observation that most of the R&D in these sectors is conducted by large firms is not surprising.

Probably the most striking change in industrial R&D performance during the past two decades is the nonmanufacturing sector's increased prominence. Until the 1980s, little attention was paid to R&D conducted by nonmanufacturing companies, largely because service sector R&D activity was negligible compared to the R&D operations of companies in manufacturing industries.

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[19] This increase represents the overall effect on intramural R&D for the agency, which takes into account the Social Security Administration (SSA) becoming a separate agency from HHS during fiscal year 1995. That is, the percentage increase reported would be larger, though negligibly, if HHS in 1995 had been defined as excluding SSA, as it is in 1996.

Text table 2–8.

Total (company, Federal, and other) funds for industrial R&D performance and number of R&D-performing companies in manufacturing and nonmanufacturing industries, by size of company: 1997

Distribution by size of company (Number of employees)		Funds for industrial R&D (Dollars in millions)	
Number of employees	Total	Manufacturing	Nonmanufacturing
Total	$157,539	$121,025	$36,514
Fewer than 500	24,063	8,248	15,815
500 to 999	4,966	2,905	2,061
1,000 to 4,999	19,590	14,300	5,289
5,000 to 9,999	14,266	11,670	2,596
10,000 to 24,999	21,510	16,874	4,636
25,000 or more	73,144	67,028	6,116
Number of R&D-performing companies			
Total	35,112	18,130	16,982
Fewer than 500	31,995	15,898	16,097
500 to 999	1,127	886	241
1,000 to 4,999	1,302	938	364
5,000 to 9,999	322	197	125
10,000 to 24,999	199	138	61
25,000 or more	167	73	94

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Survey of Industrial Research and Development, 1997.*

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Prior to 1983, nonmanufacturing industries accounted for less than 5 percent of the industry R&D total. By 1993, this percentage had risen to an all-time high of 26 percent. It has fallen only slightly since then and has remained above 22 percent.[20] (See text table 2-9 and figure 2-13.)

In 1997, nonmanufacturing firms' R&D performance totaled $36.5 billion—$32.4 billion in funds provided by companies and other non-Federal sources and $4.1 billion in Federal support. (See appendix tables 2-53 and 2-54.) The large upswing in the percentage of nonmanufacturing R&D primarily reflects a sharp rise in company-supported nonmanufacturing R&D from 1987 to 1991. (See figure 2-13.) Moreover, the recent drop in this percentage in 1995–97 is attributable not to any decrease in the level of R&D from nonmanufacturing companies but to a sharp increase in company-supported R&D by manufacturing firms.

Because of recent changes in classification, little historical information exists regarding the decomposition of R&D for all nonmanufacturing firms into nonmanufacturing industrial categories. In 1997, however, the largest component of R&D for nonmanufacturing companies was R&D performed by computer and data processing services, which accounted for 8.5 percent of all industrial R&D performance. (See text table 2-9.) Wholesale and retail trade account for another 6.0 percent, and engineering and management services account for 4.4 percent. The "research, development, and testing"

Text table 2–9.

Percentage share of total company and other non-Federal funds, by selected R&D-performing industries

	1987	1997
All manufacturing industries	91.6	75.7
Industrial and other chemicals (except drugs and medicines)	8.7	5.3
Drugs and medicines	6.7	8.7
Petroleum refining and extraction	3.1	1.2
Machinery	17.2	13.8
Electrical equipment	17.0	17.0
Motor vehicles and motor vehicles equipment	11.7	10.3
Aircraft and missiles	9.7	4.2
Professional and scientific instruments	8.1	6.7
All nonmanufacturing industries	8.4	24.3
Communications services	1.7	1.4
Computer and data processing services	NA	8.5
Research, development, and testing	0.9	3.6
Wholesale and retail trade	NA	6.0
Engineering and management services	NA	4.4
Health services	NA	0.5
Finance, insurance, and real estate	NA	1.1

NA = not available

SOURCE: National Science Foundation, Division of Science Resources Studies, *Survey of Industrial Research and Development, 1997.*

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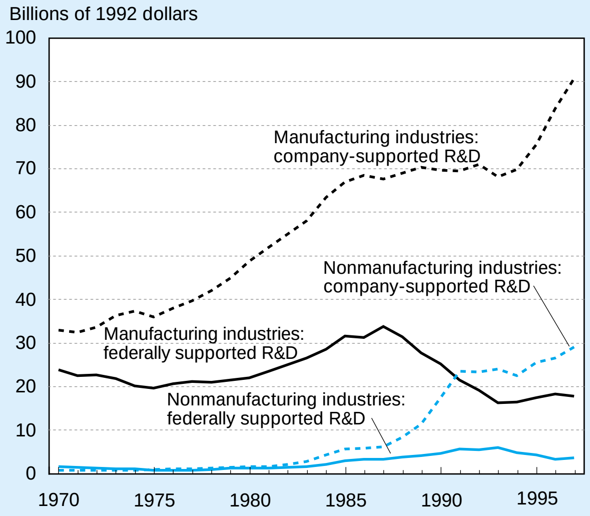
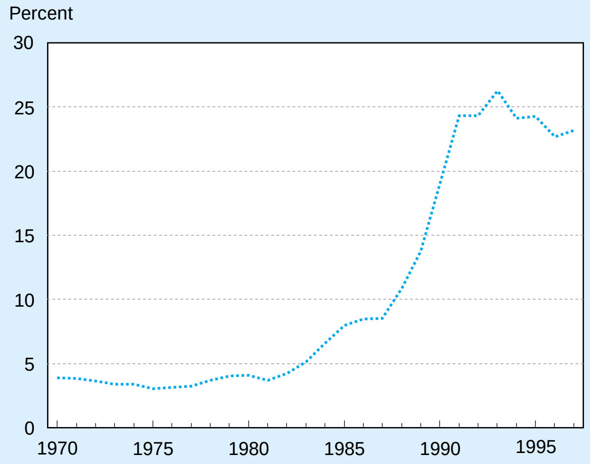
[20] As a result of a new sample design, industry R&D statistics since 1991 better reflect R&D performance among firms in the nonmanufacturing industries and small firms in all industries than they had previously. As a result of the new sample design, statistics for 1991 and later years are not directly comparable with statistics for 1990 and earlier years.

Figure 2-13.
Industrial R&D performance, by manufacturing and nonmanufacturing industries



Nonmanufacturing R&D performance as a percentage of total industrial performance



See appendix table 2-52.

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sector accounted for 3.6 percent of total industrial R&D; communications services for 1.4 percent; and finance, insurance, and real estate services for 1.1 percent.

Although a great deal of R&D in the United States is related in some way to health services, companies that are specifically categorized in the health services sector accounted for only 0.5 percent of all industrial R&D and only 2 percent of all R&D by nonmanufacturing companies. These figures illustrate that R&D data disaggregated according to standard 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.[21] (The analysis in “R&D in Chemistry, Life Sciences, and Information Technology” compensates to some extent for this limitation in the data by providing R&D expenditure levels associated with these fields.)

On average, industrial manufacturing R&D performers are quite different from industrial nonmanufacturing R&D performers. Nonmanufacturing R&D is characterized as having many more small R&D firms than manufacturing R&D performers. (See text table 2-10.) Approximately 35,000 firms in the United States perform R&D, of which 18,000 are manufacturers and 17,000 are in the nonmanufacturing sector—nearly a 50-50 split. Yet manufacturers account for 77 percent of total industry performance (including Federally funded industry performance). The main reason for this continued dominance of the manufacturing sector is simply 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 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. Among large R&D-performing firms (more than 25,000 employees) in both sectors, however, those in the manufacturing sector tend to conduct more than 10 times as much R&D per firm as those in the nonmanufacturing sector.

Top 20 U.S. Corporations in R&D Spending

Of the top 20 U.S. corporations in R&D expenditures in 1997 (see text table 2-11), only one—Microsoft Corporation, which had 22 thousand employees—had fewer than 25 thousand employees. The corporation that performed the most R&D in 1997 was General Motors ($8.2 billion); another company in the motor vehicle sector, Ford Motor Company, performed $6.3 billion in R&D. The next three corporations were IBM, Lucent Technologies, and Hewlett-Packard ($4.3, $3.1, and $3.1 billion in R&D, respectively). All of the top 20 corporations were associated with motor vehicle manufacturing, computers, communication equipment, or pharmaceuticals—with the exception of Procter and Gamble, which fell into the category of “other chemicals (soaps, ink, paints, fertilizers, explosives).”[22]

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[21] For a more detailed discussion of limitations in the interpretation of R&D levels by industrial categorization, see Payson (1997).

[22] These data on R&D for individual corporations were obtained from a source that is different from the NSF Survey of Industrial Research and Development—namely, from the U.S. Corporate R&D database, as provided by Shepherd and Payson (NSF 1999e). Consequently, the definition of R&D in this case is not equivalent to that in the Industry R&D Survey. In particular, the U.S. Corporate R&D database derives from R&D reported in the Standard and Poor’s *Compustat* database. As such, these R&D figures include R&D conducted by these companies outside the U.S., whereas the Industry R&D Survey includes only R&D performed within the U.S. Because of this difference in the data and other differences as outlined in NSF1999e, R&D data appearing in text table 2-11 and appendix table 2-58 should not be used in conjunction with R&D data originating from NSF’s Industry R&D Survey.

Text table 2–10.

Industry R&D performed by different size firms, for selected sectors: 1997

(Dollars in millions)

Industry	Sectors with more than 50 percent R&D performed by large firms (with over 25 thousand employees)	Size of company in terms of the number of employees						
		Total	Fewer than 500	500 to 999	1,000 to 4,999	5,000 to 9,999	10,000 to 24,999	25,000 or more
All Industries		**157,539**	**24,063**	**4,966**	**19,590**	**14,266**	**21,510**	**73,144**
Manufacturing		121,025	8,248	2,905	14,300	11,670	16,874	67,028
Aircraft and missiles	X	16,296	(D)	(D)	173	599	(D)	15,331
Drugs and medicines		11,589	234	54	2,047	2,207	3,737	3,311
Electrical equipment	X	24,585	1,789	854	3,628	3,114	1,953	13,248
Fabricated metal products		1,798	451	(D)	205	189	455	(D)
Food, kindred, and tobacco products		1,787	101	65	265	391	262	703
Lumber, wood products, and furniture		348	74	22	77	96	79	0
Office, computing, and accounting machines		12,840	830	(D)	1,375	904	2,952	(D)
Primary metals		988	47	22	146	233	(D)	(D)
Professional and scientific instruments	X	13,458	1,109	686	2,300	989	652	7,722
Stone, clay, and glass products		608	16	31	72	103	386	0
Transportation equipment (except aircraft and missiles)	X	15,697	(D)	(D)	115	247	(D)	14,537
Nonmanufacturing		36,514	15,815	2,061	5,289	2,596	4,636	6,116
Services		22,400	11,074	(D)	3,252	1,344	3,205	(D)
Transportation and utilities	X	3,013	56	22	138	70	128	2,598

D = data have been withheld to avoid disclosing operations of individual companies.

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Survey of Industrial Research and Development, 1997.*

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Text table 2–11.

The 20 leading industrial R&D companies, ranked by size of R&D expenditures in 1997

Rank	Company	R&D expenditures (millions)	Sales (millions)	Number of employees	Percent change in R&D from the previous year	Industrial category
1	General Motors Corp	8,200.0	168,190	608,000	–7.87	Motor vehicles & motor vehicle equipment
2	Ford Motor Co	6,327.0	153,627	363,892	–7.24	Motor vehicles & motor vehicle equipment
3	Intl Business Machines Corp	4,307.0	78,508	269,465	9.48	Electronic computers and computer terminals
4	Lucent Technologies Inc	3,100.6	26,360	134,000	68.69	Modems & other wired telephone equipment
5	Hewlett-packard Co	3,078.0	42,895	121,900	13.25	Electronic computers and computer terminals
6	Motorola Inc	2,748.0	29,794	150,000	14.79	Radio, TV, cell phone, and satellite communication eq.
7	Intel Corp	2,347.0	25,070	63,700	29.81	Electronic components (semiconductors, coils…)
8	Johnson & Johnson	2,140.0	22,629	90,500	12.34	Drugs: pharmaceutical preparations
9	Pfizer Inc	1,928.0	12,504	49,200	14.49	Drugs: pharmaceutical preparations
10	Microsoft Corp	1,925.0	11,358	22,232	34.43	Prepackaged software
11	Boeing Co	1,924.0	45,800	238,000	60.33	Aircraft, guided missiles & space vehicles
12	Chrysler Corp	1,700.0	58,622	121,000	6.25	Motor vehicles & motor vehicle equipment
13	Merck & Co	1,683.7	23,637	53,800	13.21	Drugs: pharmaceutical preparations
14	American Home Products Corp	1,558.0	14,196	60,523	9.02	Drugs: pharmaceutical preparations
15	General Electric Co	1,480.0	88,540	276,000	4.15	Electrical equipment (industrial & household)
16	Bristol Myers Squibb	1,385.0	16,701	53,600	8.54	Drugs: pharmaceutical preparations
17	Lilly (Eli) & Co	1,382.0	8,518	31,100	16.18	Drugs: pharmaceutical preparations
18	Abbott Laboratories	1,302.4	11,883	54,487	8.10	Drugs: pharmaceutical preparations
19	Procter & Gamble Co	1,282.0	35,764	106,000	5.00	Other chemicals (soaps, ink, paints, fertilizers, explosives)
20	Pharmacia & Upjohn Inc	1,217.0	6,710	30,000	–3.87	Drugs: pharmaceutical preparations

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *U.S. Corporate R&D. Volume II. Company Information on Top 500 Firms in R&D* by C. Shepherd and S. Payson. NSF 00-302. Arlington, VA: NSF.

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R&D Intensity

In addition to absolute levels of, and changes in, R&D expenditures, another key indicator of the health of industrial science and technology is R&D intensity. R&D is similar to sales, marketing, and general management expenses in that it is a discretionary (i.e., non-direct-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 Under-Invest in R&D?")

There are several ways to measure R&D intensity; the one used most frequently is the ratio of R&D funds to net sales.[23] 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 have been

- research, development, and testing services;
- computer and data processing services;
- drugs and medicines;
- office, computing, and accounting machines;

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[23] 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) and Payson (in press).

Does Industry Under-Invest in R&D?

In a report published by the National Institute of Standards and Technology, Tassey (1999) suggests that private industry may be under-investing in R&D for the following reasons:

- **Technology is risky**, not only in terms of achieving a technological advance but in terms of 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, the firm that made the discovery would not recover its R&D costs. Consequently, although 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 initiates the effort may have good reason to be skeptical about its expected gains and may therefore be reluctant to initiate the work in the first place.
- **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 result 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 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 on R&D.
- **Corporate strategies**, according to Tassey, "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 on R&D.
- **Technological infrastructure**, such as the Internet, 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 that, for some large-scale R&D projects, funds from 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 a project is successful, however, high returns on R&D might be realized.

Solutions to these problems would not be simple, but NIST is addressing them. Among NIST's general goal in this regard is to encourage a "more analytically based and data-driven R&D policy" (Tassey 1999, 2).

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* Levitt (1960) has referred to this kind of problem as "marketing myopia."

- optical, surgical, photographic, and other instruments;
- electronic components;
- communication equipment; and
- scientific and mechanical measuring instruments. (See text table 2-12 and appendix table 2-50.)

Among these sectors, the highest R&D intensity (38.5 percent in 1997) is observed in research, development and testing services (which is not surprising because, in this special case, R&D is the actual product sold rather than a means toward acquiring a better product or production process). Computer data and processing services are second, at 13.3 percent, followed by drugs and medicines at 10.5 percent.[24] The "office, computing, and accounting machines" sector had an R&D intensity as high as 12.3 percent in 1987, but its R&D intensity fell to 9.2 percent by 1997.

Text table 2–12.
Company and other (except Federal) industrial R&D funds as a percentage of net sales in R&D-performing companies for selected industries: 1987 and 1997

Industry and size of company	1987	1997
Manufacturing		
Drugs and medicines	8.7	10.5
Office, computing, and accounting machines.	12.3	9.2
Optical, surgical, photographic, and other instruments.	7.2	8.9
Electronic components	8.5	8.1
Communication equipment	5.5	8.0
Scientific and mechanical measuring instruments	8.1	6.5
Aircraft and missiles	3.6	3.9
Motor vehicles and motor vehicles equipment	3.4	3.8
Industrial chemicals	4.4	3.5
Other machinery, except electrical	3.0	3.0
Other electrical equipment	2.6	2.7
Radio and TV receiving equipment.	3.2	2.6
Other transportation equipment	2.5	2.2
Other chemicals	3.3	2.1
Stone, clay, and glass products	2.5	1.8
Fabricated metal products	1.2	1.5
Rubber products	1.6	1.4
Paper and allied products	0.6	1.1
Lumber, wood products, and furniture	0.6	0.9
Textiles and apparel.	0.4	0.9
Nonferrous metals and products	1.3	0.6
Petroleum refining and extraction	1.0	0.6
Ferrous metals and products	0.6	0.6
Food, kindred, and tobacco products	0.6	0.5
Nonmanufacturing		
Research, development, and testing services	5.5	38.5
Computer and data processing services	NA	13.3
Engineering, architectural, and surveying.	NA	2.6
Trade.	NA	2.4
Finance, insurance, and real estate.	NA	0.7
Telephone communications	NA	0.7
Electric, gas, and sanitary services	NA	0.1

NA = not available

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Survey of Industrial Research and Development, 1997*

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Sectors that were lowest in R&D intensity in 1997 included

- nonferrous metals and products;
- petroleum refining and extraction;
- ferrous metals and products;
- food, kindred, and tobacco products; and
- electric, gas, and sanitary services.

These sectors, in large part, reflect the "smokestack industries" that played a dominant role in the U.S. economy in the mid-1900s in terms of new directions of technological change.

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 1997.[25] These data cover R&D performance by industry, academia, and Federal agencies, as well as Federally funded R&D activities of nonprofit institutions. The state data on R&D cover 52 records: the 50 states, the District of Columbia, and "other/unknown" (which accounts primarily for 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. Consequently, the distribution of R&D by state indicates primarily where R&D is undertaken in Federal, industrial, and university facilities.

In 1997, total R&D expenditures in the United States were $211.3 billion, of which $199.1 billion could be attributed to expenditures within individual states; the remainder was "other/unknown." (See appendix table 2-20.) The statistics and discussion below refer to state R&D levels in relation to the distributed total of $199.1 billion.

R&D is concentrated in a small number of states. In 1997, California had the highest level of R&D expenditures performed within its borders ($41.7 billion, representing approximately one-fifth of U.S. total). The six states with the highest levels of R&D expenditures—California, Michigan, New York, New Jersey, Massachusetts, and Texas (in descending order)—accounted for approximately half of the entire na-

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[24] R&D outlays in the semiconductor equipment and materials industry are estimated to be about 12–15 percent of sales (Council on Competitiveness 1996). The broad industry classification system used in NSF's industrial R&D survey can mask pockets of high-tech activity.

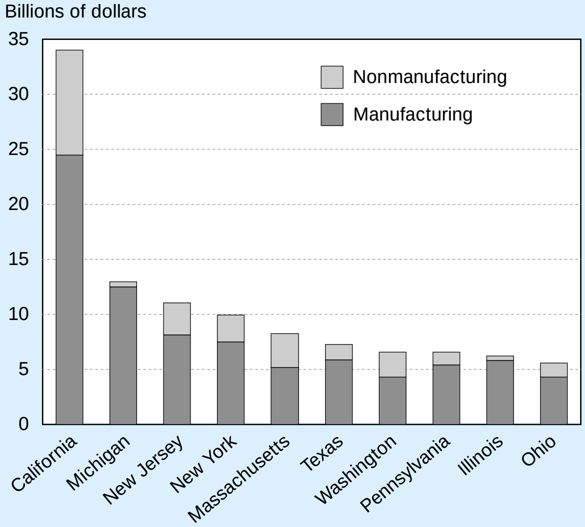
[25] Although annual data are available on the location of R&D performance by the academic and Federal sectors, until recently, NSF has conducted surveys on the state distribution of industrial R&D performance only in odd-numbered years. At this writing, the 1998 industry R&D survey data have not been processed, making 1997 the most recent year for which the state-specific R&D totals can be reported.

tional effort. The top 10 states—the six states listed above plus (in descending order) Pennsylvania, Illinois, Washington, and Maryland—accounted for approximately two-thirds of the national effort. (See appendix table 2-20.) California's R&D performance exceeded by a factor of three the next-highest state, Michigan ($14.0 billion). After Michigan, R&D levels decline relatively smoothly to approximately $7.4 billion for Maryland. The 20 highest-ranking states in R&D expenditures accounted for about 86 percent of the U.S. total; the lowest 20 states accounted for 4 percent.

States vary widely in the size of their economies owing to 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 economic size or the nature of their R&D efforts. A simple 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 2-52.) As with 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." Overall, the Nation's total R&D to GDP ratio in 1997 was 2.6 percent in 1997. The top 10 states with regard to R&D intensity were (in descending order) New Mexico (6.7 percent), the District of Columbia (5.3 percent), Michigan (5.1 percent), Massachusetts (5.0 percent), Maryland (4.8 percent), Washington (4.4 percent), Idaho (4.4 percent), New Jersey (4.1 percent), California (4.0 percent), and Rhode Island (3.7 percent). New Mexico's high R&D intensity is largely attributable to Federal support (provided by the Department of Energy) for the Sandia National Laboratories and Los Alamos National Laboratory FFRDCs in the state.[26]

States have always varied in terms of the levels and types of industrial operations they contain. Thus, they vary as well 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 nonmanufacturing sector as opposed to the manufacturing sector. Among the top 10 states in 1997 in industrial R&D performance, California, New Jersey, New York, Massachusetts, and Washington all had relatively high levels of R&D in the nonmanufacturing sector (25 percent or more of the total). (See figure 2-14.) Michigan, Texas, Pennsylvania, Illinois, and Ohio had lower levels of R&D in nonmanufacturing, as a percentage of the total.

Figure 2-14.
Industrial R&D performance in the top 10 states in industrial R&D in 1997: R&D in manufacturing and nonmanufacturing



NOTE: These levels include R&D performed by industry-administered FFRDCs.

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Survey of Industrial Research and Development, 1997*

See appendix table 2-20. *Science & Engineering Indicators – 2000*

Trends in National R&D by Character of Work

The traditional way to analyze trends in R&D performance is to examine the amount of funds devoted to basic research, applied research, and development. (See sidebar, "Definitions.") These terms are convenient because they correspond to popular models that depict innovation occurring in a linear progression through three stages: (1) scientific breakthroughs from the performance of basic research lead to (2) applied research, which leads to (3) development or application of applied research to commercial products, processes, and services.

The simplicity of this approach makes it appealing to policymakers, even though 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 in the real world.[27] Additionally, many analysts argue that the distinctions between basic research and applied research are becoming increasingly blurred. Nonetheless, these general categories are generally useful to characterize the relative expected time horizons and types of investments.

The United States spent $37.9 billion on the performance of basic research in 1998, $51.2 billion on applied research, and $138.1 billion on development. (See figure 2-15.) These

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[26] For additional information about the geographic distribution of R&D within the United States, see NSF, "Science and Engineering State Profiles: 1999," by R. Bennof and S. Payson, forthcoming.

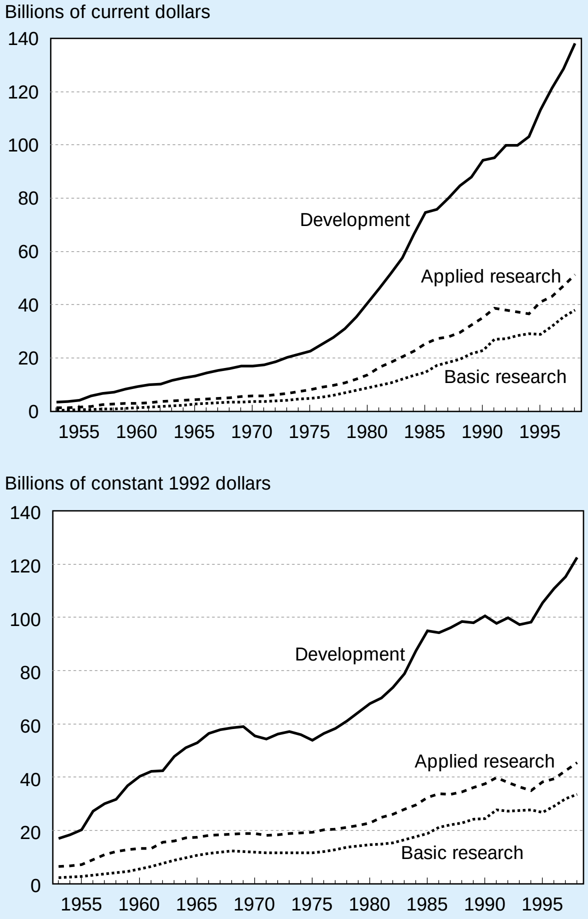
[27] See NSB (1996), chapter 4, "Alternative Models of R&D and Innovation." According to the Council on Competitiveness (1996), "The old distinction between basic and applied research has proven politically unproductive and no longer reflects the realities of the innovation process. The United States [should adopt] a new and more up-to-date vocabulary, one that accounts for changing calculations of R&D risk and relevance over short-, medium- and long-term horizons." In its report, the Council identified three types of research (short-term/low-risk, mid-term/mid-risk, and long-term/high-risk) and the economic sectors that have primary and secondary responsibility for each. In contrast, another study found that R&D managers/directors and financial officials/accountants in manufacturing and nonmanufacturing firms generally agree that NSF's classification of R&D expenditures into basic research, applied research, and development appropriately describes the scope of their companies' self-financed R&D activities (Link 1996).

Definitions

NSF uses the following definitions in its resource surveys. They have been in place for several decades and are generally consistent with international definitions.

- **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.
- **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.
- **R&D plant**. Federal obligations for R&D plant include the acquisition of, construction of, major repairs to, or alterations in structures, works, equipment, facilities, or land for use in R&D activities at Federal or non-Federal installations.

Figure 2-15.
National R&D funding, by character of work



See appendix tables 2-7, 2-8, 2-11, 2-12, 2-15, and 2-16.

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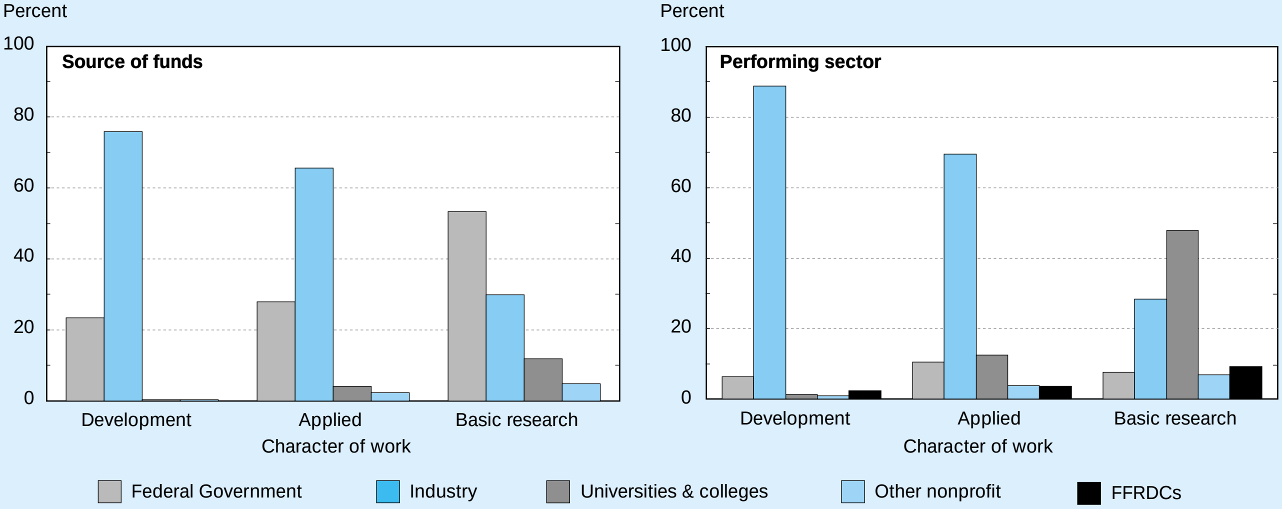
totals reflect continuous increases over several years. In particular, since 1980 there has been a 4.7 percent annual increase, in real terms, in basic research; a 3.9 percent increase in applied research; and a 3.4 percent increase in development. As a share of all 1998 R&D performance expenditures, basic research represented 16.7 percent, applied research 22.5 percent, and development 60.8 percent. These shares have not changed very much over time. For example, in 1980 basic research accounted for 13.9 percent, applied research 21.7 percent, and development 64.3 percent.

Basic Research

In 1998, basic research expenditures reached $37.9 billion. (See text table 2-1.) The annual growth rate of basic research performance has changed over time, but not as dramatically as total R&D. This annual rate, adjusted for inflation, had an average as high as 5.2 percent between 1980 and 1985; the growth rate slowed to 4.4 percent between 1985 and 1994 and increased to 5.0 between 1994 and 1998.

In terms of support, the Federal Government has always provided the majority of funds used for basic research. (See figure 2-16 and appendix table 2-9.) The Federal share of funding for basic research as a percentage of all funding, however, has dropped—from 70.5 percent in 1980 to a 53.4 percent ($20.2 billion) in 1998. (See figure 2-17.) This decline in the Federal share of basic research support does not reflect a decline in the actual amount of Federal support, which grew

Figure 2-16.
National R&D expenditures, by source of funds, performing sector, and character of work: 1998



See appendix tables 2-7, 2-9, 2-11, 2-13, 2-15, 2-16, and 2-17.

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3.1 percent per year in real terms between 1980 and 1998. Rather, it reflects a growing tendency for the funding of basic research to come from other sectors. Specifically, from 1980 to 1998, non-Federal support for basic research grew at the rate of 7.4 percent per year in real terms.

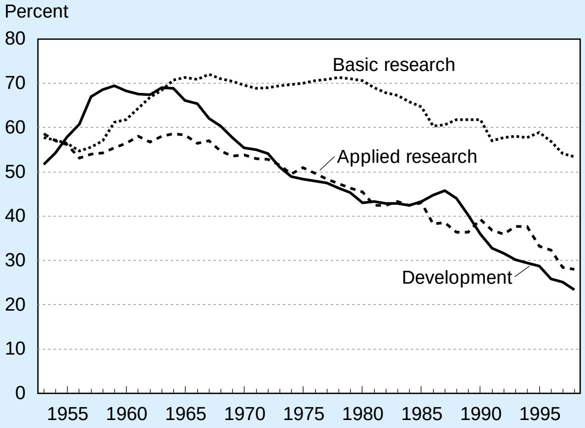
With regard to the performance of basic research in 1998, universities and colleges (excluding FFRDCs) accounted for the largest share—47.8 percent ($18.1 billion). Their performance of basic research has increased, on average, 4.6 percent annually in real terms since 1980. When the performance of university-administered FFRDCs is included, the academic sector's share climbs to 55.0 percent. In 1998, the Federal Government provided 62.1 percent of the basic research funds used by the academic sector. Non-Federal sources—including industry, state and local governments, universities and colleges themselves, and nonprofit organizations—provided the remaining 37.9 percent.

Applied Research

Applied research expenditures were $51.2 billion in 1998. Applied research is performed much more by nonacademic institutions. These expenditures have been subject to greater shifts over time, as a result of fluctuations in industrial growth and Federal policy. Applied research experienced an average annual real growth of 7.2 percent between 1980 and 1985, followed by very low growth of 0.8 percent between 1985 and 1994; the rate of growth rose again to 6.8 percent between 1994 and 1998. Increases in industrial support for applied research explains this recent upturn. Industrial support accounted for 65.6 percent ($33.6 billion) of the 1998 total for applied research; Federal support accounted for 28.0 percent ($14.3 billion).

During the 1980s, Federal support for applied research was intentionally deemphasized in favor of basic research. Even with the current administration's greater willingness to support generic/precompetitive applied research, Federal funding in 1998 for applied research was only 70.8 percent of that for basic research ($14.3 billion versus $20.2 billion, respectively), as reported by research performers.

Figure 2-17.
Federal share of total U.S. funding of basic research, applied research, and development



See appendix tables 2-9, 2-13, and 2-17.

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With regard to performance, 69.9 percent (accounting for $35.8 billion) of the Nation's applied research was performed by industry and industry-administered FFRDCs in 1998. Federal sources funded 28.0 percent ($14.3 billion) of the Nation's applied research.

In the same year, most of the Nation's nonindustrial applied research was performed by universities and colleges and their administered FFRDCs ($7.9 billion) and the Federal Government ($5.4 billion). With regard to Federal intramural applied research, in FY 1998 23.6 percent was performed by DOD, another 23.4 percent by HHS, and 11.5 percent by NASA.[28] Total Federal applied research performance has been remarkably level for more than 30 years, experiencing only a 0.6 percent average annual growth, in real terms, since 1966.

Development

Expenditures on development in 1998 totaled $138.1 billion. Most R&D expenditures are on development. Therefore, historical patterns of development expenditures mirror historical patterns of total R&D expenditures. From 1980 to 1985, development grew on average by 7.0 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 2-18.) Between 1985 and 1994, on the other hand, development in real terms grew at an average annual rate of only 0.4 percent—from $74.5 billion in 1985 to $103.1 billion in 1994. Between 1994 and 1998, annual growth was back up to 5.7 percent in real terms, to $138.1 billion in 1998—of which 75.8 percent was supported by industry and 23.4 percent by the Federal Government.

In terms of performance, industry (including industrial FFRDCs) accounted for 89.9 percent ($124.1 billion) of the nation's 1998 development activities. The Federal Government accounted for 6.4 percent ($8.8 billion), and all other performers account for 3.7 percent ($5.2 billion).

Federal Obligations for Research, by Field

Federal Obligations for Basic Research

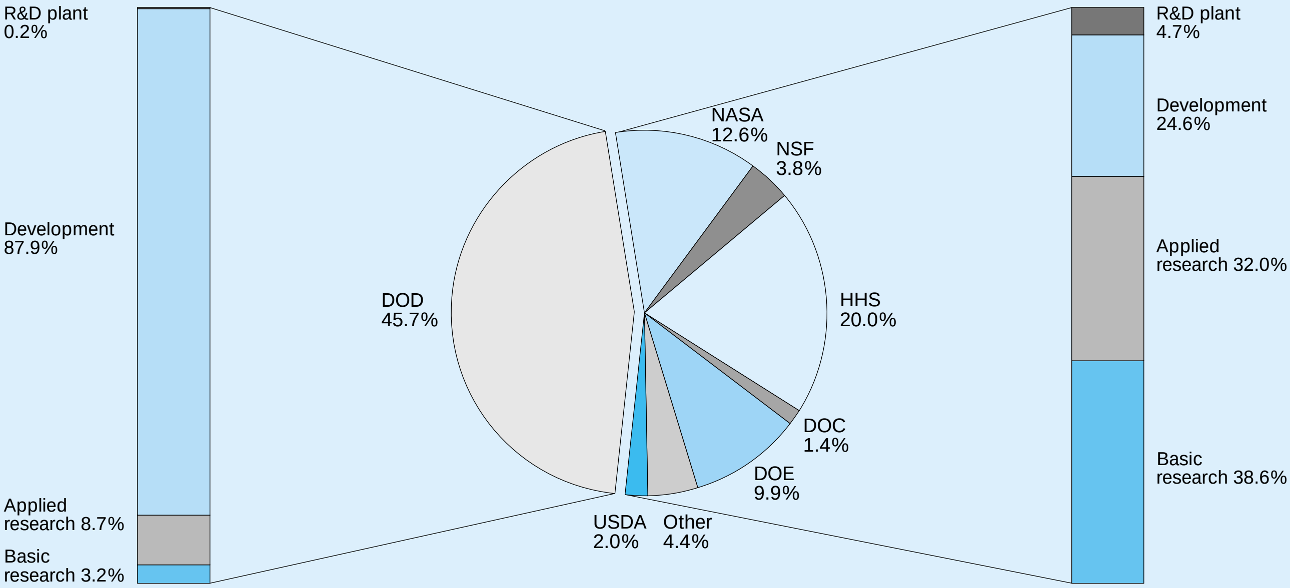
Among fields receiving Federal research support, life sciences garner the largest share of basic and applied research obligations. (See appendix table 2-47.) In FY 1999, an estimated $8.3 billion was obligated for basic research in the life sciences (which includes the biological, medical, and agricultural subfields)—nearly half the basic research total of $16.9 billion. This level of funding has grown steadily since the mid-1980s, although growth in real terms was stagnant from 1993 to 1995 (consistent with the growth pattern for all of HHS, the major funding agency for life sciences). By preliminary estimates, Federal support for basic research in the life sciences has grown rapidly between FY 1997 and FY 1999(averaging 6.2 percent per year in real terms. (See figure 2-20 and appendix table 2-47.)

DOE is the largest provider of funding for basic research in the physical sciences. According to preliminary estimates, DOE provided $1,358 million of a total of $3,305 million in FY 1999; NASA provided $972 million, and NSF provided $551 million (devoted to a wide variety of fields). Federal support for basic research in the physical sciences grew in real terms from 1985 to 1991, then declined from 1991 to 1996, and has since been rising again. (See figure 2-20.)

Federal Obligations for Applied Research

Life sciences received the largest Federal support for applied research: an estimated $6.1 billion in FY 1999 (38 percent of the $16.1 billion total). Engineering received the next largest share, with $4.3 billion in obligations (27 percent of

Figure 2-18.
Projected Federal obligations, by agency and character of work: 1999



See appendix tables 2-27, 2-29, 2-31, and 2-33.

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[28] These percentages are derived from preliminary Federal obligations as reported in NSF (1999a).

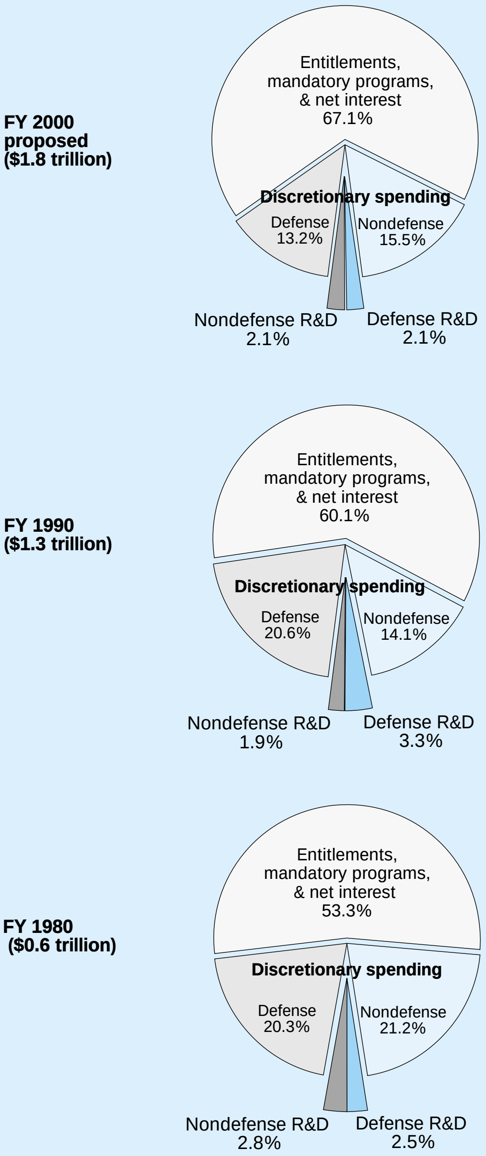
R&D Continues to Fare Well Despite Fiscal Austerity

Reducing the deficit has been an overriding goal of Congress and the Clinton Administration. To gain a better understanding of the difficulty involved in accomplishing this objective, it is helpful to split total Federal spending into two categories—"mandatory" and "discretionary." Certain program expenditures—including those for Social Security, veterans' benefits, Medicare, Medicaid, and interest on the national debt—are considered mandatory items in the Federal budget. That is, the government is already committed by law to finance those programs at certain levels and cannot cut them without a change in the law through an act of Congress. In contrast, discretionary items, including R&D programs, do not enjoy the same level of protection from budget-cutting proposals; the Federal Government does not have to, or is not already committed by law to, finance such programs at particular levels.

In FY 2000, mandatory programs (including interest on the national debt) are expected to account for 67 percent of total Federal outlays. (See appendix table 2-22.) Despite the vulnerability of R&D as a component of discretionary spending, Federal support for R&D has received bipartisan support and has fared well during the fiscal austerity of the past two decades. (See figure 2-19.) For example, an examination of R&D as a percentage of the total Federal budget reveals the following:

- Although all Federally funded R&D is expected to fall from 5.2 percent of the budget in 1990 to 4.3 percent in 2000, nondefense R&D as a percentage of the total budget is expected to rise slightly—from 1.9 percent in 1990 to 2.1 percent in 2000.
- As a proportion of total discretionary outlays, R&D increased from 11.5 percent in 1980 to 13.1 percent in 1990 and is expected to be 13.0 percent in 2000.
- Nondefense R&D as a percentage of nondefense discretionary spending has been holding fairly steady since 1980, at just less than 13 percent.

Figure 2-19.
R&D share of the Federal budget

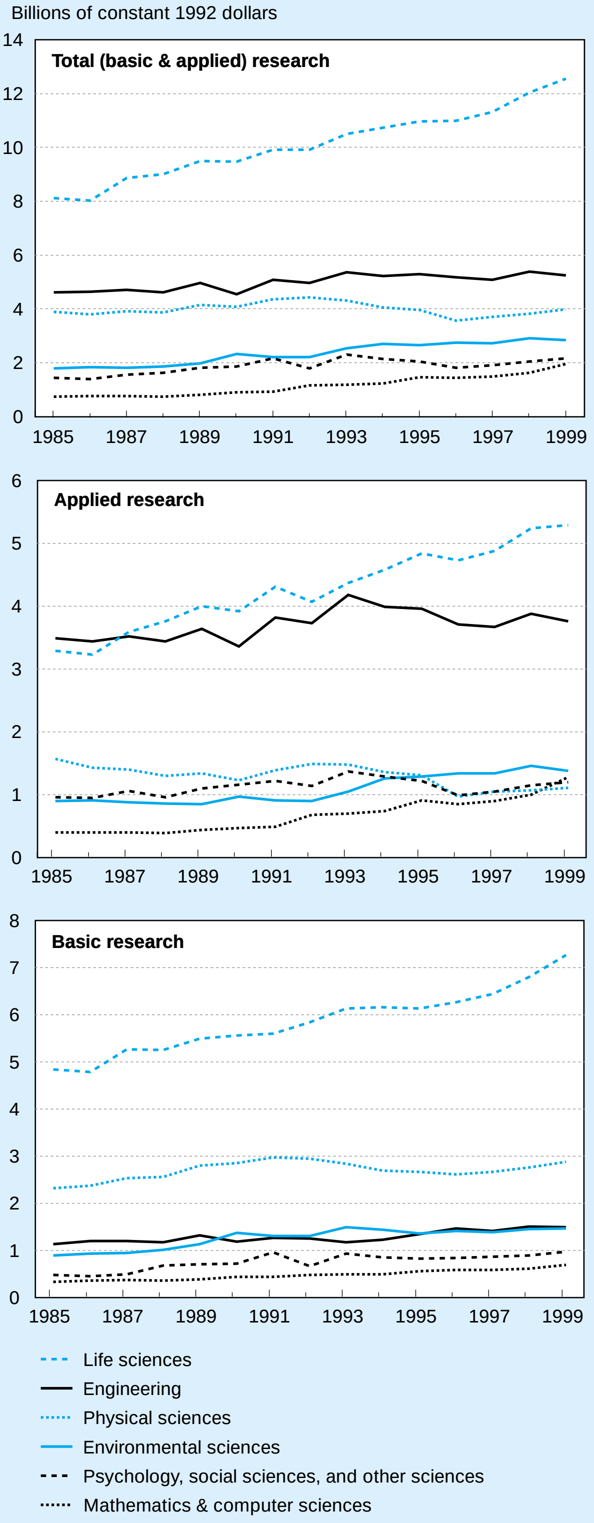


SOURCE: AAAS, *Research and Development: FY 2000*.

See appendix table 2-22. *Science & Engineering Indicators – 2000*

the total). In real terms, Federal support for applied research in the life sciences has grown substantially between 1985 and 1999 (from $3.3 billion to $5.3 billion in constant 1992 dollars. Federal support for applied research in mathematics and computer sciences has experienced particularly strong growth over the same period, from $402 million to nearly $1.3 billion in 1992 dollars. In contrast, Federal support for applied research in engineering, psychology, social sciences, and other sciences has grown very little or decreased slightly in real terms over the same period. Environmental sciences showed moderate growth between 1985 and 1999, from $898 million to nearly $1.4 billion in 1992 dollars. Federal support for applied research in the physical sciences, however, showed a decline in real terms—from $1.6 billion to $1.1 billion in 1992 dollars. On the other hand, Federal support for the physical sciences had been rising since its low of $966 million (in constant 1992 dollars) in 1966.

Figure 2-20.
Federal obligations for research by field: basic research, applied research, and total research



See appendix tables 2-47 and 2-48.

Science & Engineering Indicators – 2000

Federal Obligations for Research (Basic and Applied)

Considering basic and applied research together, the growth of Federal support for research the life sciences vis-a-vis research in other fields is even more pronounced. (See figure 2-20.) In terms of rates of growth, Federal support for research in mathematics and computer sciences has grown rapidly as well.[29]

Cross-Sector Field-of-Science Classification Analysis

A challenging, open-ended—yet promising—method of classifying R&D expenditures, in various sectors in addition to academia, is by field of science. Such classification, applied to historical data, indicates how R&D efforts in various fields of science and engineering have grown in economic importance over time. This information is potentially useful for science policy analysis and for planning and priority-setting. Moreover, scientists and engineers themselves can benefit from information about how R&D expenditures in various fields of science and engineering have evolved over time. For example, such information might influence decisions by scientists and engineers—and science and engineering students—about taking on new research endeavors or exploring new career opportunities.

Classification of academic R&D by field of science is provided in detail in chapter 6 of this report. The only additional sector for which extensive data by field exist is the Federal Government. Industrial R&D—which represents three-quarters of all R&D performed in the United States—has not been subdivided by field of study, for three reasons: (1) Unlike research performed by universities and Federal agencies, much of the research by private firms is confidential (for obvious reasons), and the provision of such information might compromise that confidentiality; (2) most private companies do not have the accounting infrastructure in place to compile such statistics, so any efforts on their part to provide this additional information could be significantly burdensome to them; and (3) 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. Therefore, the collection of such data is unlikely.

Nonetheless, some analysis along these lines, wherever possible, could shed light on overall levels of R&D support for general lines of inquiry. The analysis that follows circumvents this problem by grouping fields with standard industrial categories, creating nine general categories of R&D that can be associated with fields of science and engineering and with related industrial categories.

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[29] For much more detailed data on Federal support by field of science, see Board on Science, Technology, and Economic Policy (1999).

R&D in Chemistry, Life Sciences, and Information Technology

In this section, R&D is categorized into three broad areas; each area is associated with academic fields of study and with industrial end-products that tend to be associated with those fields. For easier data interpretation, all academic and Federal fiscal year data were converted to calendar year data so they would be comparable to data pertaining to industry categories (which are collected and provided on a calendar year basis). Furthermore, all dollar amounts in this section are in real (constant 1992) terms, thereby allowing the analysis to focus on effects that are independent of inflation.

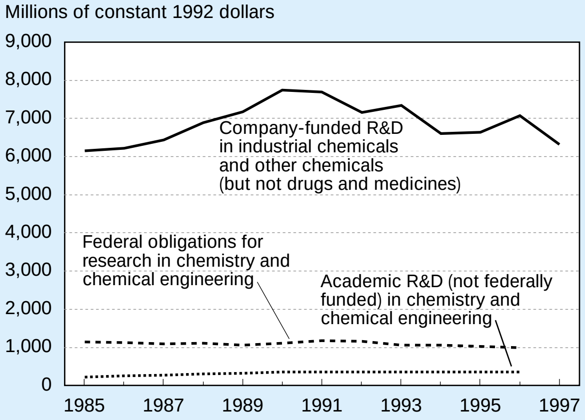
Chemistry (Nonmedical) and Chemical Engineering

Three categories of R&D were identified that could be associated primarily with chemistry and chemical engineering. (See figure 2-21 and appendix table 2-49.) These categories exclude chemistry associated with medicine, which was included instead under the broad category of life sciences. The largest of these categories, by far, is company-funded R&D in industrial chemicals and other chemicals (but not drugs and medicines). In real terms, expenditures in this category grew from $6.1 billion in 1985 to $7.7 billion in 1990 and then eventually declined, on average, to $6.3 billion in 1997—only slightly higher than the level 12 years earlier. The next two categories were much smaller. Federal obligations for research in chemistry and chemical engineering remained at roughly $1 billion (in constant 1992 dollars) throughout the 1985–96 period. The smallest category—academic R&D (not Federally funded) in chemistry and chemical engineering—grew steadily in real terms, from $223 million in 1985 to $361 million in 1996.

Life Sciences

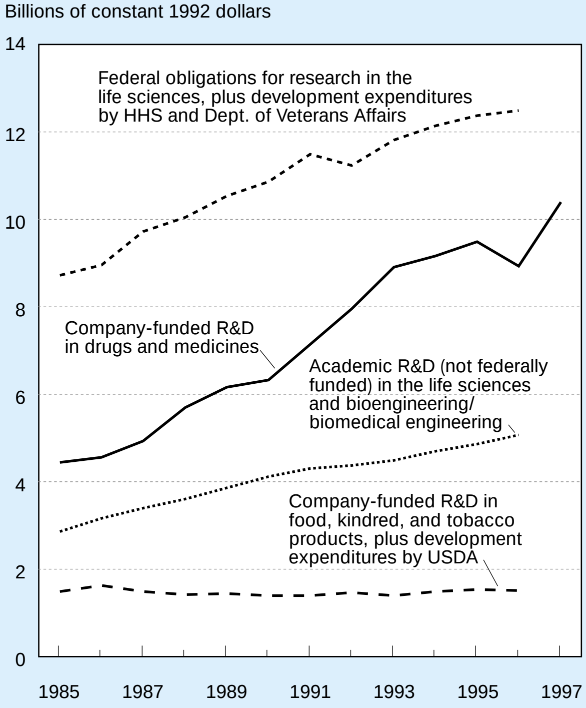
R&D in the broad area of the life sciences is characterized by strong and fairly-continuous real growth in its three largest categories. (See figure 2-22 and appendix table 2-50.) The largest category, Federal obligations for research in the life sciences, increased from $8 billion in 1985 to $11 billion in 1996. Company-funded R&D in drugs and medicines grew dramatically in real terms, from $4 billion in 1985 to $10 billion in 1997. Likewise, academic R&D (not Federally funded) in the life sciences and bioengineering/biomedical engineering grew continuously, from $3 billion in 1985 to $5 billion in 1996. Real growth in R&D also occurred in development expenditures by HHS and the Department of Veterans Affairs. With regard to food and other agricultural products that are also associated with life sciences, real growth occurred in the relatively small levels of development expenditures by USDA (from $41 million to $77 million between 1985 and 1996), but very little real change occurred in company-funded R&D in food, kindred, and tobacco products (which grew from $1.4 billion to $1.6 billion between 1985 and 1997).

Figure 2-21.
R&D associated primarily with chemistry (nonmedical) and chemical engineering



See appendix table 2-49. *Science & Engineering Indicators – 2000*

Figure 2-22.
R&D associated primarily with the life sciences

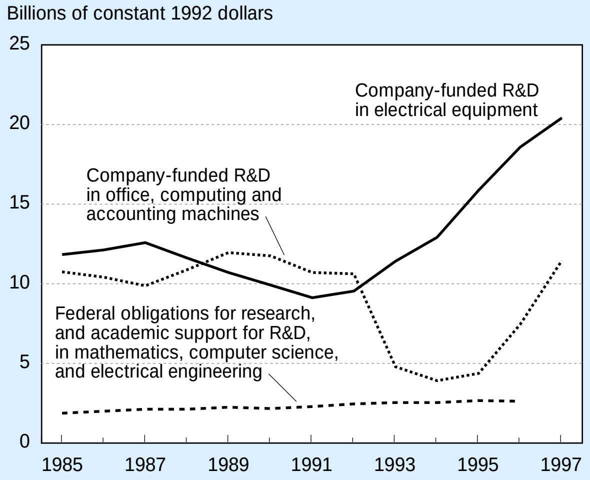


See appendix table 2-50. *Science & Engineering Indicators – 2000*

Mathematics, Computer Science, and Communication and Electrical Equipment

Although seven categories of R&D fall under this broad area, two clearly dominate the others in terms of the magnitude of their expenditure levels. (See figure 2-23 and appendix table 2-51.) The largest area, by 1997, was company-funded R&D in electrical equipment, which held steady at

Figure 2-23.
R&D associated primarily with mathematics, computer science, and communication and electrical equipment (excluding DOD-supported development of military equipment)



See appendix table 2-51. *Science & Engineering Indicators – 2000*

close to $10 billion (in constant 1992 dollars) throughout 1985–92, after which it doubled to more than $20 billion by 1997. The second-largest category in 1997—company-funded R&D in office, computing and accounting machines—remained at or above $10 billion between 1985 and 1992 as well. It then fell sharply in 1993 to below $5 billion but recovered between 1995 and 1997; by 1997 it represented more than $11 billion in R&D. The third-largest category, Federal obligations for research in mathematics and computer science, grew from $745 million in 1985 to nearly $1.5 billion in 1996. Federal obligations for research in electrical engineering (not Federally funded) declined from $813 million to $601 million over the same period. Three small academic categories—R&D in mathematics, computer science, and electrical engineering—each nearly doubled in real terms between 1985 and 1996.

Inter-Sector and Intra-Sector Domestic Partnerships and Alliances

In the performance of R&D, organizations can collaborate, either within the same sector (e.g., a partnership between firms) or between sectors (e.g., a partnership between a firm and the Federal Government). Decisions by organizations to form these partnerships are based on economic considerations, legal and cultural frameworks, scientific and technological conditions, and policy environments.

Economic Considerations Underlying R&D Partnerships

Collaboration allows individual partners to leverage their resources, reducing costs and risks and enabling research ventures that might not have been undertaken otherwise. In the case of intra-sector collaboration, the underlying theme is that more can be accomplished at lower cost when resources are pooled, especially if organizations can complement each other in terms of expertise and/or research facilities. For private companies, another advantage of partnerships is that they reduce (or eliminate) competition between the allied companies, which may thereby enjoy higher profits once their jointly developed product is marketed.

With regard to university-industry alliances, companies can benefit from the extensive research infrastructure (including the students), as well as the store of basic scientific knowledge, that exists at universities—which those firms would not be able afford on their own.[30] Universities, on the other hand, benefit from alliances with firms by being better able to channel academic research toward practical applications" (Jankowski 1999).

In the case of collaboration between Federal laboratories and industry—in the form of Cooperative Research and Development Agreements (CRADAs)—a wide range of economic benefits to both parties have been noted. The main reason for the creation of CRADAs was that industry would benefit from increased access to government scientists, research facilities, and the technology they developed. Government, in turn, would benefit from a reduction in the costs of items it needs to carry out its objectives (Lesko and Irish 1995, 67). Both would benefit from technology transfer, and Federal R&D in national labs would be more useful to U.S. industry. Some analysts have argued as well that Congress created CRADAs[31] to simplify negotiations between the Federal Government and industry in the process of technology transfer, by making the process exempt from Federal Acquisition Regulation (FAR) requirements.

With regard to collaboration between academia and the Federal Government, little exists in the strict sense of employees from both working together, side-by-side, on R&D projects. On the other hand, collaboration in a broad sense is quite extensive in that academia receives research grants to perform "targeted research."[32] (See "Federal Support to Academia.") Some of this research is designed to meet Fed-

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[30] On the topic of firms benefiting from the tacit knowledge of universities, Prabhu (1997)—citing earlier work by Tyler and Steensma (1995)—suggests, "The greater the tacitness of technology (hard to document in writing, residing in individuals, systems and processes of the firm, and difficult to transfer through market mechanisms), and the greater the complexity of technology (variety and diversity of technologies that must be incorporated into the development process), the more likely it is that executives will consider technological collaboration a mode of technology development."

[31] See the next section on the legal reasons for partnerships and alliances.

[32] Targeted research as a policy goal is discussed in U.S. Congress, House Committee on Science (1998).

eral needs, in cases in which the Federal Government does not have the physical or human resources to perform the research itself. In other cases, the Federal Government may support academic research (or research in other sectors) for the sake of creating a "public good" that would be expected to provide economic benefits to society. As many people know, one of the public goods that arose from this kind of collaborative effort is the Internet, which originated from a project funded by the Defense Advanced Research Projects Agency (DARPA) and then greatly advanced through NSF funding to universities.

Finally, international competition adds two additional considerations. First, Federal-industry partnerships and other types of partnerships in the performance of R&D in the United States may be desirable as a means of competing adequately against similar partnerships carried out in other nations. Second, the United States may choose to enter into international projects with the idea that, just like firms, nations may be able to pool resources that collectively enhance their R&D capabilities.

Federal Technology Transfer Programs

The term "technology transfer" can cover a wide spectrum of activities, from informal exchanges of ideas between visiting researchers to contractually structured research collaboration involving the joint use of facilities and equipment. Only since the late 1980s, however, has technology transfer become an important mission component of most Federal labs. Some agencies, however, have long shared their research with the private sector (e.g., USDA's Agricultural Research Experiment Stations and NASA's civilian aeronautics programs), and several laws passed in the early 1980s encouraged such sharing—notably, the Stevenson-Wydler Technology Innovation Act of 1980. (See sidebar, "Principal Federal Legislation Related to Cooperative Technology Programs.")

The emphasis, in the past decade, on technology transfer stems from practical considerations: Industry was interested in such programs, Federal money was available, and government defense labs were amenable to such activities as an alternative to their declining defense work (OTA 1995). Moreover, technology transfer was regarded as a means of addressing Federal concerns about U.S. industrial strength and world competitiveness. Another reason was that the Federal Technology Transfer Act (FTTA) of 1986 authorized government-owned and -operated laboratories to enter into CRADAs with private industry. Only after the 1989 passage of the National Competitiveness Technology Transfer Act (NCTTA), however, could contractor-operated labs (including DOE's FFRDCs) also enter into CRADAs. According to most available indicators, Federal efforts to facilitate private-sector commercialization of Federal technology have made considerable progress since 1987.

Four measures of the extent of Federal technology commercialization efforts and Federal-industry collaboration between 1987 and 1998 can be described as follows:

Principal Federal Legislation Related to Cooperative Technology Programs

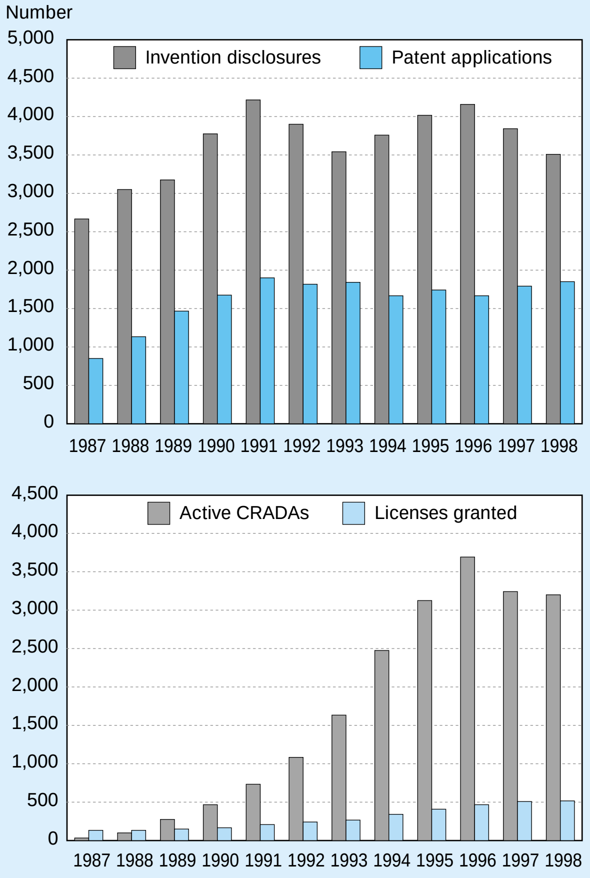
Since 1980, a series of laws have been enacted to promote Federal–civilian partnerships and to facilitate the transfer of technology between sectors. Among the most notable pieces of legislation have been the following:

- **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 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 (RJV) participants to work together in the application of technologies they jointly acquire.

- **CRADAs** grew in number geometrically, from 34 in 1987 to 3,688 in 1996—an average growth rate of more than 68 percent per year. Between 1996 and 1997, however, not only did the growth cease, the number of active CRADAs declined to 3,239. This number decreased slightly in 1998, to 3,201. (See figure 2-24.)

- **Invention disclosures** arising out of CRADAs increased rapidly at first, from 2,662 in 1987 to 4,213 in 1991(a 58 percent increase in only four years). Over the succeeding seven years (to 1998), however, that level was not reached again; the largest number was 4,153 in 1996. On the other hand, there is no apparent trend in the annual numbers of invention disclosures since 1991; those levels seem to be random, averaging 3,815 and remaining above 3,500 each year. (See figure 2-24.)

Figure 2-24.
Federal technology transfer indicators



CRADA = cooperative research and development agreement.

NOTE: Does not include CRADAs entered into by NASA.

See appendix table 2-60. *Science & Engineering Indicators – 2000*

- **Patent applications** have had a similar history. They rose in number from 848 in 1987 to a high of precisely 1,900 in 1991(a 124 percent increase). After 1991, patent applications averaged 1,765, with no apparent trend.

- **Licenses** granted rose in number steadily between 1987 and 1998, from 128 to 510.

Differences in Motivations and Goals of CRADA Participants

Studies have indicated that although partnerships between sectors offer economic and scientific benefits to the parties involved, those partnerships may be constrained by cultural differences between sectors. Some observers have argued that industrial scientists and engineers tend to place much greater emphasis than their government colleagues on profitability, international competitiveness, and turnaround time. Conversely, government scientists and engineers tend to have longer-range and more idealistic perspectives. For example, Lesko and Irish (1995) describe the Federal defense employee's "traditional view" as one in which "the primary missionis.to develop, produce, enhance, and support the military systems that provide a warfighting capability for the U.S. that is second to none" (Lesko and Irish 1995, 33–34).

Rogers et al. (1998) surveyed participants in CRADA partnerships at Los Alamos National Laboratory. They found that, according to private companies in these partnerships, the top five objectives of CRADAs were (in descending order of importance) to obtain new technology/information/patents, to save money in developing a process/product, to save costs, to improve research ability within the company, and to obtain a new product. In contrast, the top five objectives according to Federal R&D laboratory partners were to improve the research ability of the Federal R&D laboratory, such as adding capabilities; to obtain new funding; to obtain technology/information/patents; to gain credibility/prestige/employee satisfaction; and to develop or gain access to new facilities/tools. According to Rogers et al., such differences in orientation have been a major obstacle to further increases in the number of CRADAs. Rogers et al. conclude, "Since 1994, Federal funding for establishing new CRADAs has almost disappeared, mainly due to partisan differences about the role of the Federal Government in its relations with private companies" (Rogers et al. 1998, 87).

On the other hand, Lesko and Irish (1995) are more optimistic about the future ability of scientists and engineers from these different cultures to get along:

> Significant differences in the perspectives of government and industry can and do impede progress in cooperative ventures. As both sides realize that they need each other's perspectives and combined resources to survive global competition and effectively manage shrinking resources, their goals and procedures will change toward becoming more and more cooperative. Good communications can be a key to identifying, understanding, and overcoming culturally derived barriers to this process (Lesko and Irish 1995, 29).

Scientific and Technological Conditions Underlying R&D Partnerships

The complexity and interdisciplinary nature of R&D has continued to increase in recent years, as discoveries in one area of science or engineering (e.g., modular robotics systems) have had bearing on other areas (e.g., space exploration). As the scope of R&D on any topic expands, researchers from individual institutions may find themselves less able to approach the topic as broadly as they think they should; they may therefore search for collaborators who can complement their knowledge or research facilities. For example, academic researchers increasingly have sought to leverage resources and talents in the conduct of R&D. Not only does such an approach offer opportunities for alternative funding, such partnership provides an essential means for undertaking work that is becoming ever more complex and multidisciplinary (Jankowski 1999).

At the same time that scientific and engineering developments are increasing the need for—and the benefits of—R&D partnerships and alliances, advances in communication equipment and software are creating new tools that make such collaborative efforts much easier. Hazlett and Carayannis (1998) describe recent developments in "virtual teams"—especially between industry and academia—whereby communication, data acquisition, data sharing, and document sharing can all take place virtually among individuals in distant organizations. In effect, the operational costs of collaborating have been reduced enormously, thereby encouraging increased collaboration among researchers of the same or similar topics.

Current research on expanding Internet capabilities offers even more powerful tools for collaborative efforts. DOE and NSF have been sponsoring research that has been moving scientists and engineers closer to having the ability to collaborate in virtual laboratories or conference rooms through "telepresence." That is, researchers at remote physical locations interact with one another in a virtual, three-dimensional environment, experiencing each other's artificial presence as though everyone were in the same room. Such capabilities will undoubtedly enhance collaboration potential.[33]

Industrial R&D Consortia

In the early 1980s, increasing international competition and the resulting erosion in U.S. technological leadership led legislators and policymakers to conclude that existing U.S. antitrust laws and penalties were too restrictive and could be impeding the ability of U.S. companies to compete in the global marketplace. U.S. companies were at a disadvantage relative to their foreign counterparts because an outdated antitrust environment—designed to preserve domestic competition—prohibited them from collaborating on most activities, including R&D.

Restrictions on multi-firm cooperative research relationships were lifted with the passage of NCRA in 1984. This law was enacted to encourage U.S. firms to collaborate on generic, precompetitive research. To gain protection from antitrust litigation, NCRA requires firms engaging in RJVs to register them with DOJ.[34] In 1993, Congress again relaxed restrictions—this time on cooperative production activities—by passing the National Cooperative Research and Production Act, which enables participants to work together to apply technologies developed by their RJVs.

The advantages of RJVs over individual firms conducting R&D on their own have been identified as follows:[35]

- Through RJVs, companies have "the ability to pool research resources in order to achieve a critical minimum mass and pursue more and larger research projects than any single company could afford."
- RJVs can exploit synergies from the complementary research strengths of their members, creating a whole greater than the sum of its parts.
- RJVs are expected to be in a better position than any single firm to maintain the necessary continuity of effort for long-term research projects.
- RJVs pool risk both in terms of a larger number of participants in each research project and a larger number of projects.
- RJVs can reduce duplication of effort among member firms by concentrating larger resources on projects of common interest.
- RJVs can attract supplemental support from external sources, including the government, by increasing the visibility of essential industrial research projects.
- RJVs can create new investment options in technologies that are out of the reach of individual member firms because of high resource commitment required, high uncertainty, insufficient appropriability of the research outcome, inadequacy of existing capabilities, and so forth.

By the end of 1998, 741 RJVs had been registered; organizations such as Sematech have helped U.S. industries regain leadership in global markets for high-tech products such as semiconductors. On the other hand, by 1998 the number of new RJV filings per year had fallen sharply to 31, after reaching a peak of 115 in 1995 (Link 1999). (See figure 2-25.)

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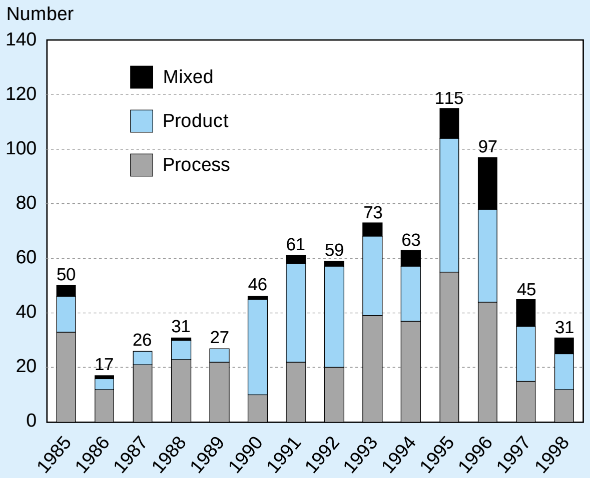
[33] See Smith and Van Rosendale (1998), Larson (1998), and chapter 9 of this report.

[34] According to NCRA, an RJV is "any group of activities, including attempting to make, making, or performing a contract, by two or more persons for the purpose of (a) theoretical analysis, experimentation, or systematic study of phenomena or observable facts, (b) the development or testing of basic engineering techniques, (c) the extension of investigative findings or theory of a scientific or technical nature into practical application for experimental and demonstration purposes, (d) the collection, exchange, and analysis of research information, or (e) any combination of the [above]." RJV members can be from different sectors as well as from different countries.

[35] These points are taken from Vonortas (1997); however, Vonortas credits these ideas to Douglas (1990).

Figure 2-25.
Growth in R&D consortia registered under the National Cooperative Research and Production Act



SOURCE: Link (1999) and unpublished tabulations.

Science & Engineering Indicators – 2000

Other observations include:

- The industry with the most RJVs over the 1985–98 period was communication services (standard industrial classification, or "SIC," number 48), which claimed 131 of the 741 total. The electronics industry (SIC 36) was a close second with 120, followed by transportation equipment (SIC 37) with 115.
- The average number of members per RJV over the 1985–98 period was 13; this number varied by industry, however, from an average of only 6 members for the communications services industry to an average of 25 for the electronics industry.
- Only 10 percent of all RJVs included Federal laboratories as research members. Among RJVs in the communications services industries, less than 1 percent had Federal labs as members. Among those in machinery and computer equipment (SIC 35), 21 percent included Federal labs; among those in electronics, 20 percent included Federal labs.
- Sixteen percent of all RJVs included universities as research members. For communications services, this percentage was as low as 5, whereas for electronics it was as high as 34.
- As many as 29 percent of all RJVs had foreign affiliates as research members, ranging from 17 percent for transportation equipment to 45 percent for the oil and gas extraction industry (SIC 13).
- Fourteen percent of RJVs had an environmental research focus; no RJVs in communications services had an environmental research focus, whereas 43 percent in chemicals and allied products (SIC 28) had that focus.
- Forty-nine percent of RJVs (365 of the 741 total) had research that was process-focused; 41 percent (307) had research that was product-focused; and the remaining 9 percent (69) had research that included both. (See figure 2-25.)

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. Findings from a study of 25 countries by Porter and Stern (1999) indicate that human talent and R&D spending are among the most important factors contributing to nations' innovative capacity. Consequently, the relative strength of a particular country's current and future economy—and the specific scientific and technological areas in which a country excels—is further revealed through comparison with other major R&D-performing countries. This section provides such comparisons of international R&D spending patterns.[36] It examines absolute and relative expenditure trends, contrasts performer and source structural patterns, reviews the foci of R&D activities, and looks at government priorities and policies. Although R&D performance patterns by sector are 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. Foreign sources of R&D 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 $500 billion in estimated 1997 R&D expenditures for the 28 OECD[37] countries, 85 percent is expended in just 7 countries (OECD 1999d). 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.[38] (See appendix table 2-2.)

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[36] Most of the R&D data presented here are from reports to OECD, which is the most reliable source of such international comparisons. A fairly 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 (ISPF 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.

[37] Current OECD members are Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, South Korea, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.

[38] Although PPPs technically are not equivalent to R&D exchange rates, they better reflect differences in countries' laboratory costs than do market exchange rates. (See sidebar, "Purchasing Power Parities: Preferred Exchange Rates for Converting International R&D Data.")

Advanced Technology Program Funding Slows

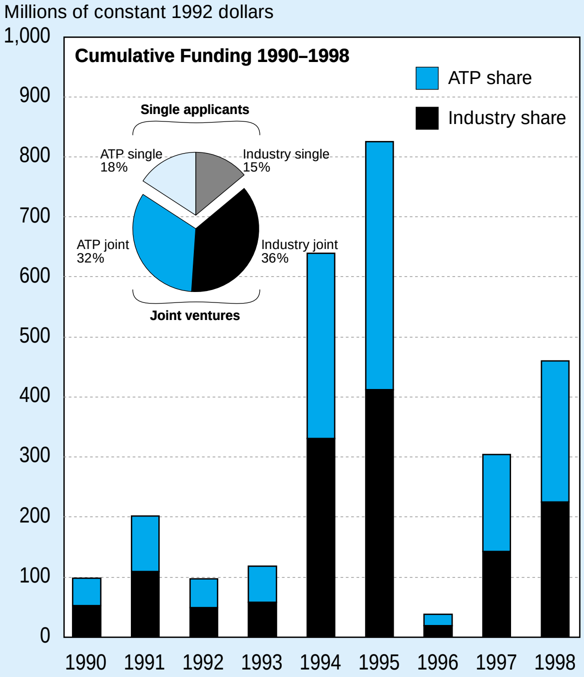
Two Federal technology partnership programs were started in the 1990s: DOC's Advanced Technology Program (ATP) and DOD's Technology Reinvestment Project (TRP). The purpose behind both programs was to spur the development and deployment of high-risk enabling technologies through an industry-driven, cost-sharing process whereby industry proposed the research and supplied at least half of the funding. Of the two programs, only ATP survives, and its budget was sharply reduced in 1996.

The cumulative shares of ATP funding from 1990 to 1998 by government and industry have been nearly the same: $1.3 billion in constant 1992 dollars. (See appendix table 2-61.) The 285 single-applicant projects have a cumulative total funding level of $851 million in constant 1992 dollars, with ATP funds accounting for 55 percent and industry funds accounting for 45 percent. The average award size across single applicants and joint ventures has been $6.1 million in constant 1992 dollars. The 146 joint ventures have had a cumulative funding level of $1.8 billion in constant 1992 dollars, of which 53 percent was provided by industry participants.

ATP runs two kinds of competitions—general and focused. Companies or consortia can submit proposals for support in any technology area(s) in the general competitions, whereas the focused competitions are for specific technologies. Proposals are selected through a peer review process and are judged on their technical merit and their potential for commercial success.

The ATP program was most active in 1994 and 1995. (See figure 2-26.) In fact, funding in these two years alone, in real terms, accounted for 53 percent of all funding over the 1990–98 period. In 1996, funding had nearly vanished to $34 million (in 1992 dollars), but it has picked up again in 1997 and 1998, with levels of $273 million and $408 million, respectively. In every year from 1990 to 1998, the ATP and industry shares have been close to 50 percent each.

Figure 2-26.
Advanced Technology Program funding



SOURCE: U.S. Department of Commerce, National Institute of Standards and Technology.

See appendix table 2-61. *Science & Engineering Indicators – 2000*

The United States accounts for roughly 43 percent of the OECD member countries' combined R&D investments; U.S. R&D investments continue to outdistance, by more than 2–to–1, R&D investments made in Japan, the second largest R&D-performing country. Not only did the United States spend more money on R&D activities in 1997 than any other country, it 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 appendix table 2-63.)[39] In only three other countries—the Netherlands, Australia, and Sweden—do R&D expenditures exceed 1 percent of the OECD R&D total (OECD 1999d).

In 1985, spending in G-7 countries other than the United States was equivalent to 90 percent of U.S. R&D expenditures that year. The non-U.S. total climbed steadily to peak at 105 percent of the U.S. total in 1993. Since then, however, non-U.S. G-7 R&D expenditures have slipped back to an amount equivalent to about 98 percent of the U.S. total. (See figure 2-27.) Initially, most of the United States' relative improvement vis-á-vis the other G-7 countries since 1993 resulted from a worldwide slowing in R&D performance that was more pronounced in other countries than in the United States. That is, 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. In fact, large and small industrialized countries worldwide

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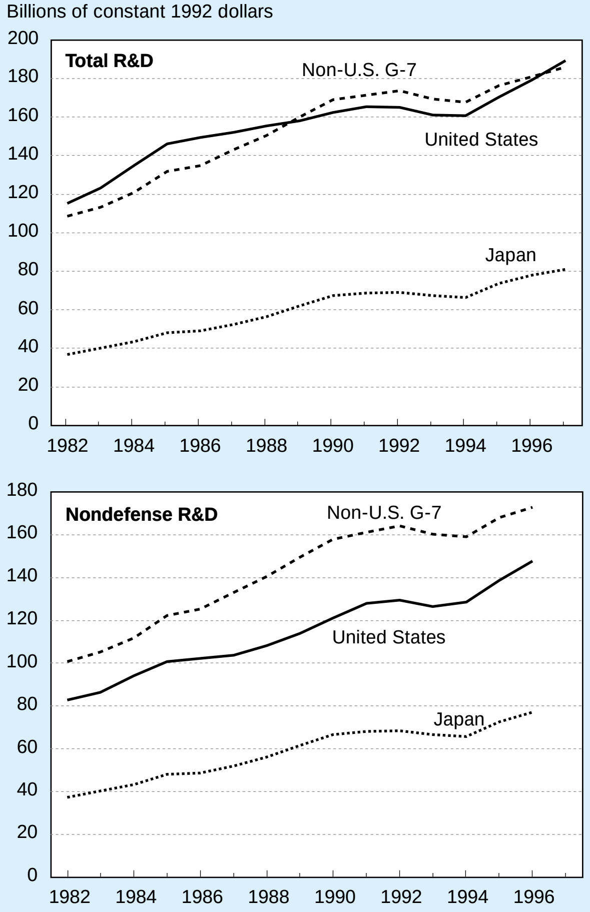
[39] International data availability has become less timely over the past several years, so 1997 is the most recent year for which R&D statistics are widely available from many countries. Part of the delay in obtaining current R&D statistics is a result of resource pressures affecting national statistical offices; part is a result of resource constraints facing international organizations that provide internationally comparable data.

Figure 2-27.
U.S. and other G-7 countries' R&D expenditures



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

See appendix tables 2-63 and 2-64.

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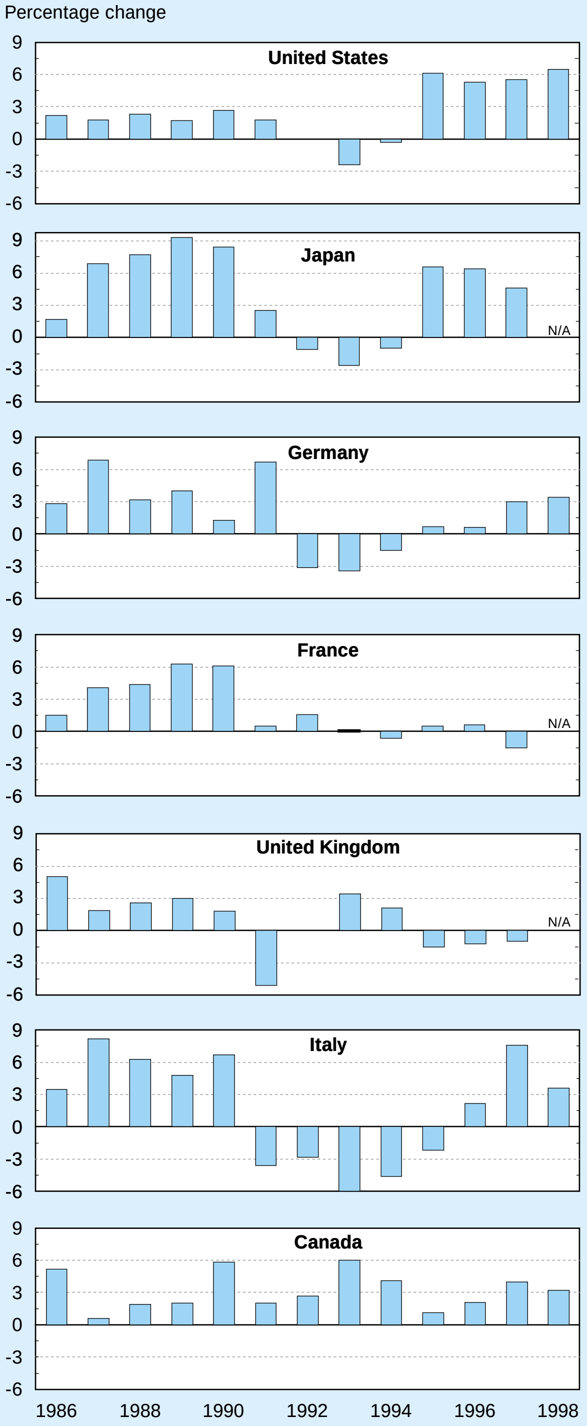
experienced substantially reduced R&D spending in the early 1990s (OECD 1999d). For most of these countries, economic recessions and general budgetary constraints slowed industrial and government sources of R&D support. More recently, R&D spending has rebounded in several of the G-7 countries (though not in France or the United Kingdom, according to the latest available statistics), as has R&D spending in the United States. Yet since annual R&D growth generally has been stronger in the U.S. than elsewhere (see figure 2-28), the difference between the U.S. and the combined other G-7 countries' R&D spending has continued to narrow.

Concurrent with the relative increase in the U.S. share of the G-7 countries' R&D performance has been a reduction in the U.S. R&D share of all OECD countries' R&D spending. In 1986 the United States accounted for 48 percent of the R&D reported by OECD countries; by 1997 the U.S share had dropped to less than 43 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 mem-

Figure 2-28.
Rates of change in total inflation-adjusted R&D spending



N/A = not available

NOTES: 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 2-63.

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Purchasing Power Parities: Preferred Exchange Rates for Converting International R&D Data

Comparisons of international statistics on R&D are hampered by the fact that each country's R&D expenditures are denominated, obviously, in its home currency. Two approaches are commonly used to normalize the data and facilitate aggregate R&D comparisons. The first method is to divide R&D by GDP, which results in indicators of relative effort according to total economic activity and circumvents the problem of currency conversion. The second method is to convert all foreign-denominated expenditures to a single currency, which results in indicators of absolute effort. The first method is a straightforward calculation, but it 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.

Because (for all practical purposes) there are no widely accepted R&D-specific exchange rates, the choice is between market exchange rates (MERs) (available from IMF 1998) and purchasing power parities rates (PPPs) (available from OECD 1999d). These rates are the only series consistently compiled and available for a large number of countries over an extended period of time.

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. Sizeable 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—currency speculation, political events such as wars or boycotts, and official currency intervention—that have little or nothing to do with changes in the relative prices of internationally traded goods.

For these reasons, an alternative currency conversion series—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 research spending than that given by MERs. (See figure 2-29.) For example, Japan's R&D in 1996 totaled $85 billion based on PPPs and $130 billion based on MERs; German R&D was $40 billion and $54 billion, respectively. (By comparison, U.S. R&D was $197 billion in 1996.)

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. Although there is considerable difference in 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 2-29.) 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 1986 and 1996, German and Japanese R&D expenditures each increased in three separate years by 20 percent or more. In reality, nominal R&D growth never exceeded 12 percent in either country during this period. PPP conversions generally mirror the R&D changes denominated in these countries' home currencies.

bership (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. If actual "world" R&D totals were available (rather than for the OECD countries only), the decline in the U.S. share would likely be more pronounced.

Distribution of Nondefense R&D Expenditures

The policy focus of many governments on economic competitiveness and commercialization of research results has shifted attention from nations' total R&D activities to nondefense R&D expenditures as indicators of scientific and technological strength.[40] 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. In absolute dollar terms, the U.S. international nondefense R&D position is still considerably more favorable than that of its foreign counterparts; the

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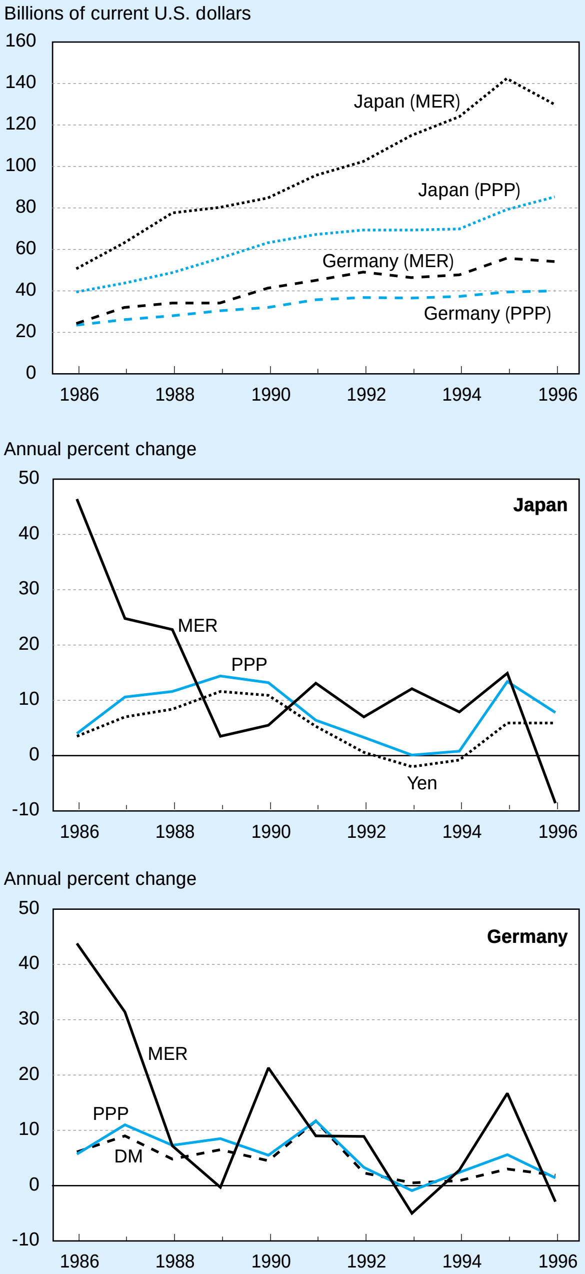
[40] This is not to say that defense-related R&D does not benefit the commercial sector. Unquestionably, technological spillovers have occurred from defense to the civilian sector. Almost as certainly, however, the benefits are less than if these same resources had been allocated directly to commercial R&D activities. Moreover, considerable anecdotal evidence indicates that the direction of technological flow is now more commonly from commercial markets to defense applications rather than the reverse.

Figure 2-29.
Japanese and German R&D expenditures and annual changes in R&D estimates



NOTES: MER = market exchange rate; PPP = purchasing power parity; DM = deutsche mark

See appendix tables 2-1, 2-2 and 2-63.

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United States is not nearly as dominant, however, as when total R&D expenditures are compared. In 1996 (the latest year for which comparable international R&D data are available from most OECD countries), U.S. nondefense R&D was almost twice that of Japan's, but the non-U.S. G-7 countries' combined nondefense total was 17 percent more than nondefense R&D expenditures in the United States alone.

Between 1982 and 1990, growth in U.S. nondefense R&D spending was similar to nondefense R&D growth in other industrial countries (except Japan, where nondefense R&D expenditure growth was notably faster). As an equivalent percentage of the U.S. nondefense R&D total, comparable Japanese spending jumped from 45 percent in 1982 to 55 percent in 1990. (See appendix table 2-64.) During this period, Germany's annual spending equaled 26–29 percent of U.S. nondefense R&D spending. France's annual spending during this same period was equivalent to 17–18 percent of the U.S. total, and the United Kingdom's annual spending fluctuated narrowly between 14 and 16 percent of the U.S. total.

Since 1990, the worldwide slowing in R&D spending and the subsequent industrial rebound in the U.S. has narrowed the gap between U.S. nondefense R&D spending and that in the other G-7 countries. In 1996, the combined nondefense R&D spending in the six non-U.S. G-7 countries is estimated at $173 billion (in constant PPP dollars), compared with $148 billion (constant dollars) in the United States. Japanese and German nondefense spending relative to U.S. spending declined to 52 and 24 percent, respectively.

Trends in Total R&D/GDP Ratios

One of the 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 2-30.) 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.[41] The United States and Japan each reached local peaks—at 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, before rising again to 2.7 and 2.9 percent. Growth in industrial R&D accounted for most of the recovery in each of these countries. Electrical equipment, telecommunications, and computer services companies have accounted for some of the strongest R&D growth since 1995 in the United States. In Japan, spending increases were highest in the electronics, ma-

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[41] 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 the level and change in a country's R&D/GDP ratio. 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/GDP ratios depending on the share of industrial output in the economy, whether the industries that account for the industrial output are traditional sites of R&D activity (for example, food processing firms generally do less R&D than do pharmaceutical companies), and whether individual firms in the same industries devote substantial resources to R&D or emphasize other activities (that is, firm-specific intensities). For example, economies with high concentrations in manufacturing (which has traditionally been more R&D intensive than nonmanufacturing or agricultural economies) have different patterns of R&D spending. See text table 2-13 for the distribution of industrial R&D performance in the G-7 countries and Sweden (which has the highest R&D/GDP ratio in the world).

Text table 2–13.
Share of industrial R&D by industry sector for selected countries

	Percent of industrial R&D performance total							
	Canada 1997	Germany 1995	France 1996	Italy 1997	Japan 1996	United Kingdom 1997	Sweden 1995	United States 1996
Total manufacturing	60.9	94.6	87.7	83.6	94.5	80.4	87.5	80.5
Food, beverages & tobacco	1.1	0.8	1.8	1.2	2.5	1.9	1.2	1.1
Textiles, fur & leather	0.6	0.6	0.6	0.4	0.8	0.3	0.2	0.3
Wood, paper, printing, publishing	1.8	0.5	0.4	0.2	1.2	0.5	3.0	2.0
Coke, ref. petrol. prod. & nucl. fuel	0.9	0.2	1.3	0.6	0.6	3.7	0.3	1.1
Chemicals & chemical products	8.5	17.9	18.6	13.9	15.8	29.6	16.3	13.0
Chemicals (less Pharmaceuticals)	2.1	13.3	6.3	5.9	9.2	7.1	2.0	6.3
Pharmaceuticals	6.3	4.6	12.3	8.0	6.6	22.5	14.3	6.8
Rubber & plastic products	0.4	1.5	2.5	1.9	2.6	0.6	1.0	1.0
Non-metallic mineral products	0.1	1.0	1.2	0.3	2.1	0.5	0.5	0.3
Basic metals	1.8	1.0	1.7	1.0	3.5	0.6	1.2	0.5
Fabricated metal products	0.9	1.4	1.2	2.7	1.5	0.9	1.1	1.1
Machinery eq., instruments & trans. equip.	44.1	69.0	57.7	61.3	63.1	41.5	62.5	59.6
Machinery, n.e.c.	1.9	11.3	4.6	5.3	8.7	5.8	10.8	4.2
Office, account. & computing machinery	4.1	3.9	2.6	3.7	9.9	1.1	1.4	8.8
Electrical machinery	0.9	7.2	3.4	4.8	10.9	4.4	1.6	2.3
Electro. equip.(radio, TV & comm.)	23.8	10.0	11.5	19.4	16.1	6.9	19.9	13.2
Instruments, watches & clocks	1.2	6.0	9.5	1.8	3.6	3.5	6.9	8.4
Motor vehicles	1.8	21.2	11.9	14.7	12.8	10.1	16.4	11.1
Other transport equipment	10.3	9.4	14.3	11.6	1.1	9.8	5.5	11.6
Aerospace	10.3	8.1	13.7	9.7	0.7	9.3	5.1	11.2
Ships, other transport nec.	0.1	1.2	0.6	2.0	0.3	0.4	0.5	0.3
Furniture, other manufacturing nec.	0.7	0.6	0.6	0.1	0.8	0.3	0.2	NA
Electricity, gas & water	2.6	0.4	3.1	3.0	1.1	1.4	0.9	0.2
Construction	0.2	0.3	0.7	0.3	2.2	0.1	0.5	0.2
Total services	33.5	3.5	6.9	13.1	4.2	17.5	10.0	19.5
Wholesale, retail trade, motor veh. repair etc.	6.4	0.1	NA	0.2	NA	0.1	NA	4.4
Hotels & restaurants	NA	NA	NA	0.0	NA	NA	NA	0.2
Transport & storage	0.2	0.2	2.9	0.2	0.1	0.1	0.2	0.2
Communications	2.1	NA	NA	4.1	2.4	5.2	2.5	2.8
Financ. intermediation (inc. insur.)	5.5	0.1	NA	0.0	NA	NA	NA	0.9
Real estate, renting & bus. activities	19.3	2.5	3.9	8.4	1.8	12.0	7.1	NA
Computer & related activities	6.8	0.4	2.3	1.1	1.8	7.4	1.5	5.1
Research & development	9.6	0.7	NA	5.9	NA	3.5	5.0	3.8
Other business activities nec.	2.9	1.4	1.6	1.4	NA	1.2	0.6	NA
Comm., soc. & pers. serv. activ.,etc.	NA	0.1	NA	0.2	NA	0.1	0.2	NA

NA= Not available separately

NOTE: The underlying OECD detailed data do not sum to 100 percent.

SOURCE: Organisation for Economic Co-operation and Development (OECD), ANBERD Database (DSTI/EAS Division), 1999.

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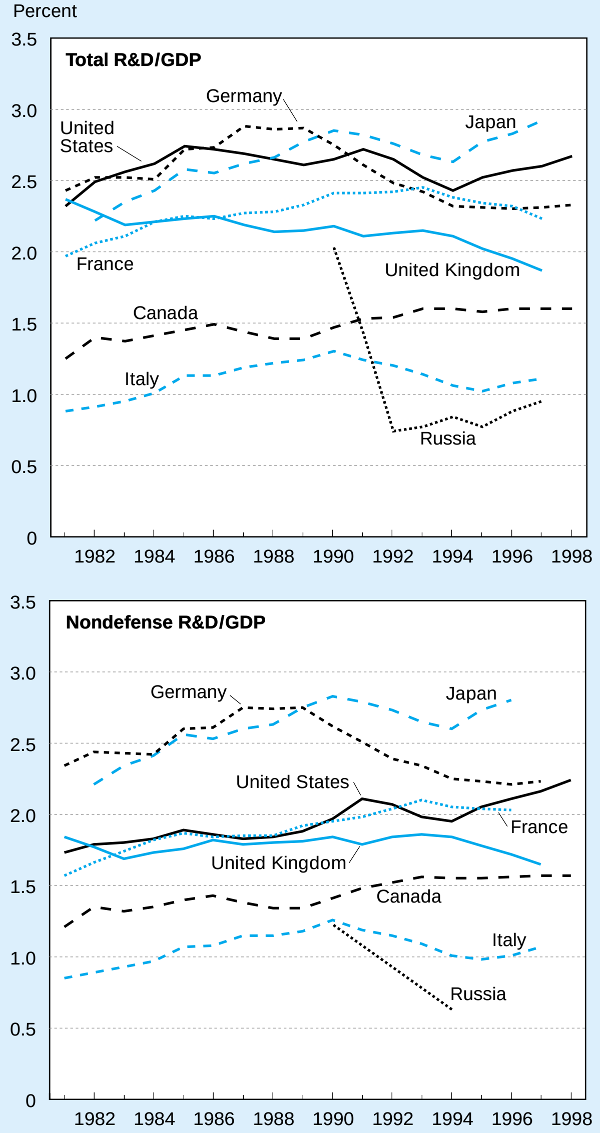
chinery, and automotive sectors and appear to be associated mainly with a wave of new digital technologies (IRI 1999). In addition, Japan's national government also has contributed to some of the renewed vigor in Japan's R&D spending. (See NSF 1997 for a summary of the Japanese government's intent to double Japan's R&D budget.)

By comparison—and with the notable exception of Canada, for which the R&D/GDP ratio has remained relatively level since the early 1990s—the other G-8 countries each report lower R&D shares now than at the beginning of the decade. The smallest share reductions occurred in Italy, the United Kingdom, and France (declining about two-tenths of a percentage point in each country, to current ratios of 1.0, 1.9, and 2.3 percent, respectively). In Germany, the R&D/GDP ratio fell from 2.9 percent at the end of the 1980s, before reunification, to its current level of 2.4 percent. 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 1.4 percent of GDP in 1991; that figure plummeted to 0.7 percent in 1992. Moreover, the severity of this R&D decline is masked somewhat in that while the R&D share was falling, it also was a declining share of a declining GDP. By 1997, R&D spending in Russia had inched back to about 1.0 percent of GDP.

Figure 2-30.
R&D as a percentage of GDP, G-8 countries



See appendix tables 2-63 and 2-64.

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Overall, the United States ranked sixth among OECD countries in terms of reported R&D/GDP ratios for the 1995–97 period. (See text table 2-14.) Sweden leads all countries with 3.9 percent of its GDP devoted to R&D—followed by Japan and South Korea (2.9 percent); Finland (2.8 percent); and Switzerland (2.7 percent). In general, southern and eastern European countries tend to have R&D/GDP ratios below 1.5 percent, whereas northern European nations and non-European OECD countries report R&D spending shares above 1.5 percent.

Nondefense R&D/GDP Ratios

Compared with total R&D/GDP ratios, the relative position of the United States is slightly less favorable if only nondefense R&D is considered. Japan's nondefense R&D/GDP ratio (2.8 percent) exceeded that of the United States (2.1 percent) in 1996, as it has for years. (See figure 2-30 and appendix table 2-64.) The nondefense R&D ratio of Germany (2.2 percent) slightly exceeded that of the United States (again, in contrast to total R&D). The 1996 nondefense ratio for France (2.0 percent) was slightly below the U.S. ratio; those for the United Kingdom (1.7 percent), Canada (1.6 percent), and Italy (1.0 percent) were much lower. The most recent nondefense R&D/GDP ratio for Russia was a 0.6 percent share in 1994.

Consistent with overall R&D funding trends, however, the U.S. nondefense R&D/GDP ratio has been improving relative to each of the G-8 countries since 1994, when ratios reported for Japan and Germany exceeded that for the United States. France also reported devoting more of its economic output to nondefense R&D activities than did the United States, and the relative ratio of U.K. nondefense R&D spending to GDP was about equal to that in the United States. Led by industry's investments in research and predominantly de-

Text table 2–14.
R&D as a percentage of gross domestic product

Sweden	3.85	Russian Federation	0.95
Japan	2.92	Venezuela	0.89
South Korea	2.89	Spain	0.86
Finland	2.78	Brazil (1996)	0.76
Switzerland (1996)	2.74	Poland	0.76
United States	2.60	Hungary	0.73
Germany	2.31	Cuba	0.70
Israel	2.30	South Africa	0.69
France	2.23	China	0.65
Netherlands (1996)	2.09	Portugal	0.65
Denmark	2.03	Chile	0.64
China (Taipei)	1.92	Indonesia (1995)	0.50
United Kingdom	1.87	Greece (1993)	0.48
Australia (1996)	1.68	Turkey (1996)	0.45
Norway	1.68	Uruguay	0.42
Canada	1.60	Colombia	0.41
Belguim (1995)	1.58	Argentina	0.38
Iceland	1.56	Panama	0.38
Austria	1.52	Malaysia (1994)	0.34
Singapore	1.47	Bolivia (1996)	0.33
Ireland	1.43	Mexico	0.42
Czech Republic	1.19	The Philippines (1992)	0.21
Slovak Republic	1.18	Thailand (1996)	0.12
Costa Rica (1996)	1.13	Hong Kong (1996)	0.10
New Zealand	1.10	Ecuador (1996)	0.08
Italy	1.08		

NOTES: Unless noted otherwise, data are for 1997.
Data for Israeli and China (Taipei) include nondefense R&D only.

Total OECD	2.17
North America	2.36
European Union	1.84

SOURCES: Organisation for Economic Co-operation and Development (OECD 1999), Centre for Science Research and Statistics (CSRS 1999), Red Iberomericana de Indicatores de Ciencia y Tecnologia (RICYT 1998), Israel Central Bureau of Statistics (1998), South Africa FRD (1998), National Science Council (1998), and Pacific Economic Cooperation Council (PECC 1997).

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velopment spending, the U.S. nondefense R&D/GDP ratio now matches or exceeds each of the world's other major R&D performing countries (except Japan).

Emerging Countries' R&D Investments

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.[42] In Latin America and the Pacific region, other non-OECD countries also have attempted to substantially increase R&D investments during the past several years (APEC/PECC 1997; RICYT 1998).[43]

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 2.3 percent nondefense R&D/GDP ratio ranks eighth 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 2-14.) 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 (RICYT 1998).

R&D in the Russian Federation in Transition

As recently as 1990, R&D accounted for about 2 percent of the Soviet Union's GDP, with about 40 percent of that amount expended on defense-related activities (Gohkberg, Peck, and Gacs 1997).[44] Indeed, the most advanced aspects of Soviet R&D efforts were undertaken in state-owned enterprises devoted to national security; much of the remaining R&D was performed in other large public industrial institutions in applied research fields that overlapped defense concerns. Most of the basic research was and continues to be in the physical sciences and engineering fields.

The introduction of a market economy to Russia brought about drastic economic restructuring, including a sharp decline in the dominance of state-owned enterprises and a 25 percent shrinkage in real GDP in just two years (IMF 1998). These trends, in turn, brought about major R&D downsizing; real R&D expenditures in 1992 collapsed to only 30 percent of the inflation-adjusted levels reported for 1990 (CSRS 1999). That is, real spending on R&D fell 70 percent with a resultant R&D/GDP ratio of about 0.7 percent. (See text table 2-15.) Reflecting the lack of core budgets, between 1990 and 1992 entire research institutes closed—including many well-equipped laboratories of the former military-industrial complex—and an estimated 19 percent of all researchers left their government R&D laboratories for the commercial sector or retirement or for other reasons, including emigration.[45]

Between 1992 and 1995, Russian R&D spending continued to deteriorate, though at a slower pace, falling 25 percent in real terms (for a total decrease of 78 percent since the start of the decade) (CSRS 1999; OECD 1998b). The rate at which researchers left their labs accelerated, however; the number of researchers at government facilities declined 39 percent during the 1992–95 period, reflecting the effect of low and unpaid salaries, declining budgets for capital and research equipment, and generally inhospitable working conditions.

In terms of R&D spending, the situation in Russia has improved slightly since 1995. Fueled by government and industrial spending, growth in R&D exceeded inflation in 1996 and 1997. Similarly, funds from foreign sources (including funding from

Text table 2–15.
Indicators of R&D in the Russian Federation

	R&D (Billions of 1989 rubles)	R&D/ GDP	R&D Personnel		
			Total*	Researchers	Technicians
			(thousands)		
1990	10.898	2.03	1,943	993	235
1991	7.290	1.43	1,678	879	201
1992	3.225	0.74	1,533	804	181
1993	3.055	0.77	1,315	645	134
1994	2.930	0.84	1,106	525	116
1995	2.446	0.77	1,061	519	101
1996	2.603	0.88	991	485	88
1997	2.797	0.95	935	455	80

* Includes science and engineering researchers, technicians, and other supporting staff.

SOURCE: Center for Science Research and Statistics (CSRS) *Russian Science and Technology at a Glance: 1998* (Moscow: CSRS, 1999)

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[42] Also see NSF (1993) and NSF (1995) for a discussion of S&T trends in several Asian countries. See NSF (1996) for information on growth in S&T activities in Europe.

[43] In addition to expanding their R&D investments, an increasing number of countries worldwide have expended considerable efforts to collect and publish science and technology (including R&D) statistics that are internationally comparable. One such effort is coordinated by the Iberoamerican Network of Science and Technology Indicators (RICYT). The Network aims to design, collect, and publish S&T indicators, as well as to train professionals specialized in these subjects (Albornoz and Poluch 1999). Together with assistance from the Organization of American States (OAS) and the Iberoamerican Program on Science and Technology for Development, RICYT has published several S&T indicator reports (available at <<http://www.unq.edu.ar/ricyt>>). The Network has the participation of all countries in the Americas, as well as that of Spain and Portugal. Similar efforts have been underway for Pacific-based economies that are members of the Asia-Pacific Economic Cooperation (APEC) and the Pacific Economic Cooperation Council (PECC).

[44] R&D data for the Russian Federation are taken from Centre for Science Research and Statistics surveys designed to collect such statistics in accordance with OECD international standards.

[45] Other former communist countries have experienced similar patterns of initial decline and restructuring in their R&D enterprise. In the transition toward market economies, however, the pattern has varied considerably among countries, reflecting the diversity of their economic and social histories and experiences (e.g., business orientation, technological openness, and role of higher education). For a review of country-specific differences and recent developments in Hungary, Poland, the Czech Republic, Slovakia, Romania, and Russia, see Radosevic and Auriol (1999).

the European Union and the U.S. Civilian Research Foundation, among others) tripled between 1995 and 1997 and now account for 7 percent of domestic R&D spending in Russia (CSRS 1999). In spite of these recent gains, real R&D spending remains 13 percent below the levels reported for 1992 and 75 percent below the estimated levels at the beginning of the decade. Furthermore, the outflow of researchers from such activities is still an important concern, as is the belief that the younger generation is not choosing science and engineering careers to the same extent as previously. Between 1995 and 1997, an estimated 65,000 scientists and engineers left their R&D work, resulting in a researcher workforce level (455,000) that was less than half of the estimated 1990 level (993,000).

International R&D by Performer, Source, and Character of Work

Performing Sectors

The industrial sector dominates R&D performance in each of the G-7 countries. (See figure 2-31.) Industry performance shares for the 1996–98 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 60 and 70 percent in Germany, France, the United Kingdom, and Canada.[46] 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 1 percent in Japan to 15 percent in the United States. (See appendix table 2-65.) By comparison, industry performance in Russia accounted for a 66 percent share of the total. However, government was the source of half of these funds (as contrasted with government's 15 percent or smaller shares in the G-7 countries), and industry itself funded just 40 percent of the Russian industrial R&D performance total.[47]

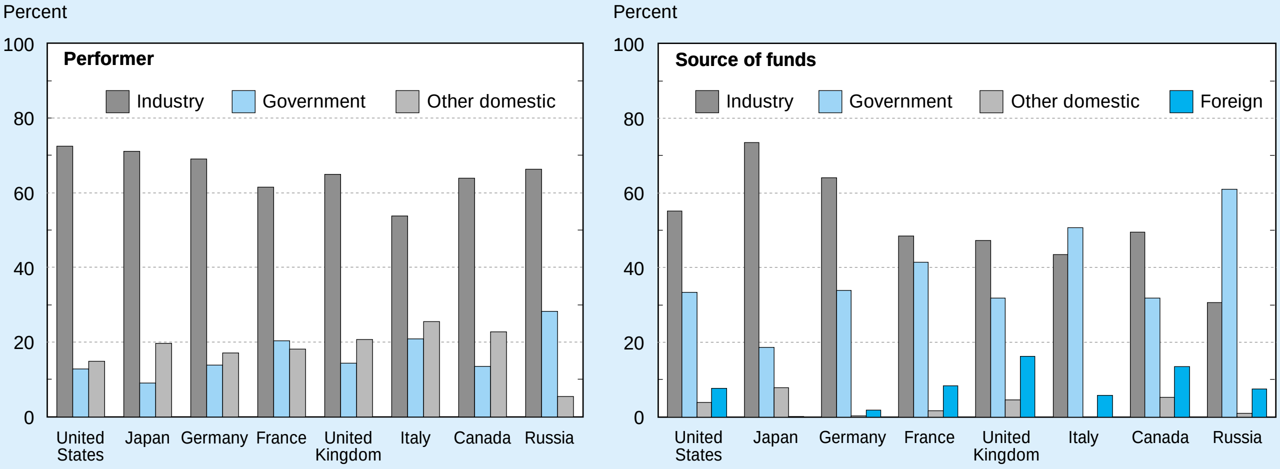
In most of these countries, the academic sector was the next-largest R&D performer (at about 12 to 25 percent of the performance total in each country).[48] Academia often is the primary location of research (as opposed to R&D) activities, however. Government was the second-largest R&D performing sector in France (which included spending in some sizeable government laboratories) and the U.S. (which includes FFRDCs), as it was in Russia (accounting for 28 percent of that nation's R&D effort). By comparison, government's R&D performance share was smallest in Japan, at about 10 percent of the country's total.

Sources of Funds

Industry R&D Funding

Consistent with the fact that the industrial sector performs most of these countries' R&D activities, it provides the great-

Figure 2-31.
R&D expenditures, by country, performer, and source: 1996–98



NOTE: Foreign performers are included in the "industry" and "other domestic" performing sectors.

See appendix table 2-65.

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[46] See text table 2-13 for the distribution of industrial R&D performance in the G-7 countries and Sweden. For detailed data on industry-specific R&D activities in other OECD countries, see OECD 1999b.

[47] Although the economic structure of the Russian system still differs considerably from that of the G-7 countries, these data were compiled and adjusted by the Russian R&D statistics organization, CSRS (1999), according to OECD sector categories to allow international comparison.

[48] The national totals for Europe, Canada, and Japan include the research component of general university funds (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 may thus be underestimated relative to the R&D effort reported for other countries.

est proportion of financial support for R&D in the G-7. Shares for this sector, however, differed from one country to another. Industry provided more than 70 percent of R&D funds in Japan; 64 percent in Germany; 55 percent in the United States; and between 44 and 49 percent in the United Kingdom, Italy, France, and Canada. In Russia, industry provided about 30 percent of the nation's R&D funding; government provided the largest share (61 percent of the country's 1997 R&D total). In most of these countries (except Russia and Italy, where it was largest), government was the second-largest source of R&D funding. In each of these eight countries, government provided the largest share of the funds for academic R&D performance.

Declining Government R&D

The most notable trend among the G-7 countries, however, has been the relative decline in government R&D funding in the 1990s. Indeed, this pattern of reduced governmental R&D support is apparent throughout the OECD, and especially in European countries (Caracostas and Muldur 1998). In 1997, roughly one-third of all R&D funds were derived from government sources—down considerably from the 45 percent share reported 16 years earlier. (See text table 2-16.) Among all OECD countries, government accounts for the highest funding share in Portugal (68 percent of its 1997 R&D total) and the lowest share in Japan (19 percent in 1996). 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). 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 vis-ávis government's. Both of these considerations are reflected in funding patterns for industrial R&D performance alone: In 1981, government provided 23 percent of the funds used by industry in the conduct of R&D within OECD countries, whereas by 1997 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 U.S.), government support to business R&D is skewed toward large firms (OECD 1999a).

Rising Foreign R&D

The R&D funding share represented by funds from abroad ranged from as little as 0.1 percent in Japan to more than 16 percent in the United Kingdom. Foreign funding—predominantly from industry for R&D performed by industry—is an important and growing funding source in several countries and reflects the increasing globalization of industrial R&D activities overall. 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 France and Italy. (See figure 2-32.) Such funding takes on even greater importance in many of the smaller OECD countries, as well as in less industrialized countries (OECD 1999d). In the United States, approximately 8 percent of funds spent on industry R&D performance in 1996 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.[49]

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[49] 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.

Text table 2–16.
Sources of total and industry R&D performed in OECD countries, selected years
(Percent)

	1981	1986	1991	1997
OECD total R&D financed by				
Industry	51.2	54.1	58.7	62.3
Government	45.0	42.0	35.8	31.4
Other domestic sources	2.5	2.4	3.4	3.8
Foreign sources	1.3	1.5	2.1	2.5
OECD industry R&D financed by				
Government	22.6	21.8	15.0	10.2
Industry and other sources	77.4	78.2	85.0	89.8

NOTE: Includes all countries that were members of the OECD in the year reported, therefore the number of countries included may differ from one year to the next.

SOURCE: OECD Main Science and Technology Indicators Database (April 1999).

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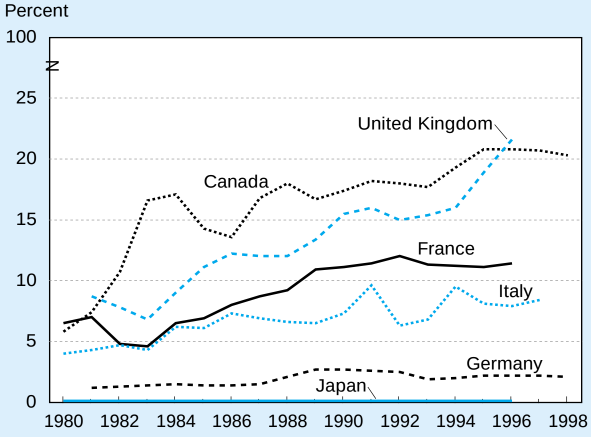
Figure 2-32.
Proportion of industrial R&D expenditures financed from foreign sources



See appendix table 2-72.

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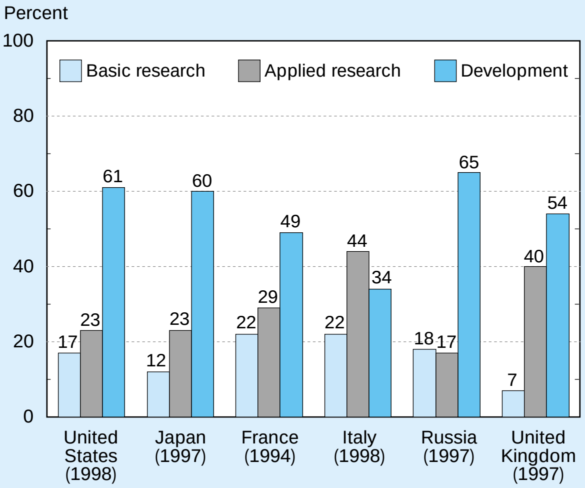
Character of R&D Effort

Not all of the G-8 countries categorize their R&D expenditures into character of work classifications (that is, basic research, applied research, or development), and for several countries that do utilize this taxonomy, the data are somewhat dated (OECD 1999c). Nonetheless, where these data exist, they are indicative of 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 about 17 percent of its R&D on activities that performers classify as basic research. (See figure 2-33.) Much of this research is funded by the Federal Government and is performed in the academic sector. The largest share of this basic research effort is in support of the life sciences.

Basic research accounts for a similar portion (18 percent) of the R&D total in the Russian Federation. In comparison with U.S. patterns, however, a considerably greater share is for engineering research activities. In Japan, a comparatively smaller amount (12 percent) of the national R&D performance effort is for basic research, but as in Russia engineering fields receive the largest share of these funds. Conversely, basic research accounts for more than 20 percent of total R&D performance reported in Italy, France, and Germany. Furthermore, basic research would likely account for a similar share of the United Kingdom's R&D were these data available and published for the academic and nonprofit sectors—traditional locations for basic research activities. Except in Italy (where applied research was dominant), development activities accounted for the largest share of national totals, with most of the experimental development work underway in their respective industrial sectors.

Figure 2-33.
Distribution of R&D by character of work, in selected G-8 countries



NOTES: The character of work for 6 percent of Japan's R&D is unknown. The U.K splits are for industrial and government performers only. R&D character of work data for the higher education and nonprofit sectors (21 percent of the national total) are unavailable. For Germany, 21 percent of its 1993 R&D was basic research; the rest was undistributed. Canada does not report any of these data. Because of rounding, detail may not sum to totals.

SOURCES: Organization for Economic Co-operation and Development (OECD). 1999c. *Basic Science and Technology Statistics: 1998* (on diskette). Paris: OECD; Center for Science Research and Statistics (CSRS) 1999. *Russian Science and Technology at a Glance: 1998*. Moscow: CSRS.

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International Comparisons of Government R&D Priorities

The downturn in R&D growth within OECD countries has been disproportionately caused by flat or declining government funding of R&D since the late 1980s. These developments reflect and add to worldwide R&D landscape changes that present a variety of new challenges and opportunities. The following sections highlight government R&D funding priorities in several of the larger R&D-performing nations, summarize broad policy trends, and detail indirect support for research that governments offer their domestic industries through the tax code.

Funding Priorities by National Objective

A breakdown of public expenditures by major socioeconomic objectives provides insight into governmental priorities, which differ considerably across countries.[50] In the United States, 54 percent of the government's $74 billion R&D investment during 1998 was devoted to national defense. This share compares with the 38 percent defense share in the United Kingdom (of an $9 billion government total); 28 percent in France (of $13 billion); and 10 percent or less each in Germany, Italy, Canada, and Japan. (See figure 2-34 and appendix table 2-66.) These recent figures represent substantial cutbacks in defense R&D in the United States, the United Kingdom, and France—where defense accounted for 63 percent, 44 percent, and 40 percent of government R&D funding, respectively, in 1990. However, defense-related R&D also seems particularly difficult to account for in many countries' national statistics. (See sidebar, "Accounting for Defense R&D: Gap Between Performer- and Source-Reported Expenditures.")

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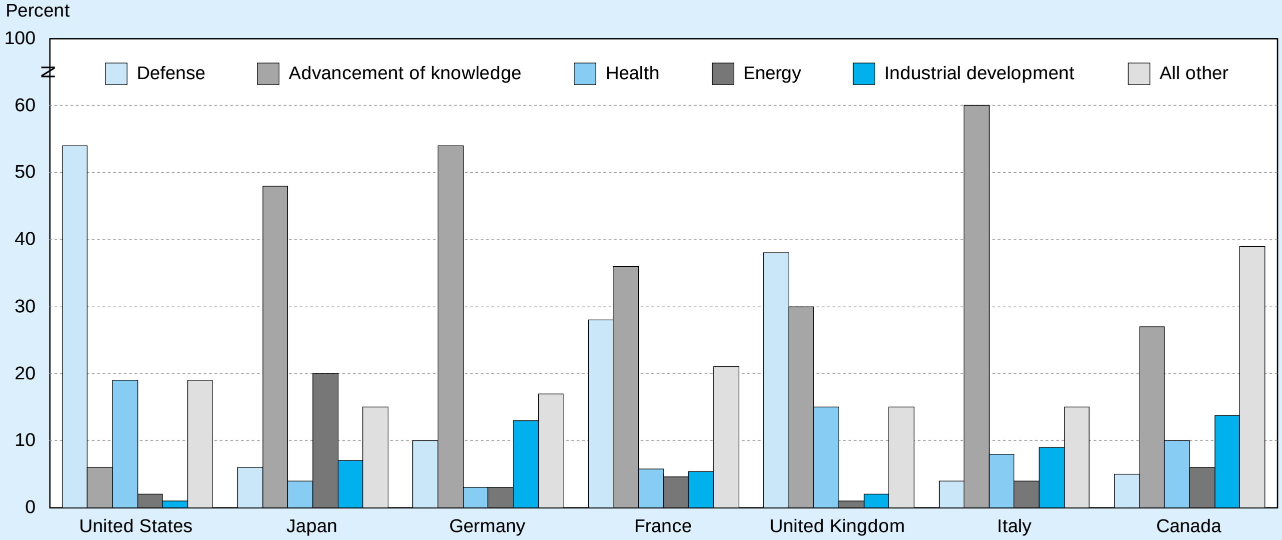
[50] Data on the socioeconomic objectives of R&D funding are rarely obtained by special surveys; they are generally extracted in some way from national budgets. Because those budgets already have their own methodology and terminology, these R&D funding data are subject to comparability constraints not 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.

Figure 2-34.
Government R&D support, by country and socioeconomic objective: 1997–98



NOTES: 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 2-66. *Science & Engineering Indicators – 2000*

International Nondefense Functions

Japanese, German, and Italian government R&D appropriations in 1997 were invested relatively heavily (48 percent or more of the $18 billion total for Japan, 54 percent of Germany's $16 billion total, 60 percent of the $6 billion total in Italy) in advancement of knowledge—that is, combined support for advancement of research and general university funds (GUF). 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.[51]

The emphasis on health-related research is much more pronounced in the United States than in other countries. This emphasis is especially notable in the support of life sciences in academic and similar institutions. In 1998, the U.S. government devoted 19 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, whereas about 90 percent of defense R&D is development.) By comparison, health R&D support ranges between 9 and 15 percent of total spending in the governmental R&D budgets of the United Kingdom, Italy, and Canada.

Different activities were emphasized in other countries' governmental R&D support statistics. Japan committed 20 percent of governmental R&D support to energy-related activities, reflecting the country's historical concern about its high dependence on foreign sources of energy. In Canada, 12 percent of the government's $3 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), whereas industrial development accounted for 9 percent or more of governmental R&D funding in Germany, Italy, and Canada. Industrial development programs accounted for 7 percent of the Japanese total but just 0.5 percent of U.S. R&D. The latter figure is understated relative to other countries as a result of data compilation differences.

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[51] In the United States, "advancement of knowledge" is a budgetary category for research unrelated to a specific national objective. Furthermore, whereas GUF is reported separately for Japan, Canada, and European countries, the United States does not have an equivalent GUF category: 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 national governments in Europe and elsewhere. Thus, these socioeconomic data are indicative not only of relative international funding priorities but also of funding mechanisms and philosophies regarding the best methods for financing research. For 1997, the GUF portion of total national governmental R&D support was 47 percent in Italy, about 38 percent in Japan and Germany, and just under 20 percent in the United Kingdom, Canada, and France.

Accounting for Defense 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 there are many reasons to expect funding and performing series to differ—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.

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 to 10 percent of the government total. This pattern reversed itself toward the end of the decade; in 1989 government-reported R&D total exceeded performer reports by $1 billion. The gap has since grown to about $5 billion. In other words, about 7 percent of the government total in the late 1990s is unaccounted for in performer surveys. (See figure 2-35.)

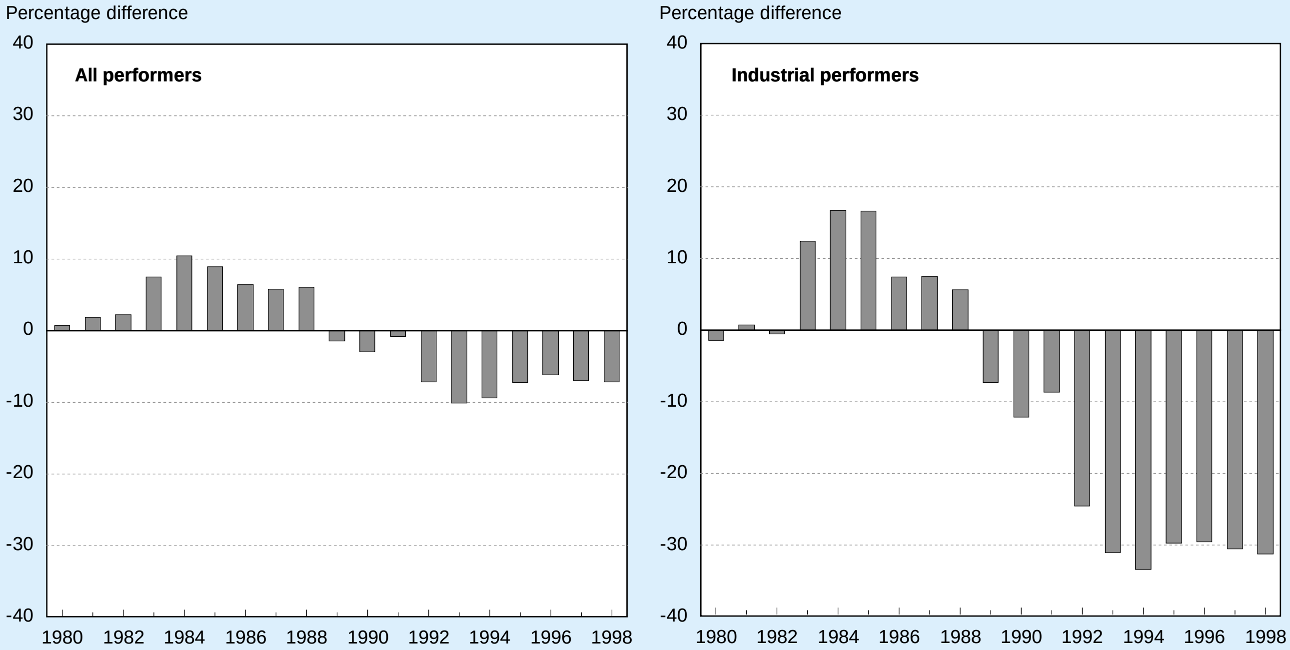
The difference in Federal R&D totals is primarily in DOD development funding of industry (primarily aircraft and missile firms). For 1997, Federal agencies reported $31.4 billion in total R&D obligations provided to industrial performers, compared with an estimated $21.8 billion in Federal funding reported by industrial performers. (DOD reports industry R&D funding of $24.2 billion, whereas industry reports using $12.6 billion of DOD's R&D funds.) Overall, industry-wide estimates equate to a 31 percent paper "loss" of Federally reported R&D support. (See figure 2-35.)

To investigate causal factors for the reporting gap, NSF—working with DOD contract-specific data—conducted on-site interviews with carefully selected companies that perform Federal R&D for DOD. Companies were asked about their R&D activities, data collection and reporting methods, and subcontracting practices. They also were asked to volunteer information about other factors that might influence the growing reporting difference. On the basis of these interviews and supplemental data analyses, the following factors appear to contribute most to the observed data gap.

Shifts in the composition of R&D, test, and evaluation (RDT&E) contracts during the past 10 years—since the end of the Cold War—introduced numerous changes in DOD's budgeting choices. Between 1991 (the last year that Federal funding and performing totals were relatively close) and 1998, DOD procurement spending (in inflation-adjusted terms) fell by 50 percent, whereas RDT&E spending declined by a relatively modest 7 percent. Concurrently, the proportion of DOD's RDT&E funding of traditional R&D program activities such as missile and space systems, tanks, ships, and other weapons systems has decreased; funding of more generalized technical, analytical and professional service contracts has increased. This trend has been accompanied by the emergence of new, nontraditional contractors (including large communication carriers and small high-technology firms) and firms specializing in program support activities within the DOD-funded R&D-performing industrial sector. Consequently, an increasing share of what DOD now funds, and therefore reports as R&D, is not necessarily perceived as R&D by industry performers. Industry representatives also mentioned significant changes in DOD's overall budget environment whereby RDT&E funds are now used to update military equipment under an emerging procurement management concept called "repeated R&D," whereby new technology is being incorporated on an ongoing basis into military systems. The effect is that RDT&E appropriations are now funding activities that could have been considered production 10 years ago. In short, there has been a change in what constitutes the R&D activity that is not similarly captured from Federal and industry respondents.

As a result of major changes in DOD's efforts to streamline its procurement environment and practices, the use of large, flexible, multiyear, multi-agency, indefinite order-type contract vehicles has become increasingly common. These contracts, which can be used

Figure 2-35.
Difference in U.S. performer-reported versus agency-reported Federal R&D



NOTE: Difference is defined as the percentage of federally reported R&D.

See appendix table 2-59.

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by nearly every Federal agency, significantly reduce administrative and procurement actions needed to acquire services and technical support from previously selected contractors. They also have very high funding "ceilings" that allow government agencies to order tasks as needed. These contract vehicle characteristics tend to hide the ultimate funding source for particular activities and confuse the original "color of money" (i.e., the nature of the originating appropriation accounts). The effects of these procurement reforms were widespread in 1992 and 1993.

Finally, the consolidation of the defense and aerospace R&D business (see figure 4-10 in NSB 1998), as well as other corporate mergers and acquisitions, has considerably complicated industries' tracking of defense-related R&D. Few firms (especially extremely large, diversified companies) maintain award-specific data on R&D contracts for their many subsidiaries. Consequently, R&D-intensive activities of acquired firms may not be visible at corporate headquarters responding to national R&D surveys. This reporting problem is magnified with recent growth in R&D outsourcing. In such circumstances, the subcontracted ("routine technical service") activity often is performed by companies with only scant knowledge of the original funding source and perhaps even less knowledge on the overall DOD R&D objective to which their work is contributing.

The relative importance of these considerations in quantifying these data differences is unknown. Clearly, however, a variety of factors affect the collection of consistently reported R&D data from performers and funders. A similar mismatching of Federal R&D to academia as reported by universities and Federal agencies is now appearing in the data series. In this instance, however, totals reported by universities exceed those reported by Federal respondents. Indeed, other countries also have difficulty tracking and matching performer and source data (see NSB 1998)—indicative of the transitional changes affecting the S&E enterprise globally.

International Comparisons of Government R&D Tax Policies

In most 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 science and technology. 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 following are the main features of the R&D tax instruments:

- Almost all countries (including the United States) allow industry R&D expenditures to be 100 percent deducted from taxable income in the year they are incurred.
- In most countries, R&D expenditures can by carried forward or deducted for 3 to 10 years. (In the United States, there is a 3-year carry-forward on R&D expenditures and a 15-year carry-forward on R&D capital assets.)
- About half the countries (including the United States; see "U.S. Federal and State R&D Tax Credits") 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 countries have special provisions that favor R&D in small and medium-size enterprises. (In the United States, credit provisions do little to help small start-up firms, but more direct Federal R&D support is provided through grants to small firms. See "Federal Support for Small Business R&D.")
- A growing number of R&D tax incentives are being offered at the subnational (provincial and state) levels, including in the United States (see "U.S. Federal and State R&D Tax Credits").[52]

International Public- and Private-Sector R&D and Technology Cooperation

Particularly in light of recent advances in information and communication technologies, international boundaries have become considerably less important in structuring the conduct of R&D and the use of research collaborations. Indicators of R&D globalization illustrate these R&D landscape changes for each of the R&D-performing sectors. Growth in international academic research collaboration is exhibited by the substantial increase in international co-authorship trends. (See chapter 6.) Extensive global growth in public-sector and industrial R&D activities is detailed below.

Public-Sector Collaboration

The rapid rise in international cooperation has spawned activities that now account more than 10 percent of government R&D expenditures in some countries. A significant share of these international efforts results from collaboration in scientific research involving extremely large "megascience" projects. Such developments reflect scientific and budgetary realities: Excellent science is not the domain of any single country, and many scientific problems involve major instrumentation and facility costs that appear much more affordable when cost-sharing arrangements are in place. Additionally, some scientific problems are so complex and geographically expansive that they simply require an international effort.[53] As a result of these concerns and issues, an increasing number of S&T-related international agreements have been forged between the U.S. government and its foreign counterparts during the past decade.

U.S. Government's Use of International S&T Agreements

International governmental collaboration in S&T and R&D activities appears to be a growing phenomenon. There are few sources of systematic information on government-to-government cooperative activities, however. A report by the U.S. General Accounting Office (GAO 1999) provides a snapshot of seven Federal agencies' international S&T agreements that were active during FY 1997. The GAO accounting is only for official, formal agreements and therefore provides a lower-bound estimate of the number of governmental global S&T collaborations. Most international cooperation is continuous and ongoing and takes place outside the framework of official, formal agreements. Nonetheless, the GAO study found that these seven agencies—DOE, NASA, NIH, NIST, the National Oceanographic and Atmospheric Administration (NOAA), NSF, and the Department of State—participated in 575 such agreements with 57 countries, 8 international organizations, and 10 groups of organizations or countries. Fifty-four of these agreements were broad-based bilateral arrangements between the U.S. government and governments of foreign countries—commonly referred to as "umbrella" or "framework" agreements. The remaining 521 agreements were bilateral agreements between research agencies and their counterparts in foreign governments and international organizations (381) or multilateral agreements (140) to conduct international cooperative research, provide technical support, or share data or equipment.

Generally, such agreements—which are indicative of government interest to cooperate internationally in R&D—have no associated budget authority. Nor is there a system in place to link international S&T agreements with actual spending on cooperative R&D. According to a study by the Rand Corporation, the U.S. government spent $3.3 billion on R&D projects involving international cooperation in FY 1995 (which may or may not have been associated with international S&T agreements) and an additional $1.5 billion on non-R&D activities associated with international S&T agreements (Wagner 1997).

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[52] See also Poterba (1997) for a discussion of international elements of corporate R&D tax policies.

[53] See OECD (1993 and 1998c) Megascience Forum publications for a concise summary of the history, concepts, and issues behind mega-projects and megascience activities. Additionally, Georghiou (1998) provides a thorough discussion on current global facilities in big science and the emergence of global cooperative programs among governments.

Among the seven agencies that GAO reviewed, DOE participated in the largest number of official international S&T agreements (257, or 45 percent of the 575 total). (See text table 2-17.) This total included almost 100 multilateral agreements with the International Energy Agency (IEA), which represents the United States and 23 other countries with common scientific interests and priorities. NASA was second among the seven agencies in terms of participation in total international S&T agreements (127, including 15 multilateral agreements with the European Space Agency).

In addition to the 140 multilateral agreements, these seven agencies participated in bilateral S&T agreements with countries from almost every region of the world. In terms of the sheer numbers, U.S. agencies were most active in their participation with Japan (78): DOE and NASA reported the largest number of their bilateral S&T agreements with that country. After Japan, U.S. S&T agreements were most commonly reported with Russia (38), China (30), and Canada (25). DOE reported more agreements with Russia and China than did any other agency; NASA accounted for the largest number of agreements with Canada. The prevalence of DOE and NASA in these and other international S&T agreements reflects the megascience attributes associated with their missions. Of the other five agencies in the GAO report, only NIST reported more than five bilateral agreements with any single country (Japan and South Korea) in FY 1997. NIST also listed five agreements with Russia and three with Canada.

Text table 2–17.
Total and bilateral international S&T agreements, by selected agency and country: FY 1997

	Total	Energy	NASA	NIH	NIST	NOAA	NSF	State
Total	575	257	127	44	56	32	26	33
Multilateral	140	107	15	1	7	7	3	0
Bilateral[a]	435	150	112	43	49	25	23	33
Asia	151	56	31	13	24	10	10	7
Japan	78	28	26	4	13	2	4	1
China	30	20	0	3	1	2	3	1
Korea	20	7	0	2	7	1	2	1
Other	23	1	5	4	3	5	1	4
Europe	150	48	37	16	11	7	13	18
Russia	38	16	8	4	5	1	3	1
France	21	9	6	1	0	4	1	0
Germany	15	1	8	3	0	0	3	0
United Kingdom.	11	5	3	1	0	1	1	0
Italy.	11	2	4	3	1	0	0	1
Other.	54	15	8	4	5	1	5	16
South & Central America	48	22	13	2	6	1	0	4
Venezuela	15	12	0	1	1	0	0	1
Brazil	12	3	6	0	1	1	0	1
Argentina	10	3	4	0	2	0	0	1
Chile	8	2	3	1	1	0	0	1
Other	3	2	0	0	1	0	0	0
North America	34	8	14	4	4	3	0	1
Canada	25	5	14	1	3	2	0	0
Mexico	9	3	0	3	1	1	0	1
South Pacific	24	8	11	2	1	1	0	1
Australia	16	5	9	1	0	1	0	0
Other	8	3	2	1	1	0	0	1
Africa	15	6	2	2	2	1	0	2
South Africa	9	3	2	1	1	1	0	1
Other	6	3	0	1	1	0	0	1
Middle East	13	2	4	4	1	2	0	0
Israel	8	1	4	3	0	0	0	0
Other	5	1	0	1	1	2	0	0

NOTES: These are official international science and technology agreements only. Bilateral agreements between the Department of State and other countries are broad government-level agreements. In some cases, they provide the formal framework for establishing bilateral agreements detailed in the table. The GAO source report included Russia in its Asia counts; Russia is included here in the Europe totals.

[a] Country counts include bilateral agreements only.

SOURCE: Government Accounting Office. 1999. *Federal Research: Information on International Science and Technology Agreements.* GAO/RCED – 99-108. Washington, DC: GAO.

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Overall, more than 90 percent of the international S&T agreements active in FY 1997 resulted in research projects or other research-related activities. In cases in which this activity did not occur, funding problems that developed after the agreements were signed or changes in research priorities generally were the reasons for their discontinuation.

International S&T collaboration can and does increasingly take place under less formal agreements, however. Consequently, these measures of formal agreements do not necessarily represent the level or intensity of R&D relationships or international collaboration between scientific communities in various countries.[54]

Private-Sector Collaboration

International R&D collaboration is on the rise in the private sector as well—as is indicated by the rising number of formal cooperative agreements or alliances between firms, the growth of overseas R&D activities performed under contract and through subsidiaries, and an increase in the number of R&D laboratories located abroad (OECD 1998a). The expansion of international industrial R&D activity appears to be a response to the same competitive factors that foster domestic collaborations. Firms reach beyond their home borders as a way of addressing rising R&D costs and risks in product development, shortened product life cycles, increasing multidisciplinary complexity of technologies, and intense competition in domestic and global markets.

International Strategic Technology Alliances

Historical Trends

Industrial firms increasingly have used global research partnerships to strengthen their core competencies and expand into technology fields they consider critical for maintaining market share. In these partnerships, organizations can expand opportunities and share risks in emerging technologies and emerging markets. During the first half of the 1970s, strategic alliances were almost nonexistent, but they expanded rapidly late in the decade. For example, the number of newly made partnerships in the three core technologies—information technologies, biotechnology, and new materials—rose from about 10 alliances created in 1970 (Hagedoorn 1996) to about 90 in 1980. R&D-related international strategic technology alliances increased sharply throughout the industrialized world in the early 1980s and accelerated as the decade continued, reaching 580 such partnerships in 1989.[55] In the early 1990s, the annual formation of newly established alliances at first tapered off from that reported in the 1980s and then rapidly increased to a peak of more than 800 new alliances formed in 1995. Since then, there has been a steady decrease in the number formed, to 564 in 1998—a total that nonetheless exceeds the number formed during any year prior to 1989. For the entire 1980–98 period, U.S., European and Japanese firms collectively entered into almost 9,000 strategic technology alliances. Most of these alliances were formed in the 1990s; most involved U.S. firms; and most were signed to foster R&D partnerships in just a few high-tech areas, notably information technologies and biotechnology. (See figure 2-36, text table 2-18, and appendix table 2-67.)

As the number of alliances has increased, the forms of cooperative activity have changed as well. The most prevalent modes of global industrial R&D cooperation in the 1970s were joint ventures and research corporations. In these arrangements, at least two companies share equity investments to form a separate and distinct company; profits and losses are shared according to the equity investment.[56] In the second half of the 1980s and into the 1990s, joint nonequity R&D agreements became the most common form of partnership. Under such agreements, two or more companies organize joint R&D activities to reduce costs and minimize risk while they pursue similar innovations; participants share technologies but have no joint equity linkages (Hagedoorn 1990, 1996).

Country Focus

Between 1990 and 1998, more than 5,100 strategic technology alliances were formed, of which 2,700 were intraregional (that is, made between firms located within the broad regions of Europe, Japan, or the United States) and 2,400 were interregional (between firms located in separate regions). Of course, many of the more than 500 intra-European alliances are also multinational because they generally involve firms from more than one European country (in contrast with the numerous intra-American and much less numerous intra-Japanese firm partnerships in which all partners have the same national ownership). For the 1990–98 period, U.S. companies participated in 80 percent of known technology alliances, about half of which were between two or more U.S. firms and about half of which included a non-U.S. company. European companies participated in 42 percent and Japanese companies in 15 percent of the 5,100 alliances formed in the 1990s. (See text table 2-18).

Consistent with overseas R&D funding trends (detailed below), just a handful of European firms account for most of that region's alliances. Of the 4,700 European alliances re-

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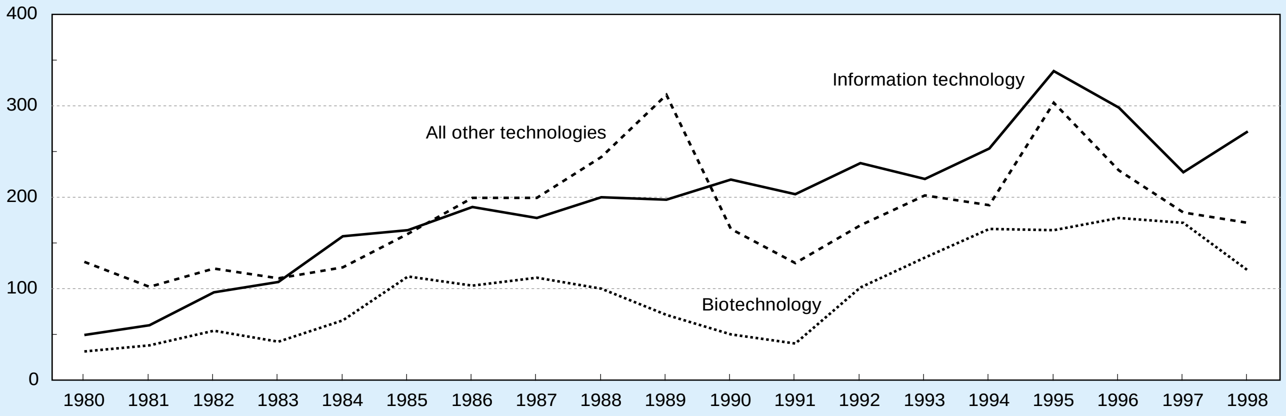
[54] See chapter 6 for information on patterns of international co-authorship.

[55] Information in this section is drawn from an extensive database compiled in the Netherlands— the Maastricht Economic Research Institute on Innovation and Technology's (MERIT 1999) Cooperative Agreements and Technology Indicators (CATI) database—on literally thousands of inter-firm cooperative agreements. The CATI database collects only agreements that contain arrangements for transferring technology or joint research. 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. The historical totals reported here differ from those reported in previous *Science & Engineering Indicators*. Previously, alliances of minority holdings coupled with research contracts were included in the totals. Here such alliances are not included in the totals. CATI is a literature-based database: Its key sources are newspapers, journal articles, books, and specialized journals that report on business events. Its main limitations are that data are limited to activities publicized by the firm, agreements involving small firms and certain technology fields are likely to be underrepresented, reports in the popular press are likely to be incomplete, and it probably reflects a bias because it draws primarily from English-language materials. CATI information should therefore be viewed as indicative and not comprehensive.

[56] Joint ventures are companies that have shared R&D as a specific company objective, in addition to production, marketing, and sales. Research corporations are joint R&D ventures with distinctive research programs.

Figure 2-36.
New international strategic technology alliances, by technology



NOTE: Includes alliances of firms located both within broad regions and across broad regions.

See appendix table 2-67.

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ported during the entire 1980–98 period (a figure that includes double-counting of partnerships with two or more European firms), the most active participants were British firms (1,036 alliances), German firms (994), French firms (715) and Dutch firms (680). More than 100 alliances were also formed by companies with Italian (338), Swiss (267), Swedish (278), and Belgian (119) ownership. Additionally, a substantial number of the international technology partnerships involved firms located outside of these major regions. During the entire 1980–98 period, Canadian firms entered into 198 strategic technology alliances (mostly with U.S. companies), South Korean firms joined 119, Russian (and other former Soviet Union) firms joined 90,[57] Chinese firms joined 86, Australian firms joined 63, Israeli firms joined 51, and Taiwanese firms joined 48.

Technology Focus

Most intraregional and interregional alliances have been between firms sharing research and technology development in information technologies (IT) and biotechnology. These two technologies alone account for two-thirds of all alliances formed since 1990. The only other technologies for which firms consistently have entered into a substantial number of partnerships relate to advanced materials and non–biotechnology-based chemicals. (See appendix table 2-67.) Forty-four percent of the technology alliances formed worldwide since 1990 dealt with information technologies such as computer software and hardware, telecommunications, industrial automation, and microelectronics. Of the roughly 2,300 IT alliances formed during this period, most have been between U.S. companies (50 percent) or between European and U.S. firms (19 percent). Among the 1,100 strategic biotechnology alliances, the regional distribution has been more diverse, although U.S.-U.S. and U.S.-European interregional partnerships are more prevalent than any other (each type accounting for more than one-third of the biotechnology total). Consistent with R&D funding trends and indicative of known core strengths, U.S.-Japanese collaborations are more common in IT activities than in biotechnology.

International Industrial R&D Investment Growth

Stiff international competition in research-intensive, high-technology products and market opportunities have compelled firms throughout the world to expand their overseas research activities. Foreign sources account for a growing share of domestic R&D investment totals in many countries. (See figure 2-32.) Many firms have R&D sites in countries outside their home base. Although the data are somewhat scant, the share of R&D performed by foreign affiliates appears to have risen perceptibly throughout the OECD during the past two decades (OECD 1998a). Currently, the share of R&D performed by foreign affiliates accounts on average for 14 percent of the industrial R&D performed in OECD countries. This share varies considerably among hosting countries, however—from a low of 1 percent in Japan to a high of 68 percent in Ireland (OECD 1999d).

Although many factors contribute to a business decision to locate R&D capabilities outside a firm's home country, the basic drivers fall into demand-side and supply-side considerations.

Multinational firms seek a foreign R&D presence to support their overseas manufacturing facilities or to adapt standard products to the demand there. R&D facilities are established to customize existing products or to develop new

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[57] See Hagedoorn and Sedaitis (1998) for summary data on international strategic technology alliances between Western companies and Russian companies.

Text table 2–18.
Strategic Technology Alliances, by region: 1980–98

	Total alliances	Information technology	Biotechnology	All other technologies
1980–1989 alliances				
Total	3,826	1,396	729	1,701
USA-Europe	809	296	152	361
USA-Japan	550	209	93	248
USA-Others	178	44	23	111
Europe-Japan	237	84	24	129
Europe-Others	188	55	15	118
Japan-Others	53	8	8	37
Intra-USA	908	400	247	261
Intra-Europe	670	242	125	303
Intra-Japan	233	58	42	133
Percent of 1980–1989 totals				
Total	100.0	100.0	100.0	100.0
USA-Europe	21.1	21.2	20.9	21.2
USA-Japan	14.4	15.0	12.8	14.6
USA-Others	4.7	3.2	3.2	6.5
Europe-Japan	6.2	6.0	3.3	7.6
Europe-Others	4.9	3.9	2.1	6.9
Japan-Others	1.4	0.6	1.1	2.2
Intra-USA	23.7	28.7	33.9	15.3
Intra-Europe	17.5	17.3	17.1	17.8
Intra-Japan	6.1	4.2	5.8	7.8
1990–1998 alliances				
Total	5,132	2,267	1,123	1,742
USA-Europe	1,284	434	403	447
USA-Japan	437	259	66	112
USA-Others	254	113	44	97
Europe-Japan	195	75	32	88
Europe-Others	174	50	33	91
Japan-Others	40	22	5	13
Intra-USA	2,150	1,140	436	574
Intra-Europe	521	142	100	279
Intra-Japan	77	32	4	41
Percent of 1990–1998 totals				
Total	100.0	100.0	100.0	100.0
USA-Europe	25.0	19.1	35.9	25.7
USA-Japan	8.5	11.4	5.9	6.4
USA-Others	4.9	5.0	3.9	5.6
Europe-Japan	3.8	3.3	2.8	5.1
Europe-Others	3.4	2.2	2.9	5.2
Japan-Others	0.8	1.0	0.4	0.7
Intra-USA	41.9	50.3	38.8	33.0
Intra-Europe	10.2	6.3	8.9	16.0
Intra-Japan	1.5	1.4	0.4	2.4

See appendix table 2-67.

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products for the local market. Additionally, such facilities may provide technical service support to local manufacturing activities as their primary purpose. In some situations, however, the location of R&D facilities is the price of entry to the local market. These arrangements constitute a home-base exploiting site, where information tends to flow to the foreign laboratory from the central home laboratory.

Conversely—and more commonly of late—the foreign site is established to tap knowledge and skilled labor from competitors and universities around the globe, including the direct employment of local talents; to participate in joint research ventures and cooperative agreements; and to passively monitor technological development abroad. These facilities have the characteristics of a home-base augmenting site, where information tends to flow from the foreign laboratory to the central home laboratory. Generally, however, there is little evidence to suggest that firms go abroad to compensate for their R&D weaknesses at home. Rather, they locate in foreign centers of excellence to supplement their existing core strengths (Patel and Vega 1999).

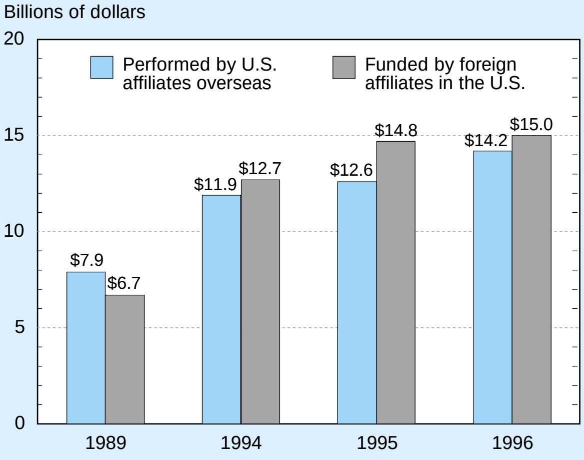
According to a study of 238 foreign R&D sites, 45 percent of the labs were home-base augmenting and 55 percent were home-base exploiting (Kuemmerle 1997).[58]

U.S. and Foreign Industrial R&D Expenditure Balance

U.S. companies' R&D investments abroad are roughly equivalent to R&D expenditures in the United States by majority-owned U.S. affiliates of foreign companies.[59] In 1996 (the latest year for which complete data from the Bureau of Economic Analysis [BEA] are available at this writing), industrial R&D flows into the United States totaled $15.0 billion, compared with $14.2 billion in R&D expenditures by U.S. multinational firms in other countries. (See figure 2-37.) This approximate balance in R&D investment flows has persisted since (at least) 1989, when the majority-owned data first became available on an annual basis. In 1989, however, U.S. companies conducted a greater amount of R&D abroad than was invested in the United States by foreign firms. The reverse now appears to be true: More industrial R&D money is flowing into the United States than U.S. firms are performing abroad. Whatever the exact "balance" in any given year, however, higher levels of U.S. R&D investment in foreign economies and non-U.S. R&D investment within the U.S. domestic economy clearly are becoming the norm (Mowery 1998a).

Europe is the primary source and the main location of performance of these U.S.-foreign industrial R&D flows. (See figure 2-38.) European firms invested $11.2 billion of R&D money in the United States in 1996; the Asian (excluding the Middle East) and Pacific region provided the second largest source of foreign R&D funds ($1.9 billion). Similarly, foreign affiliates of U.S. companies performed $9.7 billion of R&D in Europe and $2.1 billion in Asia and the Pacific region.[60] Industrial R&D investments between Canada and the United States are in the $1.5 billion range. U.S. industry's R&D flows remain relatively small (less than $1 billion) into and out of Latin America and the Middle East and are negligible with Africa.

Figure 2-37.
Globalization of U.S. industrial R&D



NOTE: Data for majority-owned (50 percent or more) non-bank affiliates only.

See appendix tables 2-69 and 2-71.

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Trends in U.S. Industry's Overseas R&D

From 1985 through 1996, U.S. firms generally increased their annual funding of R&D performed outside the country more than their funding of R&D performed in the United States. (See appendix table 2-68.) Indeed, during this period U.S. firms' investment in overseas R&D increased 2.8 times faster than did company-funded R&D performed domestically (9.7 percent versus 3.4 percent inflation-adjusted average annual growth). Overseas R&D funding accounted for about 6.0 percent of U.S. industry's total (domestic plus overseas) R&D funding in 1985; in 1996 overseas R&D accounted for 10.4 percent of U.S. industry's total R&D. In 1997, however, strong growth in U.S. companies' domestic R&D financing (up 10 percent), coupled with a 7 percent decline in

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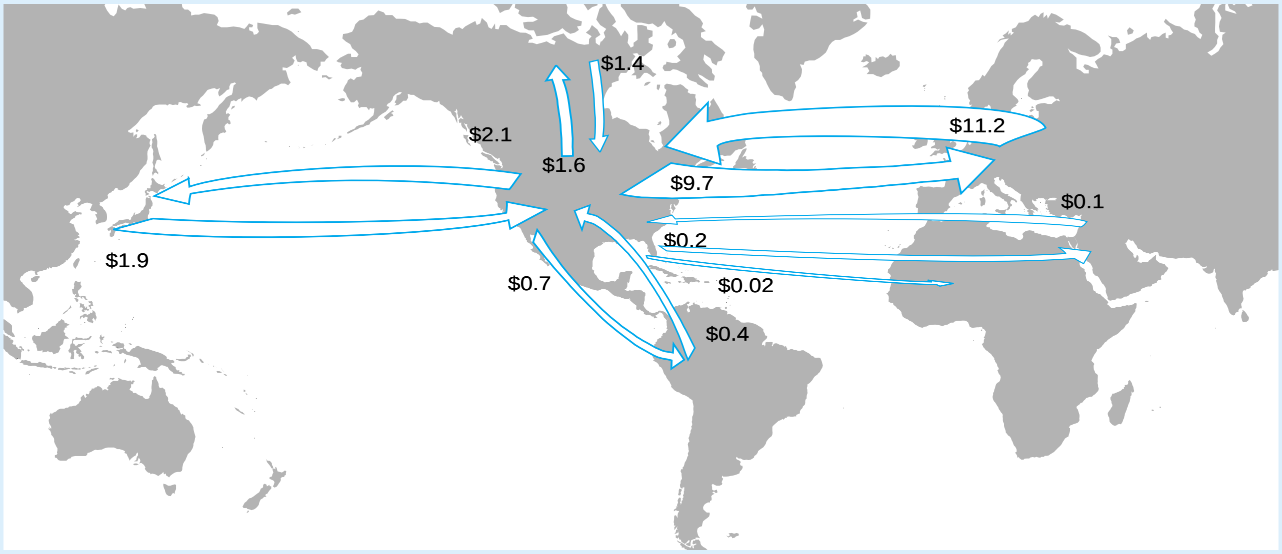
[58] The terms "home-base exploiting" and "home-base augmenting" are taken directly from Kuemmerle (1997). Others, however (e.g., Mowery 1998b and Dalton, Serapio, and Yoshida 1999), have made similar observations on the reasons for expanding global R&D arrangements. Furthermore, Mowery notes that the use of international R&D strategies to establish networks for the creation and strengthening of firm-specific technological capabilities (i.e., home-base augmenting) is likely to become more important than market exploitation-driven activities in the future.

[59] These overseas R&D data are from the BEA survey on U.S. Direct Investment Abroad. The definition used by BEA for R&D expenditures is from the Financial Accounting Standards Board Statement No. 2; these expenditures include all charges for R&D performed for the benefit of the affiliate by the affiliate itself and by others on contract. BEA detail is available for 1982 and annually since 1989. Data on foreign sources of industrial R&D performed in the United States come from an annual survey of Foreign Direct Investment in the United States, also conducted by BEA. BEA reports that foreign R&D totals are comparable with U.S. R&D business data published by NSF. Industry-specific comparisons, however, are limited because of differences in the industry classifications used by the two surveys (Quijano 1990).

[60] Analyses of the BEA data on overseas R&D activities of U.S. affiliates have become complicated as a result of a change in survey collection. Prior to the 1994 survey, BEA collected expenditure data on R&D funding by U.S. overseas affiliates regardless of whether the R&D was performed by the affiliate of by others. It excluded R&D conducted by the affiliate under contract for others. Beginning with the 1995 survey, U.S. affiliates were asked to report their R&D performance irrespective of the funding sources (i.e., they report R&D conducted in their own labs, including R&D funded by the affiliate itself and by others under contracts). R&D funded by the U.S. affiliate but conducted by other organizations are excluded. Consequently, the more recent BEA figures represent R&D performance of U.S. firms' foreign affiliates and not the foreign R&D funding made by U.S. firms.

Figure 2-38.
Industrial R&D of U.S. and foreign affiliates, by world region: 1996

Billions of dollars



See appendix tables 2-69 and 2-71.

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industry's overseas R&D spending, reduced the overseas share to 8.9 percent of U.S. companies' funding total.[61]

Additionally, according to BEA data, the majority-owned (that is, 50 percent or more) foreign-affiliate share of U.S. multinational companies' worldwide R&D expenditures increased from 9 percent in 1982 to 13 percent in 1990, where it remained through 1994 (Mataloni and Fahim-Nader 1996). According to preliminary data for 1996, the foreign-affiliate share of U.S. multinationals' total R&D funding rose to 14 percent (Mataloni 1998).

Sector Focus of Overseas R&D Activity

R&D investment by U.S. companies and their foreign subsidiaries in the chemicals (including pharmaceuticals and industrial chemicals) industry accounts for the largest share and greatest growth of foreign-based R&D activity. (See figure 2-39.) Indeed, drug companies accounted for 18 percent of total 1997 overseas R&D ($2.4 billion of the $13.1 billion total)—equivalent to 21 percent of the pharmaceutical industry's domestically financed R&D. Part of this growth undoubtedly is a function of the worldwide pattern of collaboration between integrated global pharmaceutical firms and emerging biotechnology companies in the U.S. and Europe—most notably the United Kingdom (Council on Competitiveness 1998). (See appendix table 2-68.)

Similarly, firms in the industrial and other chemicals industry spent an amount overseas ($1.5 billion) equivalent to 21 percent of their onshore R&D investment. Demand and supply factors alike seem to be driving this internationalization. R&D is performed overseas so that global firms are better able to customize their products to meet the needs of local customers and to ensure market access. Furthermore, chemicals R&D performance is becoming global because different regions of the world are becoming technologically specialized—Germany, for example, in fundamental research in organic synthesis and Japan in electronic chemicals (Arora and Gambardella 1999). Of other major R&D-performing manufacturers, recent trends show the overseas R&D investment share of total R&D financing rising considerably for scientific instruments ($1.2 billion in 1997, equivalent to 13 percent of the domestic total) and machinery equipment ($1.8 billion in 1997, equivalent to 10 percent of the domestic total).

Growth in overseas R&D investments is not limited to sectors with strong historical experience in overseas production activity. The combined total for all nonmanufacturing industries indicates substantial increases in foreign R&D activity since 1985—rising from 0.4 percent of domestic R&D funding that year to 8.6 percent in 1996. Part of this growth reflects increased international R&D financing by firms historically classified as nonmanufacturing industries

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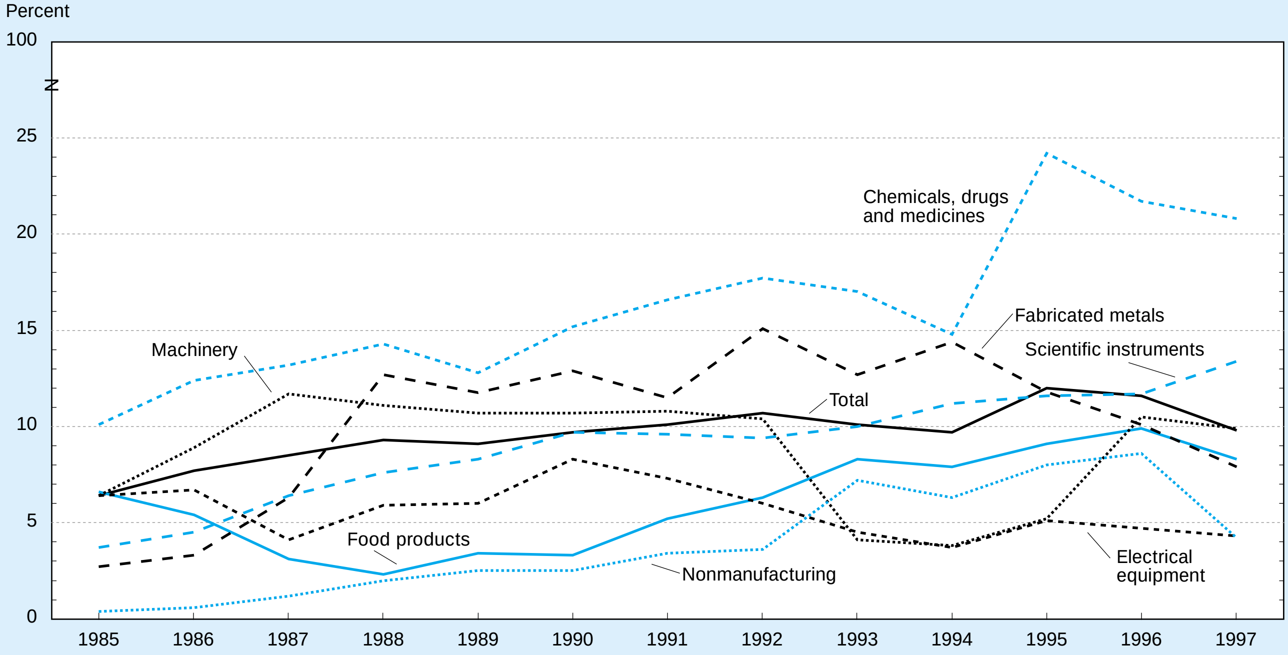
[61] These overseas R&D shares are taken from the NSF industrial R&D data series, not the BEA Direct Investment Abroad series used in the "U.S. and Foreign Industrial R&D Expenditure Balance" discussion. However, BEA data on the country destination of the U.S. overseas R&D investment are more complete than the NSF series and therefore are used to describe country patterns. NSF reports 1996 and 1997 overseas R&D totals of $14.1 billion and $13.1 billion, respectively; BEA estimates 1996 overseas R&D performance by foreign affiliates of U.S. companies (including both for the affiliate and for others) at $14.2 billion.

Figure 2-39.
Ratio of U.S. overseas R&D to company-financed domestic R&D



See appendix table 2-68.

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(particularly computer, data processing, and architectural services). Part of the increase reflects the movement of firms previously classified as manufacturers (e.g., office computing companies) to service sector industries (e.g., software development). This observation is borne out by the reduction in nonmanufacturers' overseas R&D in 1997 ($1.4 billion, down from $2.5 billion in 1996). Most of this decline reflects firms' shifting industry classifications within IT-related industries rather than an actual drop in industrial funding activity. Nonetheless, overseas R&D investments in information technologies remain substantial. One factor driving such globalization is that foreign labor markets provide U.S. companies with an ample supply of qualified (and sometimes less-expensive) science and engineering personnel—as indicated by robust IT investments in English-speaking India, Ireland, and Canada.[62] (See chapter 3 on the Science and Engineering Workforce and chapter 9 on the Significance of Information Technologies.)

Country Location of U.S. Overseas R&D Activity

As BEA data on majority-owned foreign affiliates of nonbank U.S. multinational companies indicate, most of the U.S. 1996 overseas R&D was performed in Europe—primarily Germany (22 percent of the U.S. overseas total), the United Kingdom (15 percent), and France (9 percent). (See figure 2-40 and appendix table 2-69.) Collectively, however, the current 68 percent European share of the U.S. total R&D investment abroad is less than the 75 percent share reported for 1982. Since the early 1980s, U.S. R&D investments abroad have generally shifted from the larger European countries and Canada toward Japan, several of the smaller European countries (notably Sweden and the Netherlands), Australia, and Brazil.

As indicated by affiliate industry classifications, U.S. R&D investments abroad are concentrated in specific geographic locations. Almost half of the offshore automotive R&D in 1996 was spent in Germany; spending by transportation equipment companies accounted for almost two-thirds of all U.S. affiliate R&D activity in Germany. In the United Kingdom, France, Japan, and Italy, the chemicals industry accounted for the largest share of each country's respective R&D totals; collectively these four countries accounted for 54 percent of all U.S. affiliates' chemicals-related R&D. Electrical equipment firms accounted for most of the U.S. affiliates' R&D performance in the Netherlands; except for Germany, no other country accounted for more of the U.S. affiliates' electrical equipment R&D than did this relatively small country. (See text table 2-19.) These industry R&D emphases reflect the general industrial strengths of the various countries.

After Germany ($3.1 billion) and the United Kingdom ($2.1 billion), Canada is the next-largest site of U.S. overseas R&D performance. Almost $1.6 billion was spent in major-

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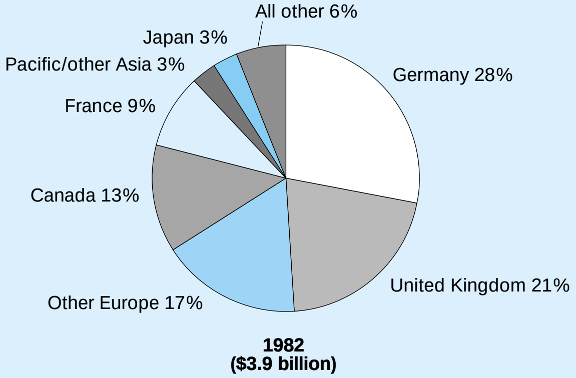
[62] For an informative discussion on the internationalization of R&D in Canada, see Anderson and Gault (1999). The information and communications sector now appears to account for 69 percent of the total foreign R&D funding provided Canada's industrial sector.

Figure 2-40.
U.S. R&D performed abroad



See appendix table 2-69.

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Text table 2–19.
R&D performed overseas by majority-owned foreign affiliates of U.S. parent companies, by selected country and industry of affiliate: 1996 (millions of U.S. dollars)

Country	All industries	Manufacturing: Total	Chemicals	Machinery	Electrical equipment	Transportation equipment	Nonmanufacturing
Total	14,181	12,358	3,700	1,063	1,258	4,252	1,823
Canada	1,582	1,457	302	28	97	D	125
Europe	9,651	8,625	2,715	746	749	2,894	1,026
Belgium	369	299	197	3	3	33	70
France	1,326	1,169	658	85	47	90	157
Germany	3,061	2,916	279	234	209	1,939	145
Italy	553	D	267	59	54	57	D
Netherlands	545	382	101	9	149	17	163
Spain	317	298	75	5	34	D	19
Sweden	439	404	D	22	9	*	35
Switzerland	189	134	29	D	D	–	55
United Kingdom	2,133	1,860	682	262	69	D	273
Rest of Europe	719	D	427	67	D	D	D
Asia and Pacific	2,073	1,582	552	262	220	D	491
Australia	409	318	85	D	1	D	91
Japan	1,337	1,002	405	184	132	2	335
Rest of Asia/Pacific	327	262	62	D	87	D	65
Western hemisphere	687	647	106	15	189	276	40
Brazil	489	482	61	10	D	D	7
Mexico	119	100	17	5	D	D	19
Middle East (Israel)	166	28	13	10	3	0	138
Africa	21	19	12	3	*	0	2

D = withheld to avoid disclosing operations of individual companies; * = less than $500,000

NOTES: Includes direct investments of majority-owned nonbank foreign affiliates of U.S. parents. Includes R&D expenditures conducted by the foreign affiliates for itself or for others under a contract.

SOURCE: U.S. Bureau of Economic Analysis, U.S Direct Investment Abroad (Washington, DC: BEA, 1998)

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ity-owned Canadian affiliates of U.S. firms. These considerable R&D investments are consistent with the overall facts that these two countries are one another's most important trade partners and that the level of U.S. investment in Canada is among the highest anywhere in the world. Unfortunately, disclosure restrictions to protect the confidentiality of specific firms' underlying R&D expenditures limit the amount of publishable data about the industries in which this considerable U.S. investment is being made.

Industry-wide, nonmanufacturing industries (including business services, with $0.9 billion) now account for 13 percent ($1.8 billion) of U.S. overseas R&D performance. Of this amount, majority-owned Japanese affiliates of U.S. multinational firms accounted for the largest single country share. (See text table 2-19.)

U.S. Industry's Overseas R&D Facilities

The U.S. Department of Commerce recently compiled data on R&D facilities located abroad (Dalton, Serapio, and Yoshida 1999). Although the information is based largely on secondary sources and is at best a sample of such activities, it nonetheless is illustrative of patterns in the establishment of U.S. R&D facilities overseas. There were 186 known foreign R&D facilities owned by 85 U.S. companies in 22 countries in 1997.

The list of U.S. facilities by country is similar to the list of countries in which U.S. firms spend the largest amounts of R&D investments abroad. Japan leads all countries as the site of U.S. R&D facilities (43), followed by the United Kingdom, Canada, France and Germany. As with foreign-owned facilities located in the United States (see "U.S. Research Facilities of Foreign Firms"), the largest number of U.S.-owned foreign facilities support the automotive (32 facilities), drugs and biotechnology (28), computers (25), and chemicals and rubber (23) industries. Although the data are not conclusive, U.S. firms have chosen to locate facilities in Japan to serve a variety of chemicals, drugs, automotive, and computer R&D needs. (See text table 2-20.)

The mix of industries represented by facility sites in major host countries is quite diverse.[63] For example, in the automotive and drug/biotechnology industries, U.S. firms own three or more facilities in five or more countries. Additionally, several emerging countries have been chosen as important locations for U.S. firms' R&D facilities. The most notable examples are Singapore (which now hosts 13 U.S.-owned facilities), Taiwan, and India—each of which has attracted relatively high levels of foreign R&D and created high-technology centers in their countries. Although China and Russia have been mentioned as potential future sites for U.S. R&D investments, protection of intellectual property remains a major concern that may limit such growth.

Motives for establishing overseas R&D facilities are manifold and differ among industries; technology or supply-oriented reasons have increasingly influenced the decision of U.S. firms to locate R&D abroad (a home-base augmenting strategy). This trend is particularly true for electronics and computer software. Even when companies initially invested abroad for the purpose of assisting their manufacturing/sales/service facilities in a local market (a home-base exploiting strategy), they increasingly are positioning these R&D facilities as regional R&D bases (Dalton, Serapio, and Yoshida 1999).

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[63] The figures in text table 2-20 represent only counts of facilities, however. The facilities themselves differ considerably in terms of dollars spent and scientists and engineers employed. More detailed information about the individual sites would permit a clearer determination of industry clustering and decentralization.

Text table 2–20.
U.S. R&D facilities abroad: 1997

Industry	Japan	United Kingdom	Canada	France	Germany	Others
Total	43	27	26	16	15	55
Automotive	6	4	4	4	5	9
Computers	7	5	0	1	2	10
Software	4	1	1	0	0	6
Semiconductors	4	1	0	1	0	6
Opto-electronics, telecom	2	0	2	2	1	6
Other electronics	3	2	2	1	1	2
Drugs, biotechnology	8	5	4	3	3	5
Chemicals, rubber	9	1	2	2	2	7
Other transportation equip	0	0	3	0	0	0
Metals, petroleum refining	0	2	6	0	0	6
Instrumentation, medical devices	0	5	3	0	0	2
Food, consumer goods, misc	1	3	4	2	0	5

NOTE: "Other countries" include 13 facilities in Singapore, 11 in China, and 8 in Belgium. These data are derived from secondary sources and are therefore a sample of the total (unknown) number of R&D facilities. The industry-specific detail may double-count some facilities because of the multiple focus of research performed. Not all industry categories are listed. The country totals do not include double-counting.

SOURCE: U.S. Department of Commerce, *Globalizing Industrial Research and Development*, by D. H. Dalton and M. G. Serapio, and P.G. Yoshida. Washington, DC, 1999.

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Foreign R&D in the United States

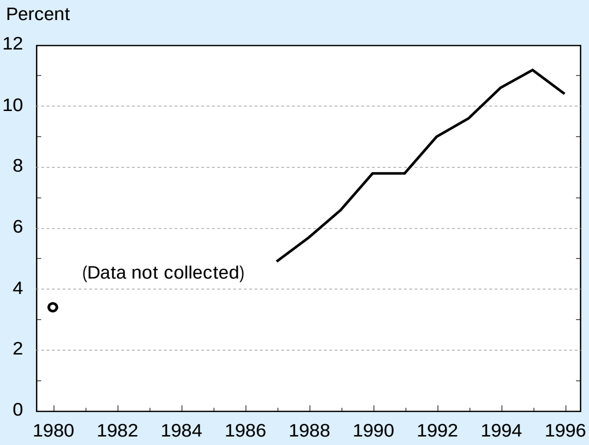
Like U.S. firms' overseas R&D funding trends, R&D activity by foreign-owned companies in the United States has increased significantly since the mid-1980s. From 1987 to 1996, inflation-adjusted R&D growth from foreign firms (U.S. affiliates with a foreign parent that owns 50 percent or more of the voting equity) averaged 10.9 percent per year. (See appendix table 2-71).[64] This growth contrasts favorably with the 3.9 percent average annual rate of real increase in U.S. firms' domestic R&D funding. It also is almost six times the 1.3 percent 1987–96 growth rate of total domestic industrial R&D performance (including activities funded by foreign firms and the Federal Government). As a result of these funding trends, foreign R&D was equivalent to 10.4 percent ($15 billion) of total industrial R&D performance in the United States in 1996. This share is more than double that of its equivalent 4.9 percent share in 1987 but slightly lower than the calculated 1995 estimate (11.2 percent). Majority-owned affiliates accounted for a 3.4 percent share of the U.S. 1980 industrial performance total. (See figure 2-41.)

Country Sources of Industrial R&D

Most R&D financed by foreign affiliates in the United States comes from firms whose parents are located in just three countries: Germany, Switzerland, and the United Kingdom. Indeed, 81 percent of foreign R&D funding in 1996 came from just six countries—those three countries, plus France, Japan, and Canada. (See figure 2-42.) With the exception of Switzerland, these six countries are the same as those that receive the largest shares of U.S. overseas R&D investments. (Italy replaces Switzerland in that listing). Thus, the globalization of R&D is characterized by significant two-way flows of cross-border activities.

Looking beyond these major R&D country centers, however, the geographic pattern of R&D flows into the United States differs from the trends for U.S. R&D spending abroad. Whereas countries other than G-7 countries (and Switzerland) have become increasingly important as destinations for U.S. funding, they are becoming relatively less important in terms of foreign R&D investments here. For example, in 1980, firms from the six countries listed above accounted for a 69 percent share of the foreign R&D flows into the United States—a considerably smaller share than they currently account for. By contrast, those six countries accounted for 76 percent of

Figure 2-41.
U.S. industrial R&D financed by majority-owned foreign firms



NOTE: Data are available for 1980, and for 1987 and later years. See appendix tables 2-3 and 2-71.

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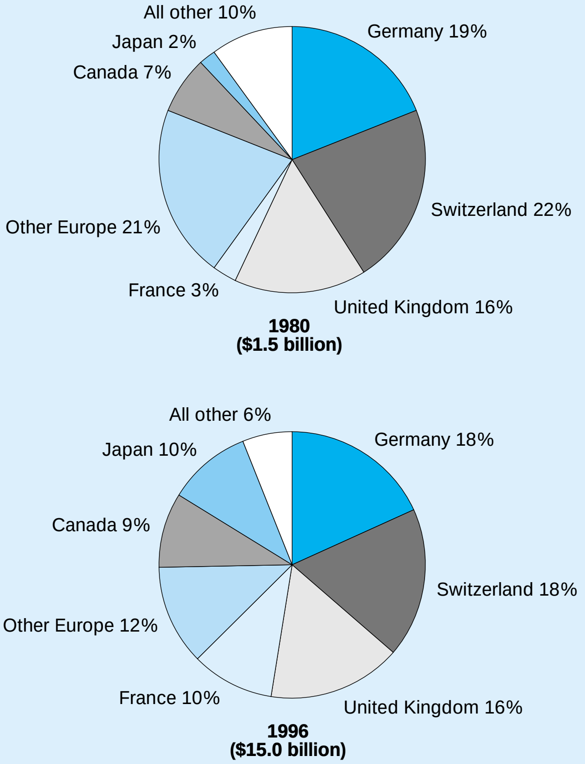
Figure 2-42.
U.S. industrial R&D financed by majority-owned foreign firms



See appendix table 2-71. *Science & Engineering Indicators – 2000*

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[64] Although BEA considers all of an investment (including R&D) to be foreign if 10 percent or more of the investing U.S.-incorporated firm is foreign-owned, special tabulations were prepared by BEA to reveal R&D expenditures in the United States of firms in which there is majority foreign ownership (i.e., 50 percent or more). For 1996, the 10 percent foreign ownership threshold results in an estimated $17.2 billion foreign R&D investment total. (See appendix table 2-70.) R&D expenditures of majority-owned U.S. affiliates of foreign companies were $15.0 billion. (See appendix table 2-71.) Tabulations for the majority-owned firms' R&D financing are used for most of the analyses here; the sole exception is the use of foreign R&D data at the 10 percent threshold for review of country-specific funding patterns for individual industrial sectors. (See text table 2-21.) Such data for majority-owned affiliates are not available.

U.S. overseas R&D in 1982 but only 68 percent in 1996. At least part of the increase in R&D flows from Canada and other European countries over the past 15 years is attributable to several major acquisitions of U.S. firms by foreign multinational companies. Such acquisitions have been particularly instrumental in changing the foreign composition shares of U.S. pharmaceutical and biotechnology firms with large R&D budgets (Dalton, Serapio, and Yoshida 1999; Fahim-Nader and Zeile 1998).

Industry Focus of Foreign R&D

Foreign-funded research was concentrated in three industries in 1996: drugs and medicines (mostly from Swiss, German, and British firms), industrial chemicals (funded predominantly by German and Dutch firms), and electrical equipment (one-third of which came from French affiliates).[65] These three industries accounted for more than half of the $17.2 billion total 1996 foreign R&D investment by affiliates in which there was at least 10 percent foreign ownership. Concurrent with gains reported for all domestic U.S. R&D performance, foreign—particularly Japanese and Swiss—R&D investment in the service sector was also significant. Services accounted for 6 percent ($966 million) of the 1996 foreign R&D investment total, with most research being funded by computer and data processing firms and companies providing research and management services. (See text table 2-21.)

U.S. Research Facilities of Foreign Firms

Consistent with the worldwide trend of multinational firms establishing an R&D presence in multiple countries, considerable growth has occurred in the number of R&D facilities operated by foreign companies in the United States. According to a 1992 survey of 255 foreign-owned freestanding R&D facilities in the United States, about half were established during the previous six years (Dalton and Serapio 1993); these data count only R&D facilities that are 50 percent or more owned by a foreign parent company.[66] An update to this study found that in 1998 there were 715 U.S. R&D facilities run by 375 foreign-owned companies from 24 different countries (Dalton and Serapio 1999). R&D facilities owned by Japanese firms continue to far outnumber those of any other coun-

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[65] Totals are for R&D expenditures for U.S. affiliates of firms in which there is 10 percent or more foreign ownership. (See previous footnote.)

[66] An R&D facility typically operates under its own budget and is located in a free-standing structure outside of and separate from the parent's other U.S. facilities (e.g., sales and manufacturing). This definition of an R&D facility consequently excludes R&D departments or sections within U.S. affiliates of foreign-owned companies.

Text table 2–21.
R&D performed in the U.S. funded by affiliates of foreign companies, by selected country and industry of affiliate: 1996
(Millions of U.S. dollars)

		Manufacturing								
Country	All industries	Total	Drugs & medicines	Other chemicals	Machinery	Electrical equipment	Transportation equip.	Instruments	Service industries[a]	Other non-manufacturing industries[b]
Total	17,150	13,807	5,849	1,517	935	2,954	454	720	966	2,377
Canada	1,397	1,228	1	20	D	D	11	11	21	148
Europe	12,516	11,007	5,754	1,413	532	1,581	360	520	607	902
France	1,712	1,641	474	144	97	487	42	90	32	39
Germany	3,084	2,767	1,343	478	[592]		196	56	52	265
Netherlands	948	743	1	375	1	D	D	1	8	197
Switzerland	3,375	2,985	2,575	55	[188]		–	64	366	24
United Kingdom	2,525	2,273	[1,528]		102	97	90	219	121	131
Asia and Pacific	2,592	1,159	[149]		[558]		80	45	355	1,078
Japan	2,070	1,001	72	55	204	242	77	37	337	732
Western Hemisphere	386	182	0	*	1	7	2	136	3	201
Middle East	121	106	D	D	73	D	0	8	10	5
Africa	81	70	0	5	D	D	0	0	*	11

D = withheld to avoid disclosing operations of individual companies * = less than $500,000 [ ] = indicates where categories have been combined.

NOTES: Includes foreign direct investments only of nonbank U.S. affiliates in which the affiliate has a 10-percent-or-more ownership interest. Includes R&D expenditures conducted by and for the foreign affiliates. Excludes expenditures for R&D conducted by the affiliates for others under a contract.

[a] Includes computer and data processing services ($642 million) and accounting, research and management services ($306 million).

[b] Includes wholesale trade ($1,735 million), retail trade ($32 million), petroleum ($436 million) and other industries ($174 million).

SOURCE: U.S. Bureau of Economic Analysis, *Foreign Direct Investment in the United States: Operations of U.S. Affiliates of Foreign Companies Preliminary 1996 Estimates* (Washington, DC: July 1998)

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tries: Japanese companies owned 251 R&D facilities in the United States, German companies owned 107, British companies owned 103, and French and Swiss companies each owned more than 40. (See text table 2-22.) South Korean companies have a rapidly growing presence in the United States, with 32 R&D facilities here in 1998—6 more than in 1994 and about 20 more than in 1992.

The activities of these foreign facilities were concentrated in a relatively small number of industries. In 1998 there were more than twice as many foreign-owned research sites for drugs and biotechnology (116 facilities) and chemicals and rubber (115 facilities) as for any other industry. Other industries for which there were more than 50 foreign-owned facilities in the United States included computers and computer software, high-definition television and other electronics, instruments and medical devices, and automotive products. Japanese companies account for most of the R&D centers in the electronics and automotive industries, whereas European companies have far more R&D sites focusing on pharmaceuticals and chemicals. A majority of the South Korean-owned facilities were devoted to research on computers and semiconductors.

Foreign R&D facilities were located in 39 states but were heavily concentrated in certain areas of the country. California ranks first with 188 foreign R&D facilities—notably around Silicon Valley and greater Los Angeles—but other prime locations for such sites include Detroit; Boston; Princeton, New Jersey; and North Carolina's Research Triangle Park. According to Dalton, Serapio, and Yoshida (1999), Japanese companies initially established R&D laboratories in California but recently have been moving east. Conversely, European companies began on the East Coast and are moving west.

Foreign companies have invested in U.S.-based R&D facilities for a variety of reasons. For example, growth in foreign automotive R&D centers on assisting the parent company in meeting U.S. environmental regulations and customer needs (a home-base exploiting strategy). Japanese companies in particular have expanded the scope of their R&D activities in the U.S. in line with their expansion of auto production here. Major factors behind the growth in foreign-owned biotechnology R&D facilities (much of which has resulted from the acquisition of U.S. firms) include the favorable research environment in the U.S. (especially relative to the situation in countries that are less hospitable to genetics-based R&D) and the availability of trained scientists to do the research (a home-base augmenting strategy). Much of the foundation for the U.S. competitive advantage in health care and life science research was laid by decades of substantial public R&D investments.

Text table 2–22.
Foreign-owned R&D facilities in the United States, by selected industry and country: 1998

Industry	Japan	United Kingdom	Germany	France	Switzerland	South Korea	Netherlands	Canada	Others
Total	251	103	107	44	42	32	30	32	74
Computers	24	0	2	2	0	6	2	1	5
Software	35	8	3	0	0	1	2	3	1
Semiconductors	18	0	2	0	0	10	2	0	0
Telecommunications	16	3	4	2	1	1	0	3	4
Opto-electronics	10	3	2	0	0	0	0	0	5
HDTV, other electronics	33	9	5	3	5	5	1	1	3
Drugs, biotechnology	26	15	26	7	15	2	5	0	20
Chemicals, rubber	25	18	27	14	7	1	6	7	9
Metals	8	5	2	4	1	0	0	2	4
Automotive	31	0	8	2	0	4	2	5	2
Machinery	5	6	3	4	2	0	0	3	6
Instrumentation, medical devices	6	19	7	3	6	0	3	2	7
Food, consumer goods, misc	10	12	6	1	8	1	9	5	10

NOTES: The industry-specific detail may double-count some facilities because of the multiple focus of research performed. Not all industry categories are listed. The country totals are comprehensive and do not include double-counting.

SOURCE: U.S. Department of Commerce, *Globalizing Industrial Research and Development*, by D. H. Dalton and M. G. Serapio, and P.G. Yoshida. Washington, DC, 1999.

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Chapter 3
Science and Engineering Workforce

Contents

Highlights

◆ **There were 12.5 million people with science or engineering degrees or who were working as scientists or engineers, residing in the United States as of April 1997—10.6 million in the workforce.** Of these 10.6 million individuals working in the United States in 1997, the vast majority (10.1 million) held at least one university degree in a science or engineering field. About 30 percent (3.1 million) of the 10.1 million S&E degree holders in the workforce were also employed in S&E occupations.

◆ **A little more than half of the 4.9 million S&E degree holders working outside S&E in 1997 were employed in either management-administration occupations (29 percent), sales and marketing jobs (16 percent), or non-S&E–related teaching positions (9 percent) in 1997.** Almost 90 percent of those employed as non-S&E teachers said that their work was at least somewhat related to their S&E degree field, compared to 71 percent of managers-administrators and 47 percent of those employed in sales and marketing jobs.

◆ **Women made up slightly more than one-fifth (23 percent) of the S&E workforce, but close to half (46 percent) of the U.S. labor force in 1997.** Although changes in the NSF surveys do not permit analysis of long-term trends in employment, short-term trends show some increase in the representation of women with doctorates in S&E employment: women represented 23 percent of scientists and engineers with doctorates in the United States in 1997. In 1993, they represented 20 percent and in 1995, 22 percent.

◆ **By age 63, 50 percent of S&E bachelor's and master's degree holders were not working full-time.** For S&E Ph.D. holders, this 50 percent mark is not reached until three years later, at age 66. By age 70, only 10 percent of bachelor's and master's degree holders and 20 percent of Ph.D. holders were working full-time.

◆ **With current retirement patterns, the total number of retirements among S&E degreed workers will dramatically increase over the next 10–15 years.** This will be particularly true for Ph.D. holders because of the steepness of their age profile.

◆ **The private for-profit sector is by far the largest employer of S&E workers**. In 1997, 73 percent of scientists and engineers who had bachelor's degrees and 60 percent of those with master's degrees were employed in a private, for-profit company. The academic sector was the largest sector of employment for those with doctorates (49 percent), but only 32 percent of S&E doctorates were in tenure-track positions at four-year institutions. Sectors employing smaller numbers of S&E workers included educational institutions other than four-year colleges and universities, nonprofit organizations, and state or local government agencies.

◆ **In 1993 only 28.5 percent of college graduates employed in computer occupations had computer science degree.** This rose to 45.2 percent of those in computer occupations who were under age 30.

◆ **In 1997 the median annual salary of employed S&E bachelor's degree holders was $52,000; for master's recipients, it was $59,000 and for doctorate holders $62,000.** Engineers commanded the highest salaries at each degree level. The second highest salaries were earned by computer and mathematical scientists at the bachelor's and master's levels, and physical scientists and computer and mathematical scientists at the doctorate level. The lowest median salaries were reported for social scientists at each degree level.

◆ **Aggregate measures of labor market conditions changed only slightly for recent doctoral recipients in S&E, defined here as those one to three years after their degree.** Unemployment fell from 1.9 percent for a similar graduation cohort in 1995 to 1.5 percent in 1997. At the same time, the proportion of recent Ph.D. recipients reporting that they were either working outside their fields because jobs in their fields were not available, or were involuntarily working part-time, rose slightly from 4.3 percent to 4.5 percent.

◆ **With the exception of young fields, such as computer sciences (where 70 percent of degree holders are under age 40), the greatest population density of individuals with S&E degrees occurs between age 40 and 49.** The aging of the S&E workforce has both positive and negative implications for different aspects of research productivity, and presages a rapid increase in the number of S&E workers of all degree levels reaching traditional retirement ages.

◆ **In April 1997, 26.1 percent of holders of doctorates in S&E in the United States were foreign born.** The lowest percentage of foreign-born doctorates was in psychology (7.2 percent), and the highest was in civil engineering (52.0 percent). Almost one-fifth (19.2 percent of those with master's degree in S&E were foreign born. Even at the bachelor's degree level, 9.7 percent of those with S&E degrees were foreign born—with the greatest proportion in chemistry (15.9 percent), computer sciences (15.6 percent), and across all engineering fields (14.9 percent).

Introduction

In 1947, the Steelman report discussed the science and engineering (S&E) labor force in a chapter entitled "Manpower: The Limiting Resource," in which it stated that research and development (R&D) activities were limited by "the availability of trained personnel, rather than the amount of money available." It reported the pool of scientists and "research engineers" in the United States to be 137,000, of whom 25,000 had doctorates. In 1997, the National Science Foundation (NSF) estimated that there were 3.1 million workers in S&E occupations and a total of 10.1 million workers with S&E degrees.[1] In spite of these larger numbers of S&E workers, there is more of a debate today as to whether the size of the S&E workforce is a constraint on new knowledge, innovation, and technological advancement. It should be noted, however, that the vast majority of those with S&E degrees, particularly at the graduate level, are employed in jobs that are relevant to their degrees, and intensive technical knowledge finds uses in many places outside the laboratory.

This chapter first examines the major indicators and characteristics of the S&E labor force. Information on the sex and racial or ethnic composition of the S&E workforce is presented next, followed by a description of the labor market conditions for recent bachelor's, master's, and doctoral S&E degree recipients. A discussion of the impact of age and retirement on the S&E labor force is presented next. The chapter also provides data on the projected demand for S&E workers over the 1998–2008 decade. It concludes with a brief section on foreign-born scientists and engineers, and presents comparisons regarding international R&D employment.

Selected Characteristics of the S&E Workforce

The data in this section are from the NSF's Scientists and Engineers Statistical data system (SESTAT), which is a unified database primarily containing information on the employment, education, and demographic characteristics of individuals with S&E degrees in the United States. (See NSF 1999f.)[2,3]

How Large Is the U.S. S&E Workforce?

Estimates of the size of the U.S. S&E labor force can vary dramatically depending on what criteria are used to define a scientist or engineer. (See the sidebar, "Who Is a Scientist or Engineer?") Educational degree levels and fields, occupational categories, or a combination of these factors may all be taken into account.[4] In 1997, more than 12.5 million people in the United States either held degrees in science or engineering or were working as scientists or engineers. (See appendix table 3-1.) The number of individuals holding a college degree in an S&E field in 1997 exceeded by a large margin the number of persons working in an S&E occupation because many S&E degree holders were not working in an S&E field. Numerous individuals were also working in S&E occupations who were educated in fields not considered science or engineering related.

Basic Characteristics

Including those either with science or engineering degrees or in science or engineering occupations, approximately 12.5 million scientists and engineers were residing in the United States as of April 1997.[5] Only 84 percent (10.6 million) of these individuals, however, were in the workforce. (See appendix table 3-1.) The remainder were either unemployed, but seeking work (193,700), or were not in the labor force (1.75 million). Of the 10.6 million employed, the vast majority (10.1 million) held at least one college degree in a science or engineering field. About 30 percent (3.1 million) of the 10.1 million S&E degree holders in the workforce were also employed in S&E occupations. (See text table 3-1.)

Relationship Between Education and Occupation

Many of the Nation's scientists and engineers hold either 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 in traditional S&E taxonomies. Of the 10.1 million S&E degree holders in the workforce in 1997, about three-fourths (7.7 million) reported that their highest degree was in an S&E field. (See appendix table 3-2.) Many of these individuals (4.9 million), however, were not principally employed in a traditional science or engineering occupation.

The likelihood of an S&E degree holder occupying an S&E job varies by field of degree. For example, about two-thirds (66 percent) of S&E degree holders whose highest degrees were in engineering fields were employed in an S&E job in

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[1] Although this clearly shows great growth in science and engineering (S&E) education and employment, these numbers probably should not be used to estimate an exact 50-year growth rate. It is not immediately clear how the Steelman estimates were made, and the 1947 number may exclude many classes of workers included in the 1997 NSF estimate.

[2] Selected tables, copies of questionnaires, data quality control information, and the ability to perform simple tabulations from the public use version of SESTAT data are all available from <<http://sestat.nsf.gov>>.

[3] SESTAT data are collected from three component surveys sponsored by NSF and conducted periodically throughout each decade: (a) the National Survey of College Graduates, (b) the National Survey of Recent College Graduates, and (c) the Survey of Doctorate Recipients. SESTAT's target population is residents of the United States with a bachelor's degree or higher (in either an S&E or non-S&E field) who, as of the study's reference period, were:

- Noninstitutionalized,
- Not older than age 75, and
- Either degreed in science or engineering or working as a scientist or engineer—that is, either had at least one bachelor's or higher degree in an S&E field or had a bachelor's or higher degree in a non-S&E field and worked in an S&E occupation as of the reference week.

For the 1997 SESTAT, the reference period was the week of April 15, 1997.

[4] For a detailed discussion of the S&E degree fields and occupations in SESTAT, see NSF 1999a.

[5] This number includes all people who have ever received a bachelor's degree or higher in an S&E field, plus people holding a non-S&E bachelor's or higher degree who were employed in an S&E occupation during either the 1993, 1995, or 1997 SESTAT surveys.

Who Is a Scientist or Engineer?

There are many different definitions that can be use to classify a scientist or engineer—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 1999c) and "Counting the S&E Workforce—It's Not that Easy" (NSF 1999d). Different definitions are used at different places for different analytic purposes in this report, and even more are used in reports elsewhere. These are the three major definitions used in this report:

- **Occupation:** The most common way of counting scientists and engineers in the workforce is to count those with an occupational classification that matches some list of S&E occupations. Although there can be considerable question of how well it is coded from individual write-ins or employer classifications, occupation comes closest to indicating what work a person is actually doing. An engineer by occupation may have a engineering degree, or not, but if classified correctly will be doing engineering work. One limitation of 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 not uncommon for a person with a science or engineering degree in such occupations to report that their work is closely related to their degree, and in many cases also report R&D as a major work activity.
- **Highest degree:** This is another way to classify scientists and engineers if you want to count or describe the characteristics of individuals in the labor force with formal S&E training. Focusing on the field of highest (or most recent) degree often best characterizes the training an individual is utilizing in the labor force (rather than occupation, as discussed above). For example, it may be more appropriate to classify a person with a bachelor's degree in chemistry who is employed as a technical writer for a professional chemists society magazine as a chemist. Using highest degree 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? Also, should individuals with a bachelor's degree in political science be counted as social scientists if they also have a law degree? Many might be comfortable classifying by highest degree in the examples above, but less comfortable excluding from an S&E labor force analysis an individual with a bachelor's degree in engineering who also has a master's degree in business administration.
- **Anyone with an S&E degree or occupation:** Another approach is to use both occupation and education. NSF's sample surveys of individual scientists and engineers attempt to include those resident in the United States with any science or engineering degree, or with a science or engineering occupation.[†]

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[*] In most collections of occupation data (SESTAT data mostly does not have this problem), the generic classification of post-secondary teacher also masks many university professors who should be included in most concepts of the S&E workforce.

[†] Those without U.S. S&E degrees are included in 1997 SESTAT data to the extent they were in the United States in 1990, 1993, 1995, and 1997 (in the case of individuals with foreign S&E degrees) or had at least a bachelor's degree in some field and were working in a S&E occupation in 1993, 1995, and 1997.

1997. However, most of the S&E degree holders who received their highest degrees in life science or social science fields (73 percent and 86 percent, respectively) were working in occupations outside the traditional S&E taxonomy, that is, "non-S&E occupations." (See appendix table 3-2.) About half of those with highest degrees in computer and mathematical sciences and physical sciences (51 percent and 46 percent, respectively) were also employed in a non-S&E occupation in 1997.

The fact that most S&E degree holders do not work in a strictly defined science or engineering occupation does not mean that they are not using their S&E training. Of the 4.9 million S&E degree holders working in non-S&E jobs in 1997, about 65 percent indicated they were working in jobs at least somewhat related to their highest S&E degree field. (See text table 3-2.)[6] Over three-fourths of those with highest degrees in computer and mathematical sciences who were employed in non-S&E jobs were doing work related to their degrees, compared to 61 percent of those whose highest degrees were in social and physical sciences.

Out of all employed individuals whose highest degree was in S&E, 74.8 percent said that their jobs were related to the field of their highest degree, and 44.8 percent said their jobs were closely related to their field.[7] This can be seen in appendix tables 3-3 and 3-4. The relatedness of a field of study to an individual's job differs in mostly predictable ways across level of degree, years since degree, and field of degree.

Figure 3-1 shows the percentage of employed S&E degree holders who say their jobs are closely related to their degrees by degree level and years since degree. For the period of one to five years after receiving their degree, 74.1 percent of S&E doctorates say their jobs are closely related to their field of

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[6] Refers to highest degree received.

[7] Although this is a highly subjective self-assessment by survey respondents, it may often capture associations between training and scientific expertise not evident through occupational taxonomies. For example, an individual with an engineering degree, but with an occupation title of "salesman," may still be heavily involved in using or developing technology.

Text table 3–1.
Employed scientists and engineers, by S&E employment status and field of highest degree: 1997

	S&E Employment Status		
	Total	In S&E	In non-S&E
Total employed	10,585,600	3,369,400	7,216,200
Total with no S&E degree	528,000	294,600	233,400[a]
Total with S&E degree	10,057,600	3,074,800	6,982,800
S&E is highest degree	7,704,000	2,840,800	4,863,200
Computer & mathematical sciences	1,003,300	494,800	508,500
Life and related sciences	1,204,700	326,200	878,500
Physical and related sciences	619,200	334,100	285,100
Social and related sciences	2,967,600	421,300	2,546,300
Engineering	1,909,200	1,264,400	644,800
Non-S&E is highest degree	2,353,600	234,000	2,119,600

[a]These individuals were employed in an S&E occupation in a previous job.

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

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), SESTAT Surveys, 1997.

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Text table 3–2.
Persons with S&E degrees employed in non-S&E occupations, by highest degree and relationship of degree to job: 1997

	Total[a]	Bachelor’s	Master’s	Doctorate
All non-S&E occupations	4,863,200	3,994,800	715,300	149,700
	Percent			
Total	100.0	100.0	100.0	100.0
Closely related	32.4	29.2	46.9	48.4
Somewhat related	32.3	32.4	31.5	33.7
Not related	35.3	38.5	21.6	18.0

[a] Includes professional degrees.

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), SESTAT surveys, 1997.

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degree, compared to 65.9 percent of those with master’s degrees and 41.1 percent of those with bachelor’s degrees. This relative ordering of relatedness by level of degree holds across all years since receipt of degree. At every degree level, however, jobs generally become less closely related to field of degree as year since degree increases.[8] There may be many reasons for this—individuals change their career interests over time, they may gain skills in a different area while on the job, they may move into management responsibilities, or some of their original college training may become obsolete. Given all of these possibilities, the career cycle decline in the relevance of an S&E degree is fairly modest.

Differences in proportion for those who said their jobs were closely related to their field of degree are shown in Figure 3-2 for bachelor’s degree holders by major groups of S&E disciplines. At one to five years after receipt of degree, the percentage of S&E bachelor’s degree holders who said their jobs were closely related to field of degree ranged from 29 percent in the social sciences to 72 percent in computer science. Between the extremes of social sciences and computer sciences, most other S&E fields have similar percentages of recent graduates in closely related jobs—53 percent for physical sciences, mathematical sciences, and engineering, and 45 percent for the life sciences.

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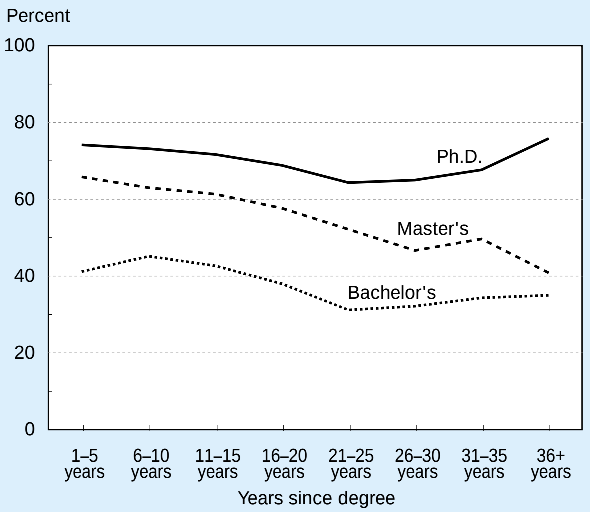
[8] One exception to this is for Ph.D. holders more than 25 years after degree, for whom the percent in closely related jobs increases. This may reflect differences in retirement rates.

Figure 3-1.
Percentage of S&E degree holders in jobs "closely related" to their degrees

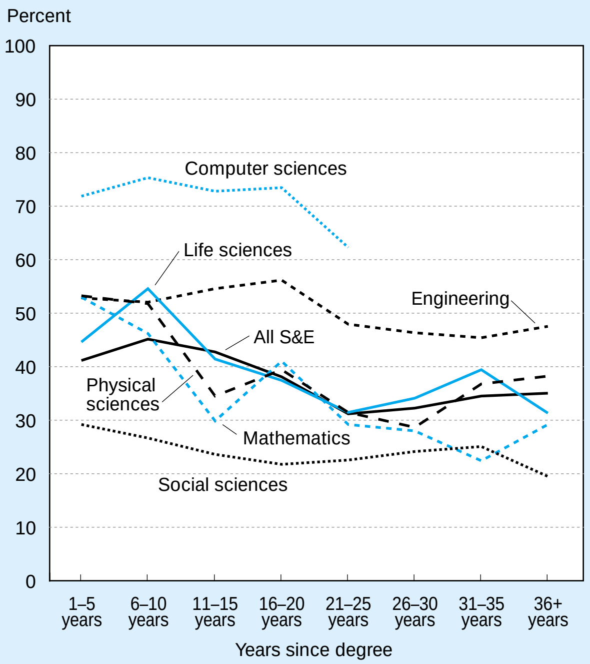


See appendix table 3-3. *Science & Engineering Indicators – 2000*

Employment in Non-S&E Occupations

A little over half of the 4.9 million S&E degree holders working outside S&E occupations in 1997 were employed in either management-administration occupations (29 percent), sales and marketing jobs (16 percent) or non-S&E related teaching positions (9 percent) in 1997. (See text table 3-3.) Almost 90 percent of those employed as non-S&E teachers said that their work was at least somewhat related to their S&E degree field, compared to 71 percent of managers-administrators and 47 percent of those employed in sales and marketing jobs.

Figure 3-2.
S&E bachelor's degree holders in jobs "closely related" to their degrees



See appendix table 3-3. *Science & Engineering Indicators – 2000*

About 82 percent of the 4.9 million S&E degree holders not working in S&E occupations in 1997 reported their highest degree as a bachelor's degree, while 15 percent listed a

Text table 3–3.
Persons with S&E as highest degree employed in non-S&E occupations, by occupation and relationship of degree to job: 1997

		Percent			
			Relationship of highest degree to job		
Occupation	Total	Total	Closely related	Somewhat related	Not related
Total non-S&E occupations	4,863,200	100.0	32.4	32.3	35.3
Managers and administrators	1,405,000	100.0	29.7	41.4	28.8
Health and related occupations	294,800	100.0	61.0	23.4	15.6
Non-S&E teachers	454,300	100.0	66.9	20.4	12.6
Non-S&E postsecondary teachers	48,700	100.0	68.4	21.7	9.9
Social services occupations	270,800	100.0	60.1	29.1	10.8
Technologists and technicians	309,800	100.0	44.9	33.6	21.5
Sales and marketing occupations	757,500	100.0	10.2	36.8	53.0
Art and humanities occupations	114,800	100.0	19.2	36.8	43.9
Other non-S&E occupations	1,207,500	100.0	19.8	25.7	54.4

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

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), SESTAT surveys, 1997.

Science & Engineering Indicators – 2000

master's degree and 3 percent a doctorate. Approximately three-fifths of bachelor's degree holders reported that their jobs were closely related to their highest degree field, compared to four-fifths of both doctorate and master's S&E degree recipients.

Employment in S&E Occupations

Of the 7.7 million scientists and engineers in the workforce in 1997 whose highest degrees were in an S&E field, a little more than a third (2.84 million) were principally employed in S&E jobs. Additionally, there were 234,000 individuals with S&E degrees whose highest degrees were in a non-S&E field who were also employed in S&E occupations. There were also 294,600 college-educated individuals employed in S&E occupations that held no degrees in an S&E field.

Altogether, approximately 3.4 million individuals were employed in an S&E occupation in 1997. (See appendix table 3-5.) Engineers represented 41 percent (1.37 million) of the S&E positions, followed by computer and mathematical scientists with 31 percent (1.04 million) of the total. Physical scientists accounted for less than 10 percent of those working in S&E occupations in 1997. By subfield, electrical engineers made up about one-fourth (365,000) of all those employed as engineers, while biological scientists accounted for a little over one-half (182,000) of the employment in the life sciences. In the physical and social science occupations, chemists (120,000) and psychologists (182,000) were the largest occupational subfields, respectively.

Almost 57 percent of the individuals employed in S&E jobs reported their highest degree type as a bachelor's degree, while 29 percent listed a master's degree and 14 percent a doctorate. Other first professional degrees were reported as the highest degree type by about 1 percent. Almost half of those with bachelor's degrees were employed as engineers. (See text table 3-4.) Another 35 percent of bachelor's degree holders had jobs as computer and mathematical scientists. These occupations were also the most prevalent among those with master's degrees (39 percent and 31 percent, respectively). Most doctorate holders were employed as social scientists (27 percent), life scientists (25 percent) and physical scientists (18 percent). (See the sidebar, "How Important Is Temporary Work for Scientists and Engineers?") (See also the sidebar, "Data on Recent Ph.D. Recipients in Professional Society Data.")

Unemployment

Of the approximately 3.5 million scientists and engineers in the labor force in 1997, only 1.5 percent (52,900) were unemployed. (See figure 3-4.)[9] This compares with 4.9 percent for the U.S. labor force as a whole in 1997 and 2.0 percent for all professional specialty workers. The highest unemployment rates were for life scientists (2.2 percent) and the lowest for social scientists (1.0 percent). By degree level, 1.6 percent of the scientists and engineers whose highest degree was a bachelor's degree were unemployed, compared to 1.4 percent of those with master's degrees or a doctorate. It should be remembered, however, that the unemployment rate is a poor indicator of labor market conditions for highly educated workers—it does not measure how well their employment uses their training.

Sector of Employment

The private for-profit sector is by far the largest employer of S&E workers. In 1997, 73 percent of scientists and engineers with bachelor's degrees and 60 percent of those with master's degrees were employed in a private, for-profit company. (See appendix table 3-6.) The academic sector was the largest sector of employment for those with doctorates (49 percent). Sectors employing smaller numbers of S&E workers include educational institutions other than four-year colleges and universities, nonprofit organizations, and state or local government agencies.

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[9] The unemployment rate is the ratio of those who are unemployed and seeking employment to the total labor force (that is, those who are employed plus those who are unemployed and seeking employment). Those who are not in the labor force (that is, those who are unemployed and not seeking employment) are excluded from the denominator. For unemployed individuals, occupation is for their last reported job.

Text table 3–4.
Percentage distribution of employed scientists and engineers by broad occupation and highest degree: 1997
(Percent)

	Total[a]	Bachelor's	Master's	Doctorate
All S&E occupations	100.0	100.0	100.0	100.0
Computer and math scientists	30.8	35.2	31.2	13.0
Life and related scientists	9.5	6.5	7.3	24.6
Physical and related scientists	8.5	6.9	7.1	18.4
Social and related scientists	10.4	3.5	15.6	26.6
Engineers	40.8	47.8	38.8	17.5

[a] Includes professional degrees.

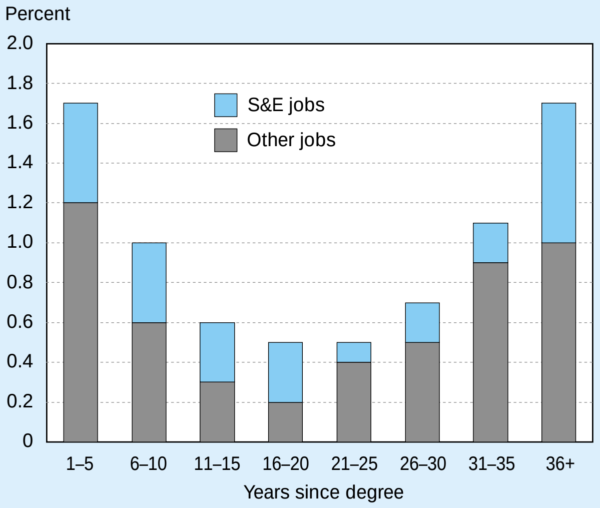
See appendix table 3–6.

Science and Engineering Indicators – 2000

How Important Is Temporary Work for Scientists and Engineers?

One common form of flexible work arrangement in the general labor force is the temporary help firm. Although best known as a way for businesses to hire temporary clerical help, major temporary help firms have long included scientists, engineers, and technicians among the workers whom they offer to other businesses on a temporary basis. How important is temporary work as a source of employment for those with S&E degrees? The answer appears to be "not very" for most S&E degree holders. Figure 3-3 shows the percentage of S&E degree holders who in 1997 reported being employed by a temporary help or employment agency. The greatest use of temporary firms occurs for those within just one to five years since receipt of their degrees (1.7 percent) and for those with more than 35 years since receipt of their degrees (1.6 percent). Only about one-third of those with temporary agency jobs are employed in S&E occupations. Ph.D. recipients are less likely than those with other S&E degrees to work for a temporary agency—only 0.4 percent even within one to five years since receipt of degree.

Figure 3-3.
S&E degree holders working through a temporary help or employment agency: 1997



See appendix table 3-20. *Science & Engineering Indicators – 2000*

Among S&E occupations, there was a wide variation in the proportions of scientists and engineers employed in private for-profit industry. While nearly three-fourths of both computer and mathematical scientists and engineers were employed in this sector, only one-fourth of life scientists and one-fifth of social scientists were so employed in 1997. Educational institutions employed the largest proportion of life scientists (48 percent) and social scientists (45 percent).

Salaries

In 1997 the median annual salary of bachelor's degree holders employed in S&E occupations was $52,000; for master's recipients it was $59,000 and for doctorate holders $62,000. (See figure 3-5 and appendix table 3-7.) Engineers commanded the highest salaries at each degree level. The second highest salaries were earned by computer and mathematical scientists at the bachelor's and master's levels, and physical scientists and computer and mathematical scientists at the doctorate level. The lowest median salaries were reported for social scientists at each degree level.

Median salaries for scientists and engineers were higher for those with more years since completion of their highest degree. For example, individuals who earned their bachelor's or master's degrees five to nine years ago earned about $12,000 and $8,000 less, respectively, in 1997 than those who received these degrees 15–19 years ago. For doctorate holders, the difference between the two groups in terms of years since receipt of degree was $14,000. (See appendix table 3-8.)

Who Performs R&D?

Although individuals with an S&E education can use that knowledge in a great many other ways—for example, teaching, writing, evaluating, and testing—there is a special interest in those engaged in research and development (R&D). Figure 3-6 shows the distribution of individuals with S&E degrees who reported R&D as a major work activity by level of degree.[10] Those with doctorates comprise only 5.6 percent of all with S&E degrees, but 13.0 percent of those reporting major R&D activities. Despite this, a majority of the S&E degree holders that report major R&D activities have only bachelor's degrees (55.5 percent). Another 28.5 percent have master's degrees, and 2.9 percent have professional degrees (mostly in medicine). Figure 3-7 shows the distribution of individuals with S&E degrees who reported R&D as a major work activity by field of highest degree. Those whose highest degree is in engineering constitute more than one-third (34.9 percent) of those reporting major R&D work activities. Notably, 13.0 percent do not have their highest degree in an S&E field. In most cases, this is a person with an S&E bachelor's degree and a higher degree in a professional field, such as business, medicine, or law.

The involvement of S&E Ph.D. recipients in R&D as a major work activity is shown by field of degree and years since receipt of Ph.D. in figure 3-8. The highest R&D rates over the career cycle are found in the physical S&E. The lowest R&D rates are in the social sciences. While the percentage of employed Ph.D. recipients with R&D as a major work activity does decline with years since degree, it remains above 50 percent in most fields. A steeper decline might have been

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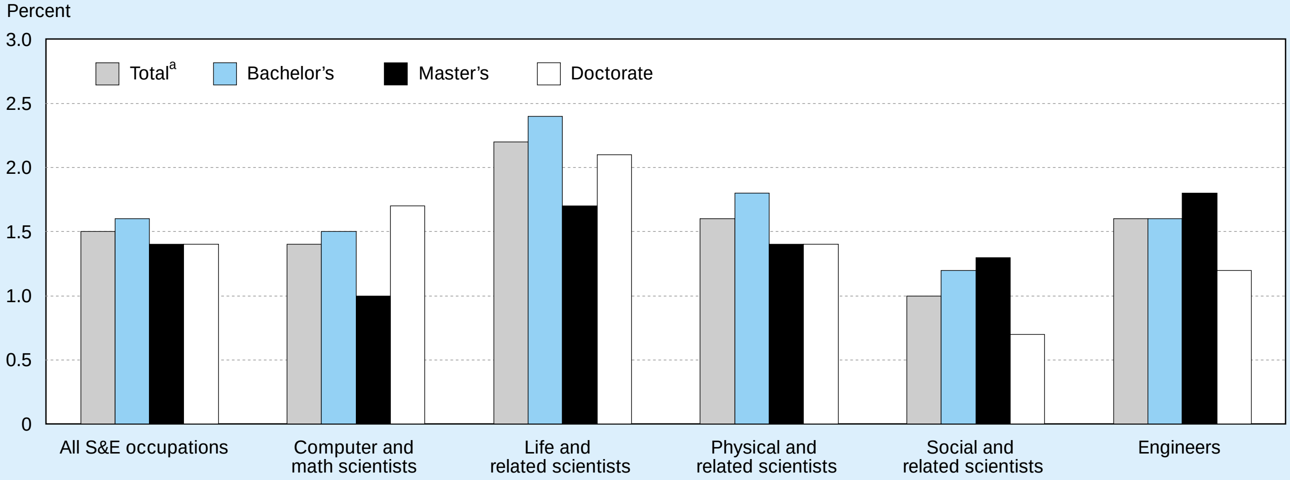
[10] Counts of full-time equivalent R&D workers in the United States are based largely on NSF/SRS surveys of employers, rather than the self-reported R&D activity reported in SESTAT that is used here. The comparative advantage of the SESTAT data is the ability to know the characteristics of the individuals involved. Major work activity is defined here as an activity on which an individuals reports spending the most, or the second most, total hours.

Figure 3-4.
Unemployment rates of scientists and engineers by broad occupation and highest degree: 1997



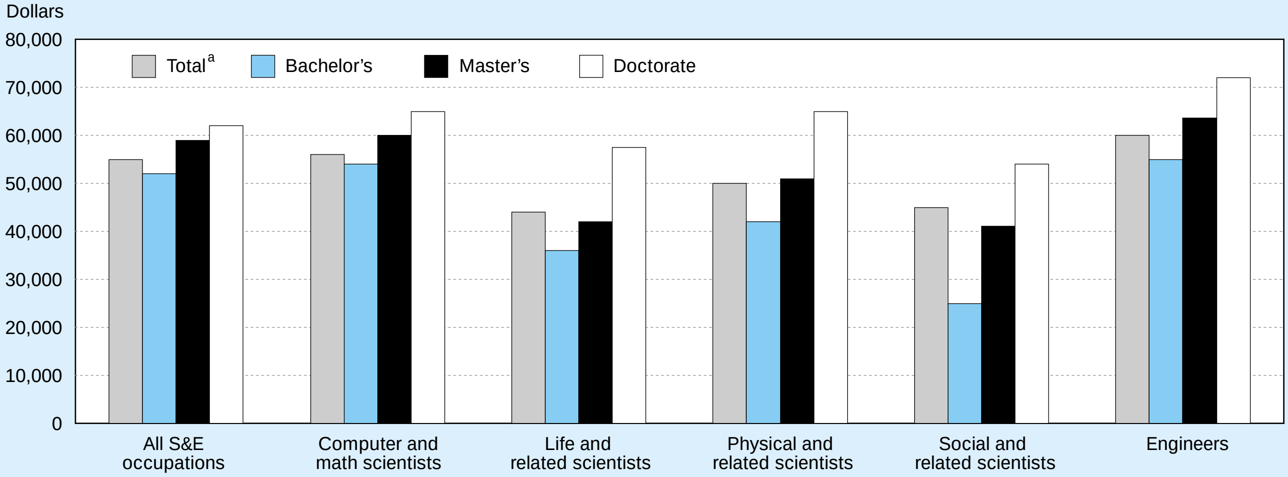
See appendix table 3-5.

NOTE: Individuals are characterized as scientists or engineers based on their current occupation of employed, or on their last reported occupation if unemployed. These figures do not reflect those S&E degree holders employed in non S&E occupations.

[a] Includes professional degrees.

Science & Engineering Indicators – 2000

Figure 3-5.
Median annual salaries of employed scientists and engineers by broad occupation and highest degree: 1997



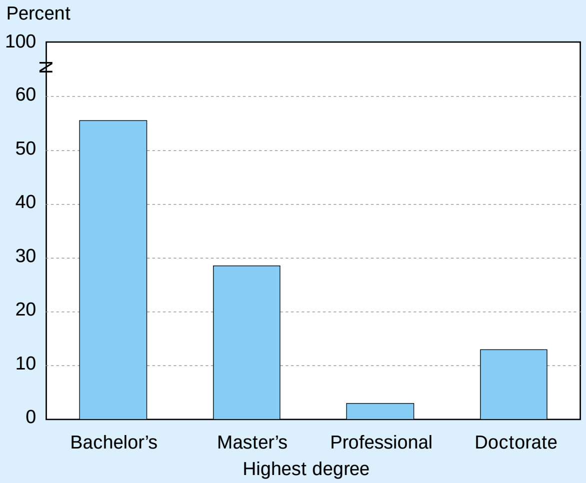
See appendix table 3-8.

NOTE: Individuals are characterized as scientists or engineers based on their current occupation.

[a] Includes professional degrees.

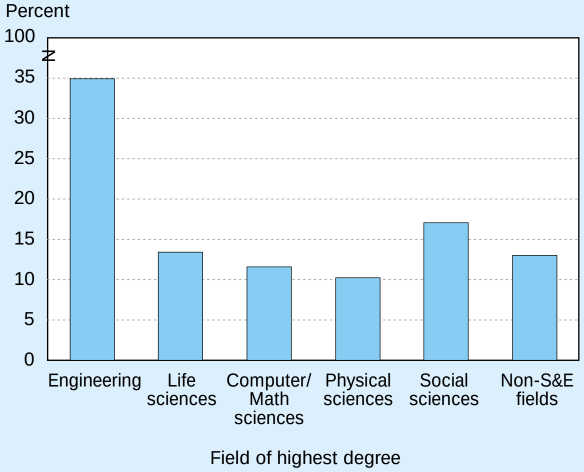
Science & Engineering Indicators – 2000

Figure 3-6.
Distribution of S&E R&D workers by degree level



See appendix table 3-26. *Science & Engineering Indicators – 2000*

Figure 3-7.
Distribution of S&E R&D workers by field of highest degree



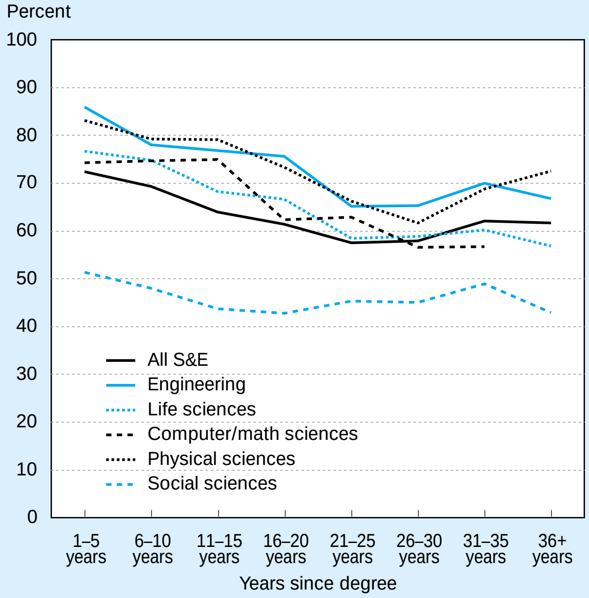
See appendix table 3-26. *Science & Engineering Indicators – 2000*

expected, which may reflect a normal career process of movement into management or into other career interests.

Women and Minorities in S&E

This section examines the participation and employment characteristics of women and minorities in the S&E labor force in 1997. Representation is examined, in most cases, in terms of age, time in workforce, field of employment, and highest degree level.[11] These factors influence employment patterns.

Figure 3-8.
Percentage of S&E Ph.D. holders engaged in R&D as a major work activity



See appendix table 3-27. *Science & Engineering Indicators – 2000*

To the extent that men and women, minorities, and nonminorities differ on these factors, their employment patterns are likely to differ as well.

Within the S&E labor force, the age distributions of women compared to men, and of minorities compared to the majority, are quite different. Because large numbers of women and minorities have entered S&E fields only relatively recently, women and minority men are generally younger and have fewer years of experience. (See appendix table 3-9.) Age or stage in career is an influence on such employment-related factors as salary, rank, tenure, and work activity. Employment patterns also vary by field, and these field differences may influence employment in S&E jobs, unemployment, salaries, and work activities. Highest degree earned is also an important influence on employment, particularly on primary work activity and salary.

Women Scientists and Engineers

Representation in S&E

Women were slightly more than one-fifth (23 percent) of the S&E workforce, but close to half (46 percent) of the U.S. labor force in 1997. Although changes in the NSF surveys do not permit analysis of long-term trends in employment, short-term trends show some increase in the representation of women with doctorates in S&E employment: women represented 23 percent of scientists and engineers with doctorates in the United States in 1997. (See appendix table 3-10.) In 1993, they represented 20 percent and in 1995 22 percent.[12]

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[11] Throughout this section, scientists and engineers are defined in terms of field of employment, not degree field.

Work Experience

Many of the differences in employment characteristics between men and women are partially due to differences in time since receipt of degree. Women in the S&E workforce are younger, on average, than men: 49 percent of women and 35 percent of men employed as scientists and engineers in 1997 had received their degrees within the previous 10 years.

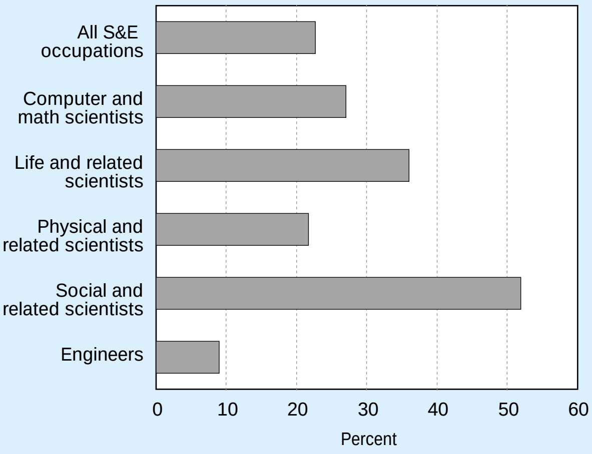
Field of S&E Occupation

As is the case in degree fields, women and men differ in field of employment. Women are more highly represented in some S&E fields than in others. For example, women were more than half of social scientists, but only 22 percent of physical scientists and 9 percent of engineers. (See figure 3-9.) Within engineering, women are also more highly represented in some fields than in others, For example, women represented 12 percent of chemical and industrial engineers, but only 6 percent of aerospace, electrical, and mechanical engineers.

Educational Background

In many occupational fields, women scientists have attained 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 42 percent of men hold doctoral degrees; in chemistry, 14 percent of women and 28 percent of men hold doctoral degrees; and in psychology, 24 percent of women and 40 percent of men hold doctoral degrees. Differences in highest degree influence the type of work performed, employment in S&E jobs, and salaries. In engineering, only about 5 percent of both men and women have doctoral degrees. (See NSF 1999b.)

Figure 3-9.
Proportion of women in S&E workforce by broad occupation: 1997



See appendix table 3-10. *Science & Engineering Indicators – 2000*

Labor Force Participation, Employment, and Unemployment

Men scientists and engineers are more likely than women to be employed full-time and to be employed in their field of highest degree. Women are more likely than men to be employed part time, and to be employed outside their field. Some of these differences may reflect differences in the age distributions of men and women or family-related reasons, such as the demands of a spouse's job or the presence of children.

The labor force participation rates of men and women with current or former S&E occupations are similar—87 percent of women and 88 percent of men are in the labor force. (See appendix table 3-11.) Conversely, 13 percent of women and 12 percent of men are not in the labor force—that is, not working and not seeking employment. Among those in the labor force, moreover, unemployment rates of men and women scientists and engineers varied somewhat: 2.2 percent of women and 1.4 percent of men were unemployed in 1997.

Sectors of Employment

Within fields, women are about as likely as men to choose industrial employment. For example, among physical scientists, 54 percent of women and 55 percent of men are employed in business or industry. (See appendix table 3-12.) Among employed scientists and engineers as a whole, however, women are less likely than men to be employed in business or industry and are more likely to be employed in educational institutions: 49 percent of women and 67 percent of men are employed in for-profit business or industry and 27 percent of women and 15 percent of men are employed in educational institutions. These differences in sector, however, are mostly related 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 1997, the median annual salary for women scientists and engineers was $47,000, about 20 percent less than the median salary for men ($58,000). (See figure 3-10 and appendix table 3-8). The salary differential could be due in part to several factors. Women were more likely than men to be working in educational institutions and in social science occupations, in nonmanagerial positions, and to have fewer years since receipt of degree, all of which are related to salary differences. Among scientists and engineers in the workforce who have held their degrees five years or less, the median annual salary of S&E women was 83 percent of that for men.

The salary differential varied greatly by broad field. In computer and mathematical science occupations in 1997, women's salaries were approximately 12 percent less than men's, whereas there was a 24 percent salary difference in social science and life science occupations. As with men,

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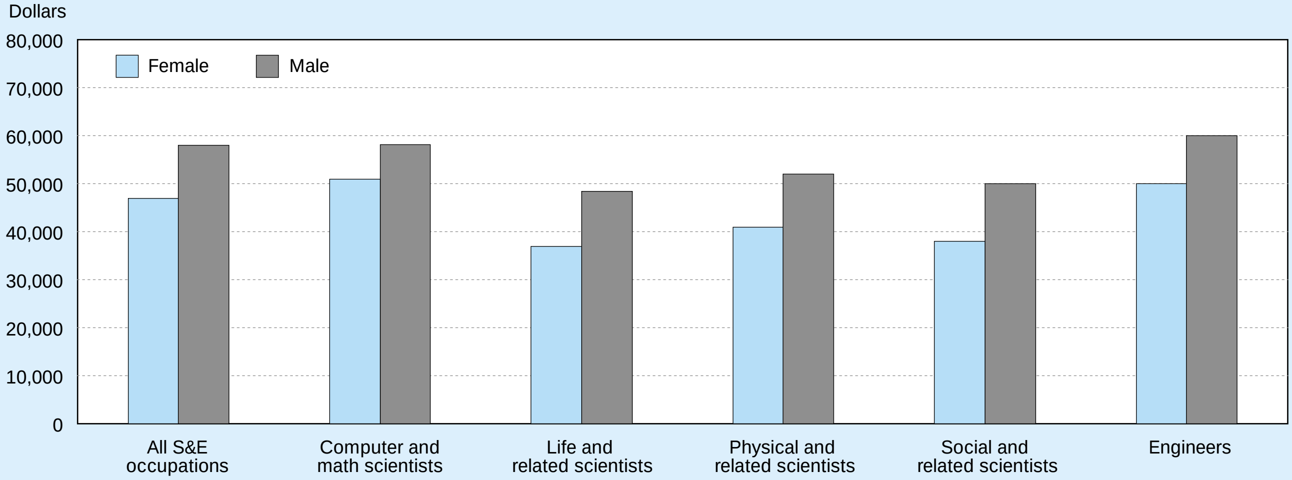
[12] For 1995 figures, see *Women, Minorities, and Persons with Disabilities in Science and Engineering: 1998* (NSF 1996, p. 99). For 1993 figures, *see Women, Minorities, and Persons with Disabilities in Science and Engineering: 1996* (NSF 1999b, p. 63).

Figure 3-10.
Median annual salaries of employed scientists and engineers, by broad occupation and sex: 1997



NOTE: Individuals are characterized as scientists or engineers based on their current occupation.

See appendix table 3-8.

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women earned the highest median salary in computer and mathematical sciences ($51,000) and the lowest in life sciences ($37,000).

Racial or Ethnic Minority Scientists and Engineers

Representation in S&E

With the exception of Asians, minorities are a much smaller proportion of scientists and engineers in the United States than they are in the total U.S. population.[13,14] Asians comprised 10 percent of scientists and engineers in the United States in 1997, although they were 4 percent of the U.S. population. Blacks (12 percent), Hispanics (11 percent), and American Indians (1 percent) as a group were 24 percent of the U.S. population and 7 percent of the total S&E labor force in 1997.[15] Blacks and Hispanics each comprised about 3 percent and Native Americans less than half of 1 percent of scientists and engineers. (See appendix table 3-13.)

Work Experience

The work experience of minority scientists and engineers, including Asians, differs from that of white scientists and engineers. As noted earlier, these differences influence differences in employment characteristics. About 36 percent of white scientists and engineers employed in 1997 had received their degrees within the previous 10 years, compared with between 47 and 52 percent of Asian, black, and Hispanic scientists and engineers. (See appendix table 3-14.)

Field of S&E

Black, Asian, and American Indian scientists and engineers are concentrated in different fields than white and Hispanic scientists and engineers. Asians are less represented in social sciences than they are in other fields. They represented 4 percent of social scientists, but more than 10 percent of engineers and computer scientists. Black scientists and engineers work more in social sciences and in computer and mathematical sciences than in other S&E fields. They represent 5 percent of social scientists, 4 percent of computer and mathematical scientists, and roughly 3 percent or less of physical scientists, life scientists, and engineers. Although the numbers are small, American Indians appear to be more concentrated in the social sciences. They represent 0.6 percent of social scientists and 0.4 percent or less of workers in other fields. Hispanics represent roughly 2.5 to 4 percent of scientists and engineers in each field.

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[13] 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 Indian/Alaska Natives. In accordance with Office of Management and Budget guidelines, the racial or ethnic groups described in this section will be identified as white and non-Hispanic; black and non-Hispanic; Hispanic; Asian or Pacific Islander; and American Indian/Alaskan Native. In text and figure references, these groups will be referred to as white, black, Hispanic, Asian, and American Indian.

[14] The data reported in this section include all in S&E occupations, regardless of citizenship or country of origin, unless otherwise noted.

[15] 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 the social sciences (included by NSF as degrees in S&E) and to be employed in social services occupations, such as social work, clinical psychology, that are defined by NSF as non-S&E occupations. See NSF 1999a for NSF's classification of S&E educational and occupational fields.

Educational Background

The educational attainment of scientists and engineers differs among racial or ethnic groups. Black scientists and engineers, on average, have a lower level of education than scientists and engineers of other racial or ethnic groups. Black scientists and engineers are more likely than white, Hispanic, or Asian scientists and engineers to have a bachelor's degree as the terminal degree: 64 percent of black scientists and engineers in the U.S. workforce have a bachelor's degree as the highest degree compared to 57 percent of all scientists and engineers in 1997. (See appendix table 3-10.)

Labor Force Participation, Employment, and Unemployment

Labor force participation rates vary by race or ethnicity. Minority scientists and engineers were more likely than whites to be in the labor force, that is, employed or looking for employment. Between 91 and 95 percent of black, Asian, Hispanic, and American Indian scientists and engineers were in the labor force in 1997, compared with 87 percent of white scientists and engineers. (See appendix table 3-13.) Age differences are part of the explanation. White scientists and engineers are older, on average, than scientists and engineers of other racial or ethnic groups: 25 percent of white scientists and engineers were age 50 or older in 1997, compared with between 15 and 18 percent of Asians, blacks, and Hispanics. Among those in similar age groups, the labor force participation rates of white and minority scientists and engineers are similar. (See NSF 1999b.)

Although minorities, for the most part, are less likely to be out of the labor force, among those who are in the labor force, minorities are more likely to be unemployed. In 1997, the unemployment rate of white scientists and engineers was significantly lower than that of other racial or ethnic groups. The unemployment rate for whites was 1.4 percent, compared with 2.6 percent for Hispanics, 1.9 percent for blacks, and 2.0 percent for Asians. The differences in unemployment rates were evident within fields of S&E, as well as for S&E as a whole. For example, the unemployment rate for white engineers was 1.6 percent; for black and Asian engineers, it was 2.5 percent and 2.1 percent, respectively.

Sectors of Employment

Racial or ethnic groups differ in employment sector, partly because of differences in field of employment. Among employed scientists and engineers in 1997, 57 percent of black, 58 percent of Hispanic, and 50 percent of American Indian, compared with 63 percent of white and 67 percent of Asian scientists and engineers were employed in for-profit business or industry. Blacks and American Indians are concentrated in the social sciences, which are less likely to offer employment in business or industry, and are underrepresented in engineering, which is more likely to offer employment in business or industry. Asians, on the other hand, are overrepresented in engineering and thus are more likely to be employed by private for-profit employers.

Black, Hispanic, and American Indian scientists and engineers are also more likely than other groups to be employed in government (Federal, state, or local): 22 percent of black, 16 percent of Hispanic, and 19 percent of American Indian scientists and engineers were employed in government in 1997, compared with 13 percent of white and 12 percent of Asian scientists and engineers.

Salaries

Salaries for scientists and engineers vary somewhat among racial or ethnic groups. Among all scientists and engineers, the median salaries by racial or ethnic group are $55,000 for whites and Asians, $48,000 for blacks, $50,000 for Hispanics, and $46,000 for American Indians. (See figure 3-11 and appendix table 3-16.) Within fields and age categories, median salaries of scientists and engineers by race or ethnicity are not dramatically different and do not follow a consistent pattern. For example, the median salary of engineers with bachelor's degrees who are between the ages of 20 and 29 ranged from $40,000 for Hispanics to $44,000 for Asians. Among those between the ages of 40 and 49, the median salary ranged from $55,000 for Hispanics to $62,600 for whites. Looking at time in the work force, the median salary of engineers with bachelor's degrees in 1997 who had received their degree within the last five years was $40,000 for all ethnicities. (See appendix table 3-17.) Among those who had received their degrees 20–24 years before, the median salary was approximately $65,000 for all ethnicities.

Labor Market Conditions for Recent S&E Degree-Holders

Bachelor's and Master's Degree Recipients[16]

Recent S&E bachelor's and master's degree recipients form a key component of the Nation's S&E workforce; they account for almost half the annual inflow to the S&E labor market. The career choices of recent graduates and their entry into the labor market affect the balance between the supply of and demand for scientists and engineers in the United States. Analysis of the workforce status and other characteristics of recent S&E graduates can yield valuable labor market information.

This section provides several labor market measures that offer useful insights into the overall supply and demand conditions for recent S&E graduates in the United States. Among these measures are median annual salaries, unemployment rates, and in-field employment rates.

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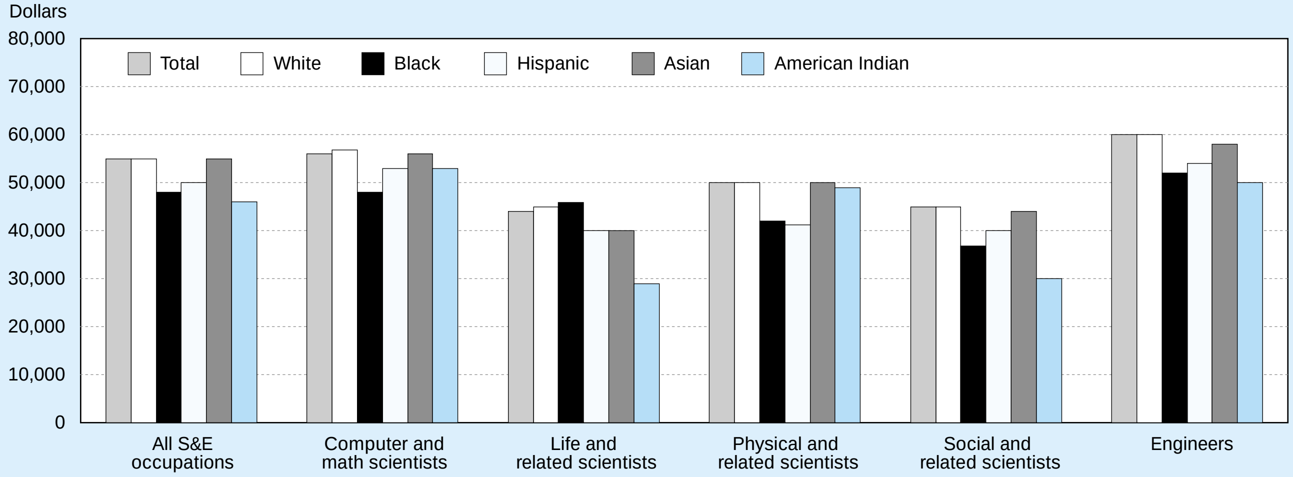
[16] Data for this section are taken from the 1997 National Survey of Recent College Graduates. This survey collected information on the 1997 workforce-other status of 1995 and 1996 bachelor's and master's degree recipients in S&E fields. Surveys of recent S&E graduates have been conducted biennially for NSF since 1978. For information on standard errors associated with survey data, see NSF (in press, a).

Figure 3-11.
Median annual salaries of scientists and engineers, by broad occupation and race/ethnicity: 1997



NOTE: Individuals are characterized as scientists or engineers based on their current occupation.

See appendix table 3-16.

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Median Annual Salaries

In 1997, the highest median annual salaries for recent full-time employed graduates with bachelor's degrees in the sciences went to those with degrees in computer and information sciences ($37,700), and the highest salaries among those with degrees in engineering went to those with degrees in electrical, electronics, computer, and communications engineering ($40,500). (See appendix table 3-18.)

The same pattern was true among recent graduates with master's degrees. The highest median annual salaries went to graduates with master's degrees in computer and information sciences ($51,200) and electronics, computer, and communications engineering ($55,000).

School versus Employment

Approximately one-fifth of 1995 and 1996 bachelor's and master's graduates were enrolled in graduate school on a full-time basis in 1997. Students who had majored in the physical and related sciences and the life and related sciences were more likely to be in graduate school as full-time students than were graduates with degrees in computer and information sciences or engineering. (See appendix table 3-18.)

Employment Related to Field of Degree

Although individuals use college degrees to enter a wide variety of career paths, the extent to which their employment is related to their degrees may be one indicator of the vocational relevance of a degree. Across all fields of S&E in 1997, 70.4 percent of recent bachelor's degree graduates and 91.4 percent of recent master's degree graduates said their jobs were related to their field of degree (appendix tables 3-3 and 3-4). At the bachelor's level, employment related to field of degree for recent S&E graduates varied from 58.8 percent in the social sciences to 92.9 percent in computer sciences and 89.3 percent in engineering. At the master's degree level, there is much less variation by field of degree—ranging from 87.6 percent of recent master's degree graduates in social sciences saying their jobs are related to their degrees, to 97.9 percent of recent computer sciences master's degree graduates.

Employment Sectors

The private, for-profit sector is by far the largest employer of recent bachelor's and master's S&E degree recipients. (See text table 3-5.) In 1997, 66 percent of bachelor's degree recipients and 59 percent of master's degree recipients were employed in private, for-profit companies. The academic sector has been 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 (9 percent) than were bachelor's degree recipients (5 percent). The Federal sector employed only 7 percent of S&E master's degree recipients and 4 percent of S&E bachelor's degree recipients in 1997. Engineering graduates are more likely to find employment in the Federal sector than science graduates. 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.

Recent Doctoral Degree Recipients

Concerns about the labor market for workers with doctorates in S&E often focus on recent Ph.D. recipients entering the labor market and attempting to begin a career. Although the vast majority of S&E Ph.D. recipients find work that is related to their degrees, there is concern that fewer opportunities may make doctoral level science careers less desirable.

Text table 3–5.
Percentage of employed 1995 and 1996 S&E bachelor's and master's degree recipients, by sector of employment and field of degree: 1997

		Sector of employment[b]						
		Educational		Noneducational institutions				
Degree and field [a]	Total employed (thousands)	4-year college and university	Other educational institutions	Private for-profit company	Self-employed	Nonprofit organization	Federal Government	State or local government
	Percentage distribution							
Bachelor's recipients								
S&E	524.4	5	9	66	7	2	4	7
All sciences	428.4	6	11	62	8	2	3	8
All engineering	96.0	2	2	85	1	1	7	3
Master's recipients								
S&E	113.6	9	10	59	7	2	7	6
All sciences	74.4	12	15	49	10	2	6	6
All engineering	39.2	5	<1	79	1	1	9	4

[a] For graduates with more than one eligible degree at the same level (bachelor's or master's), the degree for which the graduate was sampled was used.

[b] This is the sector of employment in which the respondent was working on his or her primary job held on April 15, 1997. 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 educational." Those reporting that they were self-employed but in an incorporated business were classified in the private, for-profit sector.

NOTE: Details may not add to totals because of rounding. Percentages were calculated on unrounded data.

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *National Survey of Recent College Graduates, 1997.*

Science & Engineering Indicators – 2000

Since the 1950s, the Federal Government has actively encouraged graduate training in science through a number of mechanisms. Real or perceived labor market difficulties for new Ph.D. scientists and engineers, however, could have various adverse effects on the health 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. Eventually, this circumstance could reduce the ability of industry, academia, and government to perform R&D, transfer knowledge, or perform many of the other functions of scientists in the modern economy. If labor market difficulties are long term, restructuring may need to take place within graduate education both to maintain high-quality research and to prepare students better for a wider range of career options. In either case, when much high-level human capital goes unused, society loses opportunities for new knowledge and economic advancement, and individuals feel frustrated in their careers.

Most individuals who complete an S&E doctorate are looking for more than just steady employment at a good salary. Their technical and problem-solving skills make them highly employable, but the 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 describe well the S&E labor market. Some of the available labor market indicators are discussed below.[17]

Aggregate measures of labor market conditions changed only slightly for recent doctorate recipients in S&E (defined here as those one to three years after their degree). Unemployment fell from 1.9 percent for a similar graduation cohort in 1995 to 1.5 percent in 1997. (See text table 3-6.) At the same time, the proportion of recent Ph.D. recipients reporting that they were either working outside their field because a job in their field was not available, or that they were involuntarily working part-time, rose slightly from 4.3 percent to 4.5 percent. These aggregate numbers mask a number of changes—both positive and negative—in a number of individual disciplines. In addition, in many fields the involuntarily out of field (IOF) and unemployment rates moved in opposite directions. In many ways, whether highly skilled individuals who are unable to get the type of employment they desire become unemployed or accept employment outside their field, may reflect the type of expectations they have of the labor market.

Unemployment Rates

Even compared to relatively good labor market conditions in the general economy, the 1.5 percent unemployment rate for recent S&E Ph.D. recipients is very low—the April 1997 unemployment rate for all civilian workers was 5.0 percent. (See the sidebar, "Data on Recent Ph.D. Recipients in Professional Society Data.")[18] In 1995, recent graduates in several

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[17] Data on recent Ph.D. recipients presented here comes from the NSF/SRS 1993, 1995, and 1997 Survey of Doctorate Recipients, a component of the SESTAT data file that contains a 1/11 sample of S&E Ph.D. holders from U.S. schools. Ph.D. holders from foreign institutions were not included.

[18] People are said to be unemployed if they were not employed during the week of April 15, 1997, and had either looked for work during the preceding four weeks or were on layoff from a job. Although slightly different questions are used in the SESTAT surveys, this closely approximates the definition of unemployment used by the Bureau of Labor Statistics.

Text table 3–6.
Labor market rates for recent Ph.D. recipients: 1995 and 1997

	1–3 years after Ph.D.			
	Unemployment rate		Involuntary out-of-field rate	
Field	1995	1997	1995	1997
All S&E	1.9	1.5	4.3	4.5
Engineering	1.7	1.0	3.7	3.6
Chemical engineering	4.4	1.7	3.6	5.8
Civil engineering	1.2	0.0	1.1	5.5
Electrical engineering	0.9	0.6	3.1	3.2
Mechanical engineering	2.8	0.5	4.8	2.7
Other engineering	1.6	1.6	5.2	3.0
Life sciences	2.0	1.7	2.6	2.6
Agriculture	1.1	2.2	2.2	7.3
Biological sciences	2.0	1.5	2.7	2.2
Computer/math sciences	2.6	0.6	6.1	6.5
Computer sciences	1.1	0.7	2.7	2.1
Mathematical sciences	3.9	0.6	9.2	11.0
Physical sciences	2.4	2.1	5.3	6.9
Chemistry	2.2	3.5	4.1	3.3
Geosciences	1.7	1.0	6.8	6.3
Physics/astronomy	3.0	0.7	6.7	12.2
Social sciences	1.4	1.6	5.5	5.4
Economics	1.4	0.9	2.6	5.2
Political science	2.4	2.6	11.2	7.9
Psychology	0.5	1.2	3.8	3.8
Sociology/anthropology	3.1	2.5	9.0	7.7
Other social sciences	2.5	2.5	6.8	7.1

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), 1995 and 1997 Survey of Doctorate Recipients.

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Data on Recent Ph.D. Recipients in Professional Society Data

In 1998, data from surveys of new Ph.D. recipients for 1996–97 conducted by 13 S&E professional societies on 14 different disciplines were coordinated by the Commission on Professionals in Science and Technology. A common set of core questions was used in each society's poll of its own doctoral graduates to allow for collection of comparable career-related data. One of these common data elements, the unemployment rate is shown in text table 3-7. Unemployment ranged from 1.8 percent for recent physics Ph.D. recipients to 7.0 percent for recent Ph.D. recipients in political science.

Text table 3–7.
Unemployment rates for recent Ph.D. recipients reported in professional society surveys

Field	1995–96 Ph.D. recipients in 1997	1996–97 Ph.D. recipients in 1998
Biochemistry and molecular biology	NA	4.0
Chemistry	4	4.6
Chemical engineering	2	3.2
Computer science	2	2.4
Earth and space science	3	3.9
Economics	NA	2.3
Engineering	NA	2.7
Mathematics	5	2.4
Microbiology	NA	2.2
Physics	3	1.8
Physiology	NA	2.7
Political science	NA	7.0
Sociology	NA	1.9

NA = not available.

NOTE: Data for 1997 and 1998 were reported with different numbers of significant digits.

SOURCE: Commission on Professionals in Science and Technology.

Ph.D. disciplines had unemployment rates above 3 percent—still low, but unusually high for a highly skilled group. Between 1995 and 1997, unemployment rates fell for recent Ph.D. recipients in most disciplines, but increased in a few. The largest increase was in chemistry, where the unemployment rate for recent Ph.D. recipients rose from 2.2 to 3.5 percent—also making chemistry the field with the greatest unemployment rate for recent Ph.D. recipients. In 1997 unemployment rates of less than 1 percent were found for recent Ph.D. recipients in civil engineering (0.0 percent),[19] mechanical engineering (0.5 percent), electrical engineering (0.6 percent), mathematical sciences (0.6 percent), computer sciences (0.7 percent), physics-astronomy (0.7 percent), and economics (0.9 percent).

Involuntarily Working Outside Field

Another 4.5 percent of recent S&E Ph.D. recipients in the labor force reported that they could not find full-time employment (if they wished full-time employment) that was "closely related" or "somewhat related" to their degrees.[20] Although this is a more subjective measure than unemployment rates, it often provides a more sensitive indicator of labor market difficulties for a highly educated and employable population. It is best used, however, along with the unemployment rate as measures of two different forms of labor market distress.

The highest IOF rates in 1997 were found for recent Ph.D. graduates in physics-astronomy (12.2 percent) and in mathematical sciences (11.0 percent). These two fields also had among the lowest unemployment rates, although in physics-astronomy the increase in the IOF rate from 1995 to 1997 was much greater than the decrease in unemployment. The lowest IOF rates were found in computer sciences (2.1 percent) and the biological sciences (2.2 percent).

Tenure-Track Positions

Most S&E Ph.D. recipients do not ultimately work in academia—in most S&E fields this has been true for several decades. (Also see chapter 6, "Academic Research and Development: Financial and Personnel Resources, Support for Graduate Education, and Outputs.") In 1997, of S&E Ph.D. recipients four to six years after receipt of their degrees, only 22.9 percent were in tenure track or tenured positions at four-year institutions of higher education. (See text table 3-8.) Across fields, tenure-program academic employment four to six years after Ph.D. ranged from 11.9 percent in chemical engineering to 51.2 percent in sociology-anthropology. For Ph.D. recipients one to three years after their degrees, only 16.0 percent were in tenure programs, but this reflects the

Text table 3–8.
Percentage holding tenure and tenure-track appointments at four-year institutions: comparison of recent Ph.D. recipients: 1993, 1995, and 1997

	Recent Ph.D. recipients, tenured or tenure-track at four-year institutions					
	Years since receipt of Ph.D.					
	1995		1995		1997	
Field	1–3 years	4–6 years	1–3 years	4–6 years	1–3 years	4–6 years
All S&E	18.4	26.6	15.6	26.3	16.0	22.9
Engineering	16.0	24.6	12.7	20.5	10.9	17.8
Chemical engineering	8.1	14.0	6.1	5.5	2.8	11.9
Civil engineering	24.7	27.1	25.6	29.3	24.8	23.0
Electrical engineering	17.6	26.9	10.6	21.5	8.3	16.6
Mechanical engineering	13.5	29.5	14.5	25.4	9.1	14.4
Other engineering	13.9	21.3	10.5	17.3	12.5	18.5
Life sciences	12.6	24.8	12.6	24.0	12.6	22.4
Agriculture	15.6	27.0	13.5	25.0	21.6	24.3
Biological sciences	12.1	24.8	12.5	23.7	11.7	22.3
Computer/math sciences	39.7	54.1	34.8	47.3	27.9	37.8
Computer sciences	37.1	51.5	34.3	41.5	28.4	33.3
Mathematical sciences	41.8	56.0	35.2	52.6	27.3	41.2
Physical sciences	9.7	18.2	7.3	17.2	7.6	17.6
Chemistry	7.7	16.3	6.8	14.6	6.4	16.8
Geosciences	12.7	26.2	10.8	29.7	18.4	29.5
Physics/astronomy	12.0	17.7	5.8	15.2	4.6	15.0
Social sciences	26.4	29.2	21.5	33.6	25.1	27.1
Economics	46.6	48.6	41.7	54.5	34.8	48.0
Political science	53.9	47.1	29.5	66.1	40.5	39.0
Psychology	12.7	15.5	12.7	19.4	13.0	15.8
Sociology/anthropology	37.9	46.9	30.8	48.3	35.3	51.2
Other social sciences	37.4	48.8	27.3	41.4	39.7	33.5

SOURCE: National Science Foundation, Division of Science Resource Studies (NSF/SRS), 1993, 1995, and 1997 Survey of Doctorate Recipients.

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[19] An unemployment rate of 0.0 does not mean that no one in that field was unemployed, but that the estimated rate from NSF's sample survey was less than 0.05 percent.

[20] People were considered as working involuntarily outside their field if they said their jobs were not related to their degrees and they said that one reason was because no job in their field was available, or if they were part-time and said that the only reason was because a full-time job was not available. The involuntarily out of field rate (IOF) is calculated as the percentage that such individuals are of those in the labor force.

increasing use of postdoctoral appointments (or postdocs) by recent Ph.D. recipients in many fields.

Although academia must be considered just one possible sector of employment for S&E Ph.D. recipients, the availability of tenure-track positions is an important aspect of the job market for those who do seek academic careers. The rate of tenure-program employment for those four to six years since receipt of Ph.D. fell from 26.6 percent in 1993 to 22.9 percent in 1997, which reflects both job opportunities in academia and alternate 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 33.3 percent in 1997) where other measures of labor market distress are low and organizations of computer science departments report difficulties recruiting faculty.[21] The attractiveness of other employment may also be an explanation for drops in tenure-program rates in several engineering disciplines. The attractiveness of alternate employment, however, is a less likely explanation for the smaller drops in tenure-program employment rates in fields with other measures of distress, such as physics and mathematical sciences (both of which have large IOF rates) and the biological sciences (which have low unemployment and IOF rates, but have other indications of labor market distress).

Relationship Between 1997 Occupation and Field of Degree

By a strict definition of occupational titles, 15.0 percent of employed recent Ph.D. recipients were in occupations outside S&E, often with administrative or management functions. When asked how related their jobs were to their highest degree, only a small proportion of recent Ph.D. recipients in non-S&E occupations said that their jobs were unrelated to their degrees. (See text table 3-9.) By field, these respondents ranged from 1.4 percent of recent psychology and computer science Ph.D. graduates to 6.3 percent of recent Ph.D. graduates in mathematical sciences.

Salary for Recent S&E Ph.D. Recipients

Across all fields of degree, the median salary for recent S&E Ph.D. recipients was $41,000, a increase of 2.5 percent from 1995. By field, this ranges from a low of $32,000 in the biological sciences to a high of $68,000 in electrical engineering. Text table 3-10 shows the distribution of salaries for recent Ph.D. recipients by field of degree. For all Ph.D. recipients, those at the top 10 percent of the salary distribution (the 90th percentile) were paid $71,000. (See text table 3-10.) The 90th percentile salary varied by field from a low of $55,000 for sociology-anthropology to a high of $86,000 for computer science Ph.D. recipients. At the 10th percentile, representing the lowest-paid 10 percent among each field, salaries ranged from $16,000 for sociology-anthropology Ph.D. recipients to $45,000 for industrial engineering.

Salaries for recent S&E Ph.D. recipients by sector of employment are given in text table 3-11. The median salary for a postdoc one to three years after receipt of degree was $28,000—about half the median for a recent Ph.D. recipient working for a private company ($60,000). Many of the salary differentials between different S&E fields are narrower when examined within sector of employment. For those in tenure-track positions, median salaries ranged from about $37,000 in mathematical sciences to $50,000 for computer S&E. At private for-profit companies, median salaries ranged from $43,000 for psychology to $72,000 for computer science.

Changes in median salaries for recent (defined here as one to five years after receipt of degree) bachelor's, master's, and Ph.D. graduates are shown in text table 3-12. Across all S&E fields, median salaries for Ph.D. recipients rose by just 2.3 percent from 1995 to 1997—compared with 11.1 percent for bachelor's and 10.0 percent for master's degree graduates. To a considerable extent however, the median salary across all fields of Ph.D. was held down by relatively more rapid growth in Ph.D.

Text table 3–9.
Recent Ph.D. scientists and engineers, by field of degree and relationship between field of study and occupation: 1997
(Percent)

	Employed Recent Ph.D.				
Field	Total	Same field	Other S&E	Related non-S&E	Nonrelated, Non-S&E
All S&E	100.0	71.9	13.1	12.3	2.8
Computer sciences	100.0	83.4	3.0	12.2	1.4
Engineering	100.0	75.0	17.8	5.5	1.7
Life sciences	100.0	71.8	6.3	19.2	2.7
Mathematical sciences	100.0	70.6	14.9	8.2	6.3
Other social sciences.	100.0	67.7	5.2	22.1	4.9
Physical sciences	100.0	72.0	20.5	4.5	3.0
Psychology	100.0	68.0	21.9	8.7	1.4

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), 1997 Survey of Doctorate Recipients.

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[21] See Freeman and Aspray (1997).

Text table 3–10.

Salary distribution for recent Ph.D. recipients: 1997

	Percentile				
Field	10th	25th	Median	75th	90th
Total recent S&E Ph.D.	$24,000	$30,000	$41,000	$58,000	$71,000
Computer/math, total	32,000	37,500	50,000	68,000	80,000
Computer sciences	37,500	46,000	60,000	72,250	86,000
Mathematical sciences	30,000	34,000	40,000	52,500	70,000
Life sciences, total	22,000	26,000	32,300	45,600	60,000
Agriculture	20,500	28,000	38,900	49,000	58,000
Biological sciences	22,000	25,600	32,000	45,000	60,000
Health/medical	25,000	35,000	40,500	51,500	61,000
Physical sciences, total	24,000	31,000	41,500	58,000	67,000
Chemistry	22,000	27,000	40,000	58,000	65,000
Geosciences	29,000	33,000	39,860	48,000	63,000
Physics/astronony	27,150	35,000	43,070	60,000	70,000
Social sciences, total	20,000	31,000	40,000	49,000	64,000
Economics	30,000	43,000	50,000	64,500	80,000
Political science	21,000	33,000	40,000	47,000	65,000
Psychology	20,000	30,000	38,000	46,700	60,000
Sociology/anthropology	16,000	30,000	37,000	43,495	55,000
Other social sciences	20,000	33,500	39,000	46,500	61,000
Engineering, total	35,000	49,000	60,000	70,000	80,000
Aerospace engineering	39,000	50,000	56,000	65,000	70,000
Chemical engineering	30,000	49,000	60,000	68,000	76,100
Civil engineering	31,500	40,000	48,000	56,000	72,000
Electrical engineering	44,000	55,760	68,000	75,000	85,000
Industrial engineering	45,000	52,500	60,000	70,000	80,000
Mechanical engineering	40,000	48,800	58,540	69,000	76,000
Other engineering	30,000	43,000	55,000	65,000	74,300

SOURCE: National Science Foundation, Division of Science Resource Studies (NSF/SRS), 1993, 1995, and 1997 Survey of Doctorate Recipients.

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Text table 3–11.

Median salaries for recent U.S. Ph.D. recipients, by sector of employment: 1997

Field	Total	Private/ noneducational	Government	Tenure-track at four-year institution	Postdoc	Other educational
Total	$41,000	$60,000	$53,000	$42,000	$28,000	$36,000
Computer sciences	60,000	72,000	—	50,000	—	—
Engineering	60,000	65,000	60,000	50,000	35,000	48,000
Life sciences	32,300	55,000	50,000	42,300	27,000	35,000
Math sciences	40,000	60,000	—	37,150	—	35,000
Social sciences (other than psychology)	40,000	53,000	52,400	40,000	30,500	35,000
Physical sciences	41,500	60,000	57,300	39,000	32,000	35,000
Psychology	38,000	43,000	45,000	38,000	26,700	36,000

— = Fewer than 50 cases.

SOURCE: National Science Foundation, Division of Science Resource Studies (NSF/SRS), 1993, 1995, and 1997 Survey of Doctorate Recipients.

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Text table 3–12.
Change in median salaries for S&E graduates one to five years after degree: percentage change between 1995 and 1997

Field	Bachelor’s	Master’s	Ph.D.
All S&E Fields	11.1	10.0	2.3
Engineering	8.1	6.4	7.1
Chemical engineering	2.4	6.4	1.6
Civil engineering	2.9	8.0	–3.8
Electrical engineering	13.2	10.0	15.8
Mechanical engineering	5.3	11.1	9.1
Life sciences	4.2	6.7	–1.7
Agricultural sciences	4.2	6.9	0.0
Biological sciences	6.4	6.7	6.6
Computer/math sciences	12.8	12.4	14.6
Computer sciences	16.0	12.5	11.7
Mathematical sciences	8.9	14.3	5.3
Physical sciences	10.1	2.8	9.3
Chemistry	-3.6	0.0	2.0
Geoscience	16.7	0.0	2.5
Physics	41.7	20.0	17.5
Social sciences	8.3	5.8	5.0
Economics	10.0	20.0	10.0
Political science	12.0	11.8	6.2
Psychology	14.3	4.3	0.0
Sociology/anthropology	9.1	1.8	–2.7

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), 1995 and 1997 SESTAT data file.

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Text table 3–13.
Percentage of recent S&E graduates who say they are “not at all likely” to choose the same field of study if they could do it over again (one to five years after degree)

Field	Bachelor’s	Master’s	Ph.D.
All S&E fields	20.2	12.6	16.6
Engineering	11.3	12.6	14.8
Chemical engineering	9.5	13.1	13.0
Civil engineering	14.2	16.6	20.9
Electrical engineering	8.3	6.5	9.8
Mechanical engineering	10.2	16.6	16.5
Life sciences	16.8	13.9	18.3
Agricultural sciences	20.7	18.4	20.7
Biological sciences	16.0	14.0	18.2
Computer/math sciences	8.9	6.6	14.5
Computer sciences	6.8	5.3	6.8
Mathematical sciences	12.0	10.3	22.4
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/anthropology	31.2	15.7	15.5

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS),1995 and 1997 SESTAT data file.

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production in lower-paying fields, such as the biological and social sciences. Much larger increases were found in most individual disciplines, including double-digit increases in physics (17.5 percent), electrical engineering (15.8 percent), computer sciences (11.7 percent), and economics (10.0 percent). Declines in median salaries were observed in civil engineering (–3.8 percent) and sociology-anthropology (–2.7 percent).

Happiness with Choice of Field of Study

One indicator of the quality of employment available to recent graduates is simply their answer 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 this was asked of those with S&E degrees received 1–5 years after their previous degree, 16.6 percent of Ph.D. recipients said they were “not at all likely” as compared with 20.2 percent of those with S&E bachelor’s degrees. (See text table 3-13.) This regret of field choice is lowest for recent Ph.D. recipients in computer sciences (6.8 percent) and electrical engineering (9.8 percent), and in the social sciences (12.5 percent). It is greatest in physics (24.4 percent), chemistry (23.9 percent), and mathematical sciences (22.4 percent).

Postdoctoral Appointments

A postdoctoral appointment (or postdoc) is defined here as a temporary position awarded in academia, industry, or government primarily for the purpose of gaining additional training in research. This definition has been used in the Survey of Doctorate Recipients to ask respondents about current and past postdoctorate positions they have held.[22] Data and analyses on postdoctorates are often examined in relation to recent Ph.D. labor market issues. In addition to gaining more training, recent Ph.D. recipients may accept a temporary, usually lower-paying, postdoctorate position because a more permanent job in their field is not available. The increasing use of postdocs has been a focal point of discussions about many inter-related topics—the early career paths for new Ph.D. scientists, the vocational adequacy of Ph.D. programs, and the labor market expectations of new Ph.D. recipients.[23]

Science & Engineering Indicators – 1998 included an analysis of a one-time postdoctorate module in the 1995 Survey of Doctorate Recipients that showed a slow increase the use of postdocs in many disciplines over time.[24] In addition, in physics and the biological sciences, the fields with the heavi-

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[22] It is clear, however, that the exact use of the term “postdoctorate” differs among academic disciplines, among different universities, and among the different sectors that employ postdoctorates. It is likely that these differences in labeling affected self-reporting of postdoctorate status on the Survey of Doctorate Recipients.

[23] A recent overview of issues related to postdocs was published in *Science*, September 3, 1999, “Postdocs: Working for Respect.”

[24] This was measured cross-sectionally by looking at the percentage of each graduation cohort that reported ever being in a postdoc position.

Text table 3-14.
Primary reason for taking current postdoc: 1997
(Percent)

Field	Additional training in Ph.D. field	Training outside of Ph.D. field	Postdoc generally expected in field	Work with a particular person or place	Other employment not available	Other
Biological sciences	20.1	14.7	28.1	18.7	13.5	5.0
Chemistry	21.0	13.5	25.3	14.1	25.3	7.7
Engineering	18.4	12.9	7.0	20.7	23.1	17.9
Geoscience	29.4	3.5	18.3	7.6	29.3	11.9
Physics	13.7	8.4	34.4	16.7	19.1	7.6
Psychology	29.1	9.7	21.3	19.4	12.4	8.1
All S&E fields	20.0	13.325	23.7	18.3	17.2	7.5

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), Survey of Doctorate Recipients, 1997.

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est use of postdocs, median time in postdoc positions extended well beyond the one to two years found in most other fields.

Data from 1997 show a small decline in the percentage of all recent S&E Ph.D. recipients entering postdoc positions—from 32.7 percent of 1994 graduates in 1995 to 30.7 percent of 1996 graduates in 1997. At the same time, however, Ph.D. recipients in earlier graduation cohorts in these two fields show a similar propensity to be in postdocs as those with the same years since degree in 1995. Speculatively, something like this might be observed if new graduates were the most affected by improvements in labor market conditions. In fields other than physics or biological sciences, the postdoc rate one year after degree fell only slightly, from 21.2 percent in 1995 to 19.9 percent in 1997.

Reasons for Taking a Postdoc

Postdocs in 1997 were asked to provide reasons they were in their current postdoctoral appointment—the distribution of "primary reasons" given is shown in text table 3-14. Across all fields of degree, 17.2 percent gave "other employment not available" as the primary reason they were in a postdoc. Most respondents gave as primary reasons that a postdoc was generally expected for a career in their field (23.7 percent), that they were seeking additional training either in or outside of their Ph.D. field (20.0 and 13.3 percent), or other reasons more consistent with the stated training and apprenticeship functions of postdocs.[25]

Postdoc Transitions: What Were 1995 Postdocs Doing in 1997?

Of those in postdoctorate positions in April 1995, 38.0 percent were still in a postdoctorate position in April 1997. (See text table 3-15.) This is a small reduction from the 41.6 percent of 1993 postdocs that were still postdocs in 1995. (See *Science and Engineering Indicators 1998*.) Only 16.5 percent had moved from a postdoctorate to a tenure-track position at a four-year educational institution (up from 12.1 percent in 1995); 18.3 percent found other employment at an educational institution; 18.0 percent were at a for-profit firm;

Text table 3–15.
What were 1995 postdocs doing in 1997?
(Percent)

Field	Postdoc	Tenure-track at four-year institution	Other education	For-profit	Nonprofit / government	Unemployed
Biological sciences	49.3	14.0	17.9	12.4	5.4	1.0
Chemistry	23.1	16.8	20.4	26.5	6.1	7.1
Engineering	26.8	12.9	10.4	38.4	9.1	2.4
Physics	33.1	16.6	16.5	23.2	10.4	0.1
Psychology	17.2	14.8	23.1	27.1	17.7	0.0
All S&E fields	38.0	16.5	18.3	18.0	7.7	1.5

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), merged 1995 and 1997 file from NSF's Survey of Doctorate Recipients.

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[25] Respondents may well have defined their field in far narrower terms than reported here. Hence "training out of field" may refer to a biologist doing postdoc research on a topic different from their dissertation as opposed to doing a postdoc in chemistry.

7.7 percent were employed at a nonprofit institution or government; and 1.5 percent were unemployed.

No information is available on the career intentions of those in postdoc positions, but it is often assumed that a postdoc is most valued by academic departments at research universities. More postdocs, however, in each field transition to for-profit employment than obtain tenure-track positions—and many tenure-track positions are at schools where a research record obtained through a postdoc appointment may not be of central importance.

Age and Retirement

The size of the S&E labor force, its productivity, and opportunities for new S&E workers are all greatly affected by the age distribution and retirement patterns of the S&E labor force. For many decades, rapid increases in new entries to the S&E labor force led to a relatively young S&E labor force with only a small percentage near traditional retirement ages. This general picture is rapidly changing as the large number of individuals who earned S&E degrees in the late 1960s and early 1970s are moving 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 ages may mean increased levels of experience and productivity among scientific workers. Others have argued that it can reduce the opportunities for younger scientists to perform independent work. Indeed, in many fields there is scientific folklore and some actual evidence indicate that the most creative research comes from the young. The ongoing research in cognitive aspects of aging and the sociology of science is relevant to this debate, but will not be reviewed here.[26]

Age

Age distributions for scientists and engineers in the labor force are affected by many factors—net immigration, morbidity, and mortality—but most of all by historical S&E degree production patterns. Age distributions for individuals with S&E degrees in 1997 are given by degree level and field of degree in appendix table 3-19. With the exception of new fields, such as computer sciences (where 70.0 percent of degree holders are under age 40), the greatest population density of individuals with S&E degrees occurs between ages 40 and 49. This can be seen in figure 3-12, which shows the age distribution of the S&E educated labor force broken down by level of degree. For all S&E degrees there is also a bump up in the age distribution at ages 25–29 representing 14.2 percent of S&E degree holders in the labor force. This bump up, however, appears to be largely caused by increased degree production in the social sciences (where 25- to 29-year-olds represent 17.7 percent of the total). In general, most of the S&E degreed labor force is their late 30s through early 50s.

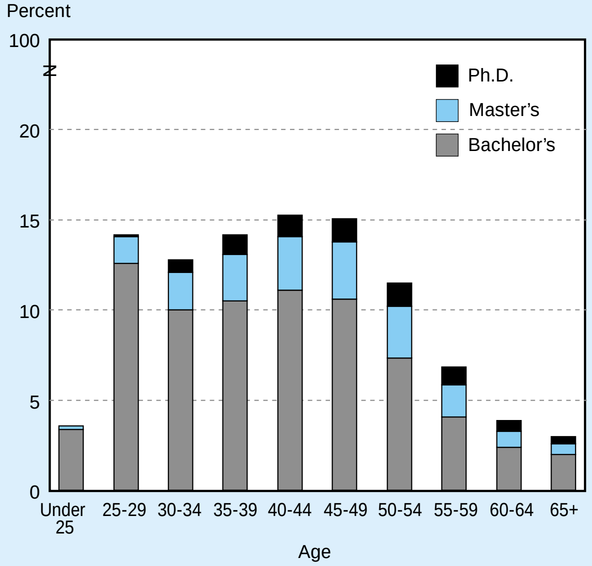
This general pattern holds true even for those with doctorates in S&E. Although Ph.D. holders are somewhat older than other S&E degree holders, this circumstance is because of fewer Ph.D. holders in the younger age categories, given the time needed to obtain this degree. The greatest population density of S&E Ph.D. holders in the labor force occurs for 45- to 54-year-olds.

S&E Ph.D. holders employed in tenured or tenure-track positions in four-year institutions of higher education (26.9 percent of all S&E Ph.D. holders) are somewhat older than all S&E Ph.D. holders—31.5 percent older than age 54 compared to 25.8 percent. (See figure 3-13.) The greatest population density of Ph.D. holders in these tenure programs occurs between ages 40 and 59. It is worth noting the sharp differences between the 55–59 and 60–64 age categories for both academic Ph.D. holders and the S&E Ph.D. population as a whole—a 48 percent drop that is much steeper than for the bachelor's or master's degreed S&E population.

At all degree levels and fields, only a small proportion of the S&E degreed labor force was near traditional retirement ages—only 13.6 percent overall were over age 54. This has several likely important and often overlooked effects on the future S&E labor force:

- Barring very large reductions in degree production or similarly large increases in retirement rates, the number of trained scientists and engineers in the labor force will continue to increase for some time. The number of individuals who are now receiving S&E degrees greatly exceeds the number of S&E degreed workers who are near traditional retirement ages.

Figure 3-12.
Age distribution of labor force with S&E high degrees



Unpublished tabulations. *Science & Engineering Indicators – 2000*

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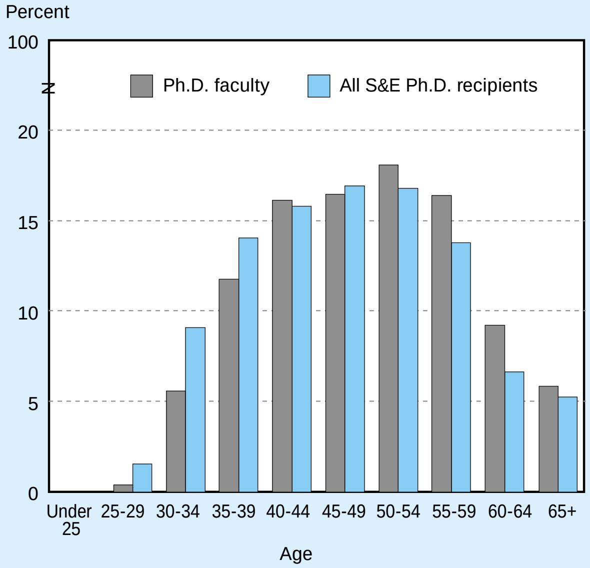
[26] See Stephan and Levin (1992) and Posner (1995) for a discussion of the role of age for scientists and other creative workers.

Figure 3-13.
1997 age distribution of S&E Ph.D. recipients in the labor force: tenured and tenure-track faculty at four-year institutions



See appendix table 3-21. *Science & Engineering Indicators – 2000*

- Barring large increases in degree production, the average age of S&E degreed workers will rise.
- With current retirement patterns, the total number of retirements among S&E degreed workers will dramatically increase over the next 10–15 years. This may be particularly true for Ph.D. holders because of the steepness of their age profile.

Retirement

Retirement behavior can differ in complex ways from one individual to the next. Some individuals “retire” from a job while continuing to work full- or part-time, sometimes for the same employer. Others leave the labor force without a “retired” designation from some formal pension plan. Three different ways of thinking about changes in labor force involvement are summarized in text table 3-16 for S&E degree holders—leaving full-time employment, leaving the labor force, and retiring from a particular job.

By age 63, 50 percent of S&E bachelor’s and master’s degree holders were not working full-time. For S&E Ph.D. holders, this 50 percent mark is not reached until three years later, at age 66. Longevity also differs by degree level with other measures. Half of S&E degree holders have left the labor force entirely by age 64 for bachelor’s degree holders, by age 65 for master’s degree holders, and not until age 68 for Ph.D. holders. 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 holder’s have “retired” from some job by age 63, compared with age 65 for S&E Ph.D. holders.

Although many S&E degree holders who formally “retire” from one job continue to work full-time or part-time, this occurs most often among those under age 63. (See text table 3-17.) The drop in labor force participation among the “retired” is more pronounced for part-time work—older retired S&E workers are actually more likely to be working full-time than part-time. Retired Ph.D. scientists and engineers follow the same pattern, albeit with somewhat greater rates of post-retirement employment than bachelor’s and master’s degree holders.

Movement out of full-time employment by S&E degree holders aged 55–70 is shown in figure 3-14. At all degree levels, the proportion of S&E degree holders who work full-time declines fairly steadily by age. After age 55, full-time employment by S&E doctorates becomes significantly greater than for bachelor’s and master’s degree holders. At age 70, over 20 percent of S&E Ph.D. holders are working full-time, compared with 10 percent of bachelor’s and master’s.

Academic employment may be one reason for somewhat slower retirement among Ph.D. holders. Text table 3-18 looks at the rate at which S&E Ph.D. holders leave full-time em-

Text table 3-16.
Retirement ages for holders of S&E degrees

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	63	64	63
Master’s	63	65	63
Ph.D.	66	68	65

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), SESTAT data file, 1997.

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Text table 3-17.
Percentage of S&E degreed individuals who have “retired,” but continue to work: 1997

	Bachelor’s		Master’s		Ph.D.	
Age group	Part-time	Full-time	Part-time	Full-time	Part-time	Full-time
50–55	52.1	15.8	65.1	17.3	62.1	20.4
56–62	27.2	13.4	35.7	13.7	36.8	18.5
63–70	9.1	12.7	8.7	15.6	13.9	17.6
> 70	4.0	8.4	5.1	9.6	5.4	10.9

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), SESTAT data file, 1997.

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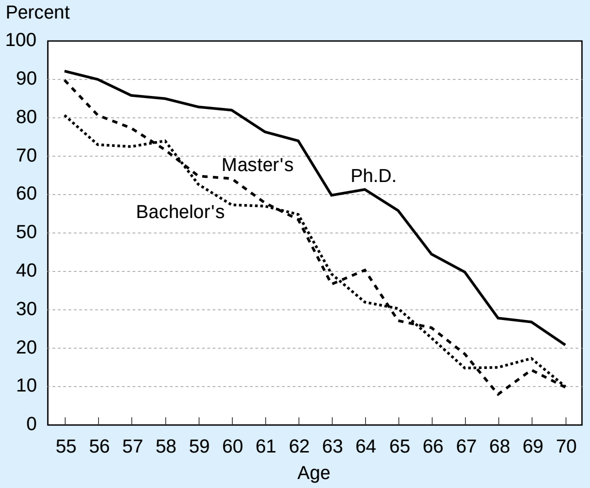
Figure 3-14.
Older S&E degree holders working full-time



See appendix table 3-22. *Science & Engineering Indicators – 2000*

Text table 3–18.
Percentage of 1995 S&E Ph.D.s leaving full-time employment by 1997: by sector of employment in 1995

Age in 1995	Four-year schools	For profit company	Govern-ment	All sectors
51–55	3.2	4.8	4.2	4.9
56–60	9.2	14.8	7.2	11.1
61–65	24.6	26.6	13.6	25.7
66–70	35.7	56.3	38.4	39.1
71–73	40.6	55.3	—	41.8

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), 1995 and 1997 Survey of Doctorate Recipients.

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ployment between 1995 and 1997 by sector of employment.[27] Within each age group, a smaller proportion of S&E Ph.D. holders employed in 1995 at four-year colleges and universities, or by the government, left full-time employment than S&E Ph.D. holders as a whole, or those employed by for-profit companies.

While slower retirement for S&E Ph.D. holders, particularly those 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 3-14 shows that their retirement patterns are much more like those of bachelor's and master's degree holders than they are different—retirement is just delayed two or three years. Even the two-year transition rates for academia in text table 3-18 shows more than a third of those aged 66–70 leaving full-time employment over a two-year period.

One reason academic Ph.D. retirement rates have been of interest has been a concern that the academic tenure system, combined with the end of mandatory retirement under U.S. antidiscrimination laws, could lead to continued employment of many less productive professors. Text table 3-19 compares two-year transition rates of leaving full-time employment for S&E Ph.D. holders employed full-time in 1995 at four-year institutions, by the number of articles they said they published within the previous five years. Within each age group, those writing six or more articles had a much lower transition rate out of full-time employment than those reporting fewer articles written. For those between the ages of 51 and 65, the transition rate for academics with zero articles was more than double the rate for those with six or more.

Projected Demand for S&E Workers

During the 1998–2008 period, employment in S&E occupations is expected to increase at almost four times the rate for all occupations. Though the economy as a whole is anticipated to provide approximately 14 percent more jobs over this decade, employment opportunities for S&E jobs are expected to increase by about 51 percent, or about 1.9 million jobs. (See text table 3-20.)

Approximately four-fifths of the increase in S&E jobs will occur in computer-related occupations. Overall employment in these occupations across all industries is expected to almost double over the 1998–2008 decade, with more than 1.5 million new jobs being added. Jobs for computer engineers and scientists are expected to increase from 914,000 to 1,858,000, while employment for computer systems analysts is expected to grow from 617,000 to almost 1.2 million jobs. (See the sidebar, "What Did Computer Workers Get Degrees In?")

Text table 3-19.
Percentage of 1995 S&E Ph.D. recipients at four-year institutions leaving full-time employment: by number of articles published in 1990–95

Age in 1995	No articles	1–5 articles	6 or more articles	All
51-55	5.7	3.5	1.0	3.2
56-60	12.2	8.6	6.7	9.2
61-65	32.6	23.5	16.1	24.6
66-70	—	43.1	28.0	35.7
71-73	—	—	28.1	40.6

— = Not available

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), 1995 and 1997 Survey of Doctorate Recipients.

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[27] 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. A two-year transition rate, however, can be calculated using the NSF/SRS SESTAT data file matched longitudinally at the individual level.

Text table 3-20.
Total S&E jobs: 1998 and projected 2008
(Numbers in thousands of jobs)

	1998	2008	Change
Total, all occupations	**140,514**	**160,795**	**20,281**
All S&E occupations	3,809	5,747	1,937
Scientists	2,347	3,995	1,647
Life scientists	173	219	45
Computer, mathematical, and operations research occupations	1,653	3,182	1,529
Computer systems analysts, engineers, and scientists	1,530	3,052	1,522
Computer engineers and scientists	914	1,858	944
Systems analysts	617	1,194	577
Mathematical scientists	123	131	8
Physical scientists	200	229	29
Social scientists	321	365	44
Engineers	1,462	1,752	290

See appendix table 3-28. *Science & Engineering Indicators – 2000*

Within engineering, electrical-electronic engineering is projected to have the biggest absolute and relative employment gains, up by 93,000 jobs, or about 26 percent. Civil and mechanical engineers are also expected to experience above-average employment gains, with projected increases of about 21 and 16 percent, respectively. Employment for all engineering occupations is expected to increase by an average of approximately 20 percent.

Job opportunities in life science occupations are projected to grow by 26 percent (45,000 new jobs) over the 1998–2008 period; at 35 percent, the biological sciences are expected to experience the largest growth (28,000 new jobs). Employment in physical science occupations is expected to increase by about 15 percent, from 200,000 to 229,000 jobs; slightly less than half of the projected job gains are for chemists (13,000 new jobs).

Social science occupations are expected to experience only average growth (14 percent) over the decade, largely because of the modest employment increases anticipated for psychologists (11 percent or 19,000 new jobs). Economists, however, are projected to experience more favorable job growth (19 percent or 13,000 new jobs).

Foreign-Born Scientists and Engineers in the United States

In April 1997, 26.1 percent of holders of doctorates in S&E in the United States were foreign born. This is shown in text table 3-22 with data from the 1997 NSF/SRS SESTAT data file, a large national sample of those with U.S. S&E degrees and those with foreign S&E degrees who were in the United

What Fields Did Computer Workers Get Degrees In?

In 1993 only 28.5 percent of college graduates employed in computer occupations had computer science degrees, with another 2.9 percent having degrees in the closely related field of computer and systems engineering and 6.7 percent in the sometimes closely related field of electrical engineering (text table 3-21).[*] Perhaps reflecting the role of business departments and schools in initially introducing computer training on many campuses, 17.7 percent had business degrees. Altogether, 32.5 percent of those in computer occupations in 1993 had degrees in fields outside science, engineering, or technology (SE&T), and another 29.6 percent had degrees in SE&T fields not directly related to computing. This picture is very different for computer workers under age 30: 45.2 percent have computer science degrees, 4.9 percent degrees in computer and systems engineering, and 8.9 percent in electrical engineering. Only 16.5 percent had degrees in non-SE&T fields.

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[*] 1993 is the only year in the 1990s for which both field of degree and occupation are available on a major workforce survey for all college graduates. The 1993 SESTAT file augmented with the non-S&E records from the 1993 National Survey of College Graduates provides a valid national sample for this population.

Text table 3–21.
Field of highest degree for 1993 computer job holders

	(Percent)		
Field of highest degree	All ages	Age < 30	Age 30+
Computer sciences	28.5	45.2	25.4
Mathematics	8.9	6.6	9.3
Life sciences	2.1	0.6	2.4
Physical sciences	3.5	2.0	3.8
Social sciences	7.0	6.5	7.1
Computer & systems engineering	2.9	4.9	2.5
Electrical engineering	6.7	8.9	6.3
Mechanical engineering	1.2	1.2	1.2
Other engineering	3.0	2.9	3.0
Business	17.7	10.5	19.0
Education	4.2	0.6	4.9
Technology	3.9	4.5	3.8
Humanities	6.1	2.7	6.7
Other non-S&E	4.5	2.7	4.8
Total (n = 1,243,300)	100.0	100.0	100.0

— = Data not available.

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), SESTAT Data file, 1993.

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Text table 3–22.
Percentage foreign-born, S&E trained U.S. scientists and engineers, by field of highest degree and degree level: 1997

Field of highest degree	Labor force, total	Bachelor's	Master's	Doctorate
All S&E	12.7	9.7	19.2	26.1
Engineering	19.8	14.9	30.1	44.0
Aerospace engineering	12.4	10.0	14.3	37.2
Chemical engineering	21.4	15.8	35.6	40.1
Civil engineering	21.2	16.5	33.8	52.0
Electrical engineering	22.7	18.0	32.2	46.8
Industrial engineering	16.9	11.2	32.3	50.9
Mechanical engineering	17.8	13.5	32.7	45.4
Other engineering	17.4	10.8	23.1	40.3
Life sciences	10.7	7.8	12.8	24.7
Agriculture	6.9	4.3	14.4	21.7
Biological sciences	12.3	9.3	13.0	25.5
Math/computer sciences	16.5	12.7	24.6	35.6
Computer sciences	20.4	15.6	30.8	49.5
Mathematical sciences	11.8	9.4	14.8	30.7
Physical sciences	16.0	11.8	17.2	28.5
Chemistry	20.0	15.9	23.9	29.1
Geosciences	8.0	5.4	10.2	19.5
Physics/astronomy	18.8	11.8	18.6	30.8
Other phys sciences	10.2	8.8	12.2	30.0
Social sciences	7.0	6.1	9.4	12.7
Economics	13.7	11.2	26.3	26.4
Political science	7.0	6.2	10.3	15.7
Psychology	5.4	5.1	5.8	7.2
Sociology/Anthropology	4.9	3.9	12.1	13.1
Other social sciences	7.7	6.3	10.7	20.3

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), SESTAT Data file, 1997.

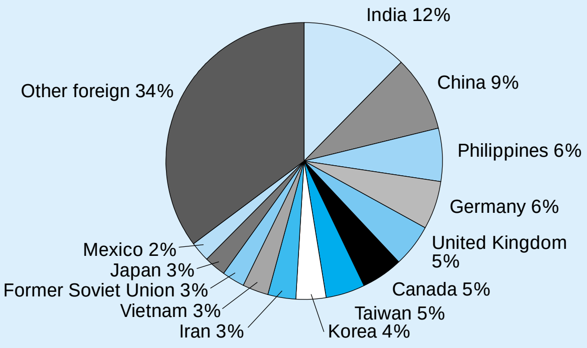
Science and Engineering Indicators – 2000

States in 1990.[28] The lowest percentage of foreign-born doctorates was in psychology (7.2 percent) and the highest was in civil engineering (52.0 percent). Almost one-fifth (19.2 percent) of those with master's degree in S&E were foreign born. Even at the bachelor's degree level, 9.7 percent of those with S&E degrees were foreign born—with the greatest proportion in chemistry (15.9 percent), computer sciences (15.6 percent), and across all engineering fields (14.9 percent).

Immigrant scientists come from a wide variety of 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 3-15. Although no one source country dominates, 12 percent originated from India, 9 percent from China, 6 percent from the Philippines, and 6 percent from Germany (including those born in the former East Germany). By region, 57 percent originated in Asia (including the Western Asia sections of the Middle East), 24 percent from Europe, 13 percent from Central and South America, 6 percent from Canada and Oceania, and 4 percent from Africa.

The Immigration and Naturalization Service (INS) counts of permanent visas issued to immigrants in S&E occupations

Figure 3-15.
Place of birth for foreign-born S&E degree holders: 1997



See appendix table 3-23. *Science & Engineering Indicators – 2000*

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[28] Since 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 a decade, counts of foreign born scientists and engineers are likely to be underestimates. Foreign degreed scientist and engineers are included in the 1997 estimate only to the extent they were in the United States in April 1990. In 1993, 34.1 percent of foreign-born doctorates in S&E and 49.1 percent foreign-born bachelor's in S&E had their degrees from foreign schools.

are shown in figure 3-16. The most recent data for 1998 show a continuing decrease in permanent visas for each S&E occupation from their peaks in 1992 and 1993, after a statutory increase in the number of work-related permanent visas. The total number of immigrants with S&E occupations is now less than in 1991 before the law took effect. (See the sidebar, “Foreign Scientists and Engineers on Temporary Work Visas.”)

Permanent visa numbers in recent years have been greatly affected by both immigration legislation and administrative changes at the INS. The 1990 Immigration Act led to increases in the number of employment-based visas available, starting in 1992. The 1992 Chinese Student Protection Act made it possible for Chinese nationals in the United States on student or other temporary visas to acquire permanent resident visas.

Foreign Scientists and Engineers on Temporary Work Visas

One area of policy discussion in recent years has been the use of various forms of temporary work visas by foreign-born scientists. Many newspaper and magazine stories centered on legislation which temporarily increased the 65,000 annual quota for the H-1b visa program through which individuals can get a visa to work in an occupation requiring at least a bachelor’s degree for up to six years. Although this is often thought of as a visa for information technology workers, it is used to hire a wide range of skilled workers. Even when a company does not at all consider a worker to be a temporary hire, an H-1b visa can be the only way to put a worker on the job while waiting for a permanent visa. 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 (text table 3-23).[*] Because applications are filed by companies for positions, rather than for a particular individual, many times more applications are filed than either visas issued or applied for. Almost half (47.5 percent) of H-1b certifications were for computer-related or electrical engineering positions. Another 29.2 percent were in medical occupations, primarily as various types of therapists and technicians, but also some medical researchers. Other S&E fields were 9.0 percent, education (including professors) was 3.6 percent, and all other occupations only 10.6 percent of total 1996 H-1b certifications.

Scientists and engineers may also receive temporary work visas through intracompany transfer visas (L-1 visas), high-skill worker visas under the North American Free Trade Agreement (TN-1 visas—currently a program primarily for Canadians, but with full access for Mexican professionals coming into place in 2004), and work visas for individuals with an outstanding ability (O-1 visas), as well as several smaller programs.In addition, there is little doubt that much research is done by students (F-1 and J-1 visas); and by postdocs and visiting scientists (J-1 visas, but often H-1b or other categories). Counts of visas issued for each of these categories are shown in text table 3-24.

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[*] The annual quota on the number of H-1b visas is controlled through the issuance of visas to workers, rather than the applications from companies. Anecdotally, some firms that expect to hire multiple workers on H-1b visas seek permission for many positions, which will also affect the distribution of occupations in text table 3-23.

Text table 3-23.
FY 1997 certifications to hire workers with H-1b temporary visas

Occupation	Certifications	Percent
Computer-related and electrical engineering	189,400	47.5
Medical	116,502	29.2
Other sciences	13,959	3.5
Other engineering and architecture	22,077	5.5
Education	14,249	3.6
Other	42,137	10.6
Total	398,324	100.0

NOTE: The actual occupational distribution of H-1b visa holders might be quite different. Certification is a permission given to a firm to try to recruit a worker who then can apply for an H-1b visa. In FY 1997, only 65,000 H-1b visas could legally be issues.

SOURCE: NSF/SRS Tabulation of Department of Labor administrative data summaries.

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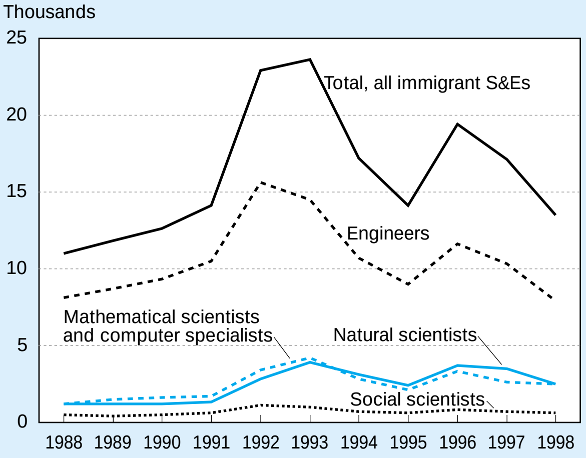
Text table 3-24.
FY 1996 temporary visas issued in major categories likely to include some scientists and engineers

Temporary work visa categories	Issued
H-1b (specialty occupations requiring the equivalent of a bachelor’s degree)	58,327
L-1 (intracompany transfers)	32,098
TN (NAFTA visa for professionals)	29,252
O-1 (persons of extraordinary ability)	2,765
O-2 (workers assisting O-1)	1,594
Temporary student/exchange visa categories	**Issued**
F-1 (students)	241,003
J-1 (exchange visitors)	171,164

SOURCE: Immigration and Naturalization Service administrative records.

Science & Engineering Indicators – 2000

Figure 3-16.
Immigration and Naturalization Service counts of permanent visas with S&E occupations



See appendix table 3-24. *Science & Engineering Indicators – 2000*

These changes resulted in at least a temporary increase in the number of scientists able to obtain permanent visas.[29]

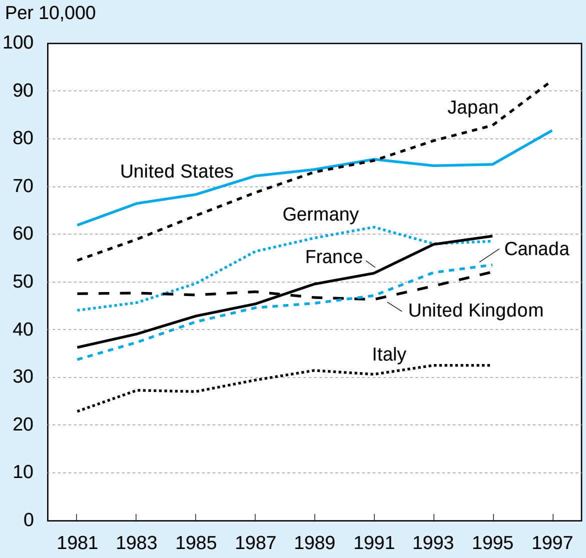
Stay Rates of Temporary Visa Ph.D. Recipients from U.S. Schools

How many of the foreign students who receive S&E Ph.D. holders from U.S. graduate schools stay in the United States? According to a report by Finn (1999), 48 percent of 1992–93 U.S. S&E doctorate recipients with temporary visas were still in the United States in 1994. By field, this percentage ranged from 29 percent in the social sciences to 55 percent in physical sciences and mathematics. (See text table 3-25.) Within each discipline, the percentage of the Ph.D. graduation cohort found in the United States increases with years since degree, reaching 53 percent in 1997. The increase in the stay rate occurs despite considerable evidence from other sources that large numbers of foreign Ph.D. recipients with U.S. degrees leave the United States after completing a postdoc, or at later points in their careers. This suggests a very dynamic picture of the international migration of Ph.D. scientists—with some graduates of U.S. schools returning to the United States even as others leave.

International R&D Employment

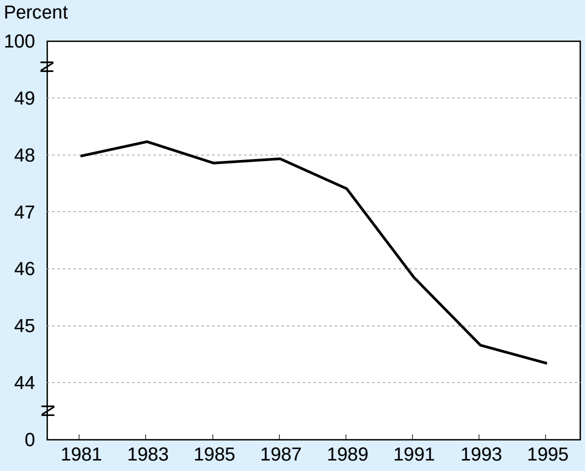
Information on the numbers of scientists and engineers engaged in R&D are contained in figure 3-17, figure 3-18, and appendix table 3-25 for the G-7 nations: the United States, Canada, France, Germany, Italy, Japan, and the United Kingdom. Since 1991, Japan has surpassed the United States in scientists and engineers engaged in R&D as a percentage of their labor force, but the United States continues to have a greater proportion of R&D workers than the other included industrial countries. In terms of total numbers of R&D scientists and engineers, the U.S. share of the G-7 total of scientists and engineers engaged in R&D, as reflected in figure 3-18, has fallen slightly from 48.0 percent in 1981 to 44.3 percent in 1995.

Figure 3-17.
S&E labor force engaged in R&D per 10,000 labor force



See appendix table 3-25. *Science & Engineering Indicators – 2000*

Figure 3-18.
U.S. scientists and engineers engaged in R&D as a percentage of the G-7 total



See appendix table 3-25. *Science & Engineering Indicators – 2000*

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[29] In addition, the easier availability of occupation-based permanent visas affect the measurements—many scientists enter on family-based visas, where reporting of occupation is optional. If more of these individuals were using occupational visas, we would identify more immigrants in S&E occupations for that reason.

Text table 3–25.
Recipients of 1992-93 doctorates with temporary visas at time of degree who were in the United States, 1994-97

Field	Temporary resident doctorate recipients	1994	1995	1996	1997
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
Total, S&E fields	16,391	48	51	52	53

SOURCE: Finn ,1999. *Stay Rates of Foreign Doctorate Recipients from U.S. Universities.* Oak Ridge, TN: Oak Ridge Institute for Science and Engineering

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Chapter 4
Higher Education in Science and Engineering

Contents

Highlights

Characteristics of U.S. Higher Education Institutions

- **The defining characteristics of U.S. higher education today that foster access—a broad array of institutional types and sizes, public and private funding, and flexible attendance patterns—were already in place by the early 1950s.** The number of institutions of higher education, however, has doubled since the early 1950s: from approximately 1,870 to 3,700 in 1996. This large and diversified set of institutions provides an undergraduate education to nearly one-third of the U.S. college-age population. This access to higher education is still among the broadest in the world.

- **In the past 50 years, enrollment in U.S. higher education has grown from 2.5 million students to more than 14 million.** The four-decade expansion in enrollment in U.S. higher education reached its peak in 1992, when 14.7 million students were enrolled. Enrollment declined and leveled off from 1993 to 1996 and started to rise again in 1997. As the college-age population increases after the year 2000, enrollment in higher education is expected to rise again.

- **Although the diverse spectrum of institutions provides relatively high access to higher education in the United States, research-intensive universities produce the majority of engineering degrees and a large proportion of natural and social science degrees at the graduate and undergraduate levels.** The country's 126 research universities awarded more than 42 percent of all science and engineering (S&E) degrees in 1996 at the bachelor's level and 52 percent of all S&E degrees at the master's level.

- **Research universities are less prominent in the undergraduate S&E education of underrepresented minority groups than they are in the overall student population.** Black students receive their undergraduate S&E education mainly in comprehensive universities and liberal arts colleges. Historically black colleges and universities (HBCUs) still play a significant role in the undergraduate S&E education of black students.

Undergraduate S&E Students and Degrees in the United States

- **The relatively low level of mathematics and science proficiency of U.S. 12th graders is evident among entering first-year college students.** In 1997, 22 percent of first-year students who intended an S&E major reported that they needed remedial work in mathematics. In addition, 10 percent reported that they needed remedial work in the sciences. The need for remedial work in mathematics and science has remained high over the past 20 years, with some differences by field of intended major.

- **In the past two decades, the U.S. college-age population declined by more than 21 percent—from 21.6 million in 1980 to 17.0 million in the year 2000.** Trends described in this chapter on decade-long declining enrollment and degrees in several fields of natural science and engineering (NS&E) reflect this demographic situation. The college-age population decline reverses itself in the year 2001, however, and increases to 19.3 million by the year 2010 (a 13-percent increase over the year 2000 figure). This increase in the college-age population portends another wave of expansion in U.S. higher education—and growth in S&E degrees at all levels.

- **Echoing this overall demographic decline, the number of students enrolling in undergraduate engineering decreased by 16 percent, from a high point of 441,200 students in 1983 to 356,000 in 1996.** This trend turned around slightly in 1997 and 1998, with a 1.5-percent increase in engineering enrollment. Trends in graduate engineering enrollment differ: graduate enrollment increased from 1979 to 1993 but has declined each year since.

- **Since the 1950s, trends in total undergraduate S&E degrees show continuous upward growth, although engineering, mathematics, and computer science fields show declining numbers of degrees in the late 1980s and the 1990s.** The growth in overall S&E degrees occurred in two waves: the first in the 1950s and 1960s and the second in the 1990s. The only fields with an increasing number of earned degrees in the 1990s have been psychology and biological sciences—fields in which women are highly represented. The entry of women into these fields has offset the overall demographic downturn.

International Comparison of First University Degrees in S&E

- **In 1997, more than 2.7 million students worldwide earned a first university degree in science or engineering.** Among reporting countries, more than 1 million of the 2.7 million S&E degrees were earned by Asian students within Asian universities. Students across Europe (including Eastern Europe and Russia) earned more than 750,000 first university degrees in science and engineering. Students in the North American region earned 500,000 first university degrees in these fields.

- **Some countries emphasize S&E fields in higher education more than others do.** In several large countries—Japan, Russia, and Brazil, for example—more than 60 percent of students earn their first university degrees in S&E fields, and in China, 72 percent do. In contrast, U.S. students study in a wide variety of non-S&E fields; they earn about one-third of their bachelor-level degrees in S&E fields (mainly in the social sciences).

- **Countries differ with regard to field emphases within science and engineering.** Engineering represents 46 percent of the earned bachelor's degrees in China, about 30 percent in Sweden and Russia, and about 20 percent in Japan and South Korea. In contrast, students in the United

States earn about 5 percent of bachelor-level degrees in engineering fields. Countries with high concentrations of university degrees in the natural sciences include Ireland (34 percent), France and India (about 20 percent), and the United Kingdom (18 percent). Natural sciences represent almost 12 percent of total U.S. bachelor-level degrees.

♦ **Among the major industrialized countries in the world, the United States is one of the leading nations in providing broad access to higher education.** In 1997, the ratio of the number of bachelor-level degrees to the 24-year-old population was 32 per hundred in the United States, 35 in the United Kingdom, 28 in Japan, and 24 in Germany. The ratios for Italy and France were 13 per hundred in that same year.

♦ **The United States ranks below many major industrialized and emerging countries, however, in the proportion of its college-age population with a natural science or engineering degree.**[1] In 1997, the ratio of the number of NS&E degrees to the 24-year-old population in the United States was about 5 per hundred. This U.S. ratio has remained relatively constant—between 4 and 5—over the past several decades. In contrast, the ratio of NS&E degrees to the college-age cohort has been rising in other countries. South Korea and Taiwan dramatically increased their ratio of NS&E degrees to 24-year-olds: from 2 per hundred in 1975 to almost 7 per hundred in Taiwan in 1997 and almost 9 per hundred in South Korea. Among European countries, by 1997 this ratio had increased to 9 per hundred in the United Kingdom and 8 per hundred in Germany.

Graduate S&E Students and Degrees in the United States

♦ **One indicator of national innovation capacity and potential international competitiveness is the size and growth of graduate programs in science and engineering.** The long-term trend of increasing enrollment in U.S. graduate programs in S&E persisted for more than four decades, from the late 1940s to the early 1990s, followed by four years of declining enrollment since 1993.

♦ **Increases in S&E degrees at the master's level persisted for more than four decades, with accelerated growth in the first half of the 1990s and a leveling off in 1996.** Master's degrees in S&E fields expanded from the modest number of 13,500 in 1954 to more than 95,000 in 1996.

♦ **Doctoral S&E degree production in U.S. universities shows two waves of strong growth in the last half of the 20th century.** The first upsurge of total doctoral S&E degrees in the late 1950s and 1960s reflected the Cold War and the space race and was followed by a long, slow decline in NS&E fields in the 1970s and in the social sciences in the 1980s. In the 1980s, the second wave of growth occurred in NS&E fields with large annual increases in academic research and development (R&D) budgets. From 1986 to 1992, increasing numbers of foreign students entered these expanded graduate programs in NS&E fields.

International Comparison of Doctoral Degrees in S&E

♦ **The United States has the highest number of doctoral degrees earned in S&E fields.** In 1997, U.S. universities awarded about 26,800 S&E doctoral degrees—more than twice the number of S&E degrees awarded in any of the other major industrial countries. However, the combined doctoral S&E degrees of the three largest European countries (Germany, France, and the United Kingdom) recently reached 27,800, surpassing the number of such degrees earned within the United States.

♦ **Asian graduate education reforms are strengthening and expanding doctoral programs; consequently, some Asian countries are becoming somewhat less dependent on U.S. universities for advanced training in S&E.** In 1997, the number of S&E doctoral degrees earned within major Asian countries (China, India, Japan, South Korea, and Taiwan) exceeded 18,500—representing a 12-percent average annual increase from 1993 to 1997. In contrast, such degrees earned by Asian students from these five countries within U.S. universities peaked at 6,900 in 1996 (representing less than a 5-percent average annual growth rate from 1993 to 1996) and declined in 1997.

♦ **China has invested heavily in graduate education.** While the number of S&E doctoral degrees earned by Chinese students within U.S. universities showed a decade-long increase until 1996, the number of such degrees earned within Chinese universities continued to increase, and at a faster rate. By 1997, Chinese students earned more than twice as many S&E doctorates within Chinese universities as within U.S. universities.

Diversity Patterns in S&E Enrollment and Degrees in the United States

♦ **The trend of increasing enrollment in undergraduate programs by underrepresented minorities (including black, Hispanic, and American Indian/Alaskan Native students) has persisted for more than a decade and continued in the 1990s.** Black enrollment increased 3 percent annually from 1990 to 1996, reaching 1.4 million in 1996. Black males have had more modest gains than black females. In the same period, Hispanic enrollment in higher education increased at an even faster rate (7.7 percent annually). The strongest growth, however, has been among Asians/Pacific Islanders (8 percent annually)—minority groups that are not underrepresented in S&E fields.

♦ **Despite the overall trend of decreasing enrollment in undergraduate engineering in the past two decades, underrepresented minority groups increased their enrollment in such programs during this same time period.** The number of minority students enrolled in engineering increased from 28,700 in 1979 to 56,900 in 1998—an average annual increase of 3.7 percent. By 1998,

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[1] Natural sciences and engineering include physical, earth, atmospheric, oceanographic, biological, and agricultural sciences; mathematics and computer science; and all fields of engineering.

underrepresented minorities represented 15.5 percent of engineering enrollment at the undergraduate level (up from 7.8 in 1979).

- **Compared with other groups, fewer underrepresented minority students complete a bachelor's degree within five years after beginning an S&E major.** In a longitudinal study, 47 percent of whites and Asians/Pacific Islanders completed an S&E degree within 5 years, compared with 25 percent of underrepresented minority groups. However, a larger percentage of underrepresented minority groups persisted in studying for an S&E bachelor's degree beyond five years. (Taking longer may reflect working part-time.) In addition, underrepresented minority groups switched to non-S&E majors more often than other groups. Attrition rates (dropping out of college) are similar across all groups—about 22 percent.

- **Students from underrepresented minority groups earn a higher proportion of degrees at the associate's level than in four-year or graduate programs.** In 1996, these students earned about 23 percent of the mathematics and computer science degrees at the associate's level, a far higher percentage than for such degrees earned at the bachelor's or advanced levels of higher education. At advanced levels, the proportion of degrees earned by underrepresented minorities drops off in fields of NS&E.

- **The United States is among the leading countries in the world in the proportion of first university S&E degrees earned by women.** By 1996, women earned 60 percent of the social and behavioral science degrees, 47 percent of the natural science degrees, 46 percent of the degrees in the mathematical sciences, 28 percent of the degrees in computer sciences, and 18 percent of the degrees in engineering. Women in the United Kingdom earn a similarly high proportion of S&E degrees. In contrast, in Japan women earn a smaller proportion of such degrees: 25 percent of natural science degrees, 23 percent of mathematics and computer science degrees, and 8 percent of engineering degrees.

- **Although low participation rates for blacks and Hispanics changed little throughout the 1980s, they have improved somewhat in the 1990s.** The ratio of college degrees earned by black students to their college-age population increased from 11 per hundred in 1980 to 18 per hundred in 1996; the ratio for Hispanic groups increased from 10 per hundred in 1980 to 14 per hundred in 1996. The ratio of NS&E degrees earned by black students to their college-age populations increased from 1 per hundred in 1980 to 2 per hundred in 1996, and the ratio for Hispanics rose from slightly under 2 per hundred in 1980 to slightly more than 2 per hundred in 1996. Even with these modest increases in the 1990s, however, participation rates of underrepresented minorities are approximately one-half the overall national rates.

- **For the period 1983–92, the strong growth in enrollment in U.S. graduate programs in S&E depended on the entry of foreign students, particularly in programs of natural science and engineering (NS&E).** In 1992, at the peak of their enrollment in U.S. graduate programs, foreign students represented one-third of the students in engineering, mathematics, and computer sciences. From 1993 to 1996, foreign graduate student enrollment declined at an average annual rate of 3 percent, with a slight upturn in 1997. The slight drop in doctoral degrees in NS&E fields in 1997 is mainly attributable to the decline in the number of foreign doctoral recipients in that year.

- **Among underrepresented minority groups, males are not as prevalent in fields of NS&E; women in these groups have a higher proportion of graduate enrollment compared with the overall average.** For example, women are one-third of the black graduate students in engineering and more than one-half of the black graduate students in fields of natural sciences. Black males are extremely underrepresented in U.S. higher education in general and in S&E fields in particular.

- **Gender equity in S&E degrees at the master's level has improved continually during the past four decades.** By 1996, women earned 58 percent of the master's degrees in the social and behavioral sciences and 49 percent in the biological sciences. However, they earned only 27 percent of computer science degrees and 17 percent of those in engineering. Degrees earned by males have declined in engineering for the past two years, mainly because of declining engineering enrollment by foreign students.

- **Each year from 1986 to 1996, an increasing number of foreign students earned S&E doctoral degrees from U.S. universities.** The number of such degrees earned by foreign students increased far faster (8 percent annually) than those earned by U.S. citizens (2 percent annually). This decade-long trend of increasing numbers of S&E doctoral degrees earned by foreign students halted in 1997. In that year, the number of degrees earned by foreign doctoral students dropped by 15 percent.

- **Like the United States, the United Kingdom, Japan, and France have a large percentage of foreign students in their doctoral S&E programs.** In 1997, foreign students earned 45 percent of the doctoral engineering degrees awarded within U.K. universities, 43 percent of the doctoral engineering degrees within Japanese universities, and 49 percent of the doctoral degrees within U.S. universities. In that same year, foreign students earned more than 21 percent of the doctoral degrees in the natural sciences in France, 29 percent in the United Kingdom, and 36 percent in the United States.

- **About 53 percent of the foreign students who earned S&E doctorates from U.S. universities in 1992 and 1993 were working in the United States in 1997.** The stay rates are higher for scientists and engineers from developing countries such as China (92 percent) and India (83 percent). In contrast, stay rates are lower for those from emerging economies such as Taiwan (36 percent) and Korea (9 percent) that can absorb highly qualified, skilled scientists and engineers.

Introduction

Chapter Overview

Many recommendations for strengthening higher education in science and engineering that were made a half-century ago in Science and Public Policy[2] are still being implemented or are still of national concern (Steelman 1947). These recommendations of the President's Scientific Research Board—referred to herein as the Steelman report—included expanding institutions of higher education, training scientists and engineers in all fields of knowledge, and providing U.S. leadership in disseminating scientific knowledge. This chapter suggests that several of these recommendations have been accomplished, as the trends regarding expansion of and greater access to higher education and the leadership role of U.S. universities in training scientists and engineers from around the world demonstrate. This chapter also addresses other recommendations that are still topics of concern, such as improving the teaching and research experience of undergraduates, educating adequate numbers of students willing and able to pursue advanced S&E programs, and creating the "right" number of S&E doctorates to meet the needs of the workplace. In addition, this chapter presents indicators on current concerns that are different from those of the past—especially the participation of women and minorities in S&E, the dependence on foreign students in U.S. graduate S&E programs, and the stay rates and return patterns of foreign doctoral recipients.

Chapter Organization

This chapter begins with a review of the growth of U.S. higher education from the early 1950s; this review presents the characteristics of the diverse set of institutions that fostered this growth. The chapter notes the prominence of research universities in the expansion of S&E degrees, as well as the continuing importance of comprehensive and liberal arts colleges. The review highlights increased access to higher education provided by community colleges.

The main body of the chapter presents trends in enrollment and degrees in broad fields of S&E at various levels—associate's, bachelor's, master's, and doctorate. The characteristics of U.S. freshmen show their intentions to major in S&E as well as some lack of readiness for college-level work. Following the review of bachelor-level trends, international data are presented to compare participation rates across several world regions. In addition, international comparisons are made at the doctoral level, and information is presented on the worldwide movement toward expansion and reform of graduate S&E education. Further international comparisons are made with regard to the participation of women in S&E fields at the bachelor's and doctoral levels and the proportion of doctoral degrees earned by foreign students.

The final sections of the chapter address patterns of diversity in U.S. higher education. The increasing representation of women and minorities in S&E degrees is shown over time and by field. Long-term trends of increasing foreign student enrollment and degrees, as well as recent downturns in these trends, are discussed.

Other chapters of this volume cover related topics in S&E education. Chapter 3, "Science and Engineering Workforce," discusses the entry of S&E graduates at various levels into the U.S. labor force in S&E occupations and the contribution of foreign doctoral recipients who remain in the United States for teaching and research. Chapter 6, "Academic Research and Development," includes indicators of graduate student financing, faculty composition, and the link between R&D funding and graduate enrollment; the bibliometric section of that chapter also provides initial indicators of the growing percentage of the world's scientific literature from countries expanding their graduate education in S&E. Chapter 7, "Industry, Technology, and the Global Marketplace," provides initial indicators of competitiveness—high technology trade and patenting—of countries that have expanded their doctoral S&E training and are building their science infrastructure. Chapter 9, "Significance of Information Technologies," includes the impact of technology on higher education.

Characteristics of U.S. Higher Education Institutions

The defining characteristics of U.S. higher education that foster access—a broad array of institutional types and sizes, public and private funding, and flexible attendance patterns—were already in place in the early 1950s. In 1953, more than 1,870 institutions—including universities; liberal arts colleges; teachers' colleges; and technological, theological, and other professional schools—were providing higher education. These diverse institutions included public and private colleges and universities and provided for part-time attendance. One-fifth of the undergraduate students were enrolled part-time (U.S. HEW 1956). Students were concentrated in universities and liberal arts colleges; only 13 percent were enrolled in junior colleges. (See text table 4-1.)

Expansion of Institutions

These underlying characteristics of U.S. higher education have persisted during the past 50 years, with expansion occurring through the establishment of many new institutions and the increasing size of universities. In 1953, the largest universities enrolled approximately 10,000 students. By 1996, the largest U.S. universities enrolled between 25,000 and 50,000 students (HEP 1996). Enrollment has surged within research and comprehensive universities. A number of teachers' colleges expanded their offerings and became comprehensive and doctoral institutions. While the number of universities has doubled since the 1950s, the number of two-

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[2] See chapter 1.

Text table 4-1.
U.S. institutions of higher education, by type and enrollment level: 1953

Type	Number	Enrollment
Total	1,871	2,534,709
Universities	131	1,154,719
Liberal arts colleges	713	636,479
Teachers' colleges	200	208,573
Technological schools	53	114,077
Theological schools	115	31,205
Other professional	138	61,986
Junior colleges	498	339,867

SOURCE: U.S. Department of Health, Education, and Welfare (HEW), *Statistics of Higher Education: Faculty, Students, and Degrees 1953–54* (Washington, DC: U.S. Government Printing Office, 1956).

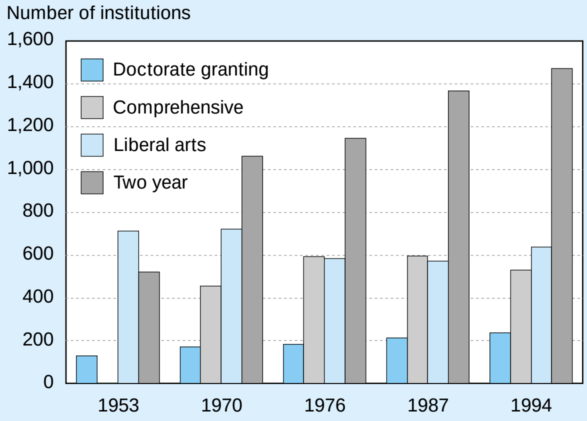
Science & Engineering Indicators – 2000

year institutions has tripled—from 521 in 1953 to 1,569 in 1996 (HEP 1996). (See figure 4-1.)

Alongside the growth of large institutions in U.S. higher education, liberal arts institutions have remained relatively small. In 1953, liberal arts colleges enrolled approximately 0.6 million students in 713 institutions. By 1996, 1.1 million students were enrolled in approximately 637 such undergraduate colleges (reflecting an average enrollment of less than 2,000 students).

Today's large and diversified set of institutions provides an education at the bachelor's level to approximately one-third of the U.S. college-age population. (See “Undergraduate S&E Students and Degrees in the United States.”) Access to U.S. higher education is still among the highest in the world, although other countries are also broadening access and expanding graduate programs, particularly in S&E. (See “International Comparison of First University Degrees in S&E,” “International Comparison of Doctoral Degrees in S&E,” and sidebar, “Graduate Reforms in Europe, Asia, and Latin America.”)

Figure 4-1.
Number of institutions of higher education, by type: 1953–94



NOTES: Universities were not categorized as "comprehensive" in 1953; 1953 data on institutional categories are not strictly comparable with the later data, which are based on the Carnegie Classification of Education. A number of comprehensive universities became doctorate-granting institutions between 1987 and 1994.

See appendix table 4-1. *Science & Engineering Indicators – 2000*

In the United States, there were 3,660 (1,580 public and 2,080 private) two- and four-year institutions of higher education in 1996 (HEP 1996). These institutions enrolled 14.5 million students at all degree levels in that year and awarded 2.2 million degrees, one-quarter of which were in S&E. (See figure 4-2.)

More than 5 million of the 14.5 million students are enrolled in community colleges. These institutions increase the openness of U.S. higher education; through considerable remedial coursework, they provide a second chance for students who were not well served by, or well motivated during, their high school education. They also foster movement into four-year institutions through arrangements that allow students to transfer their credits from community colleges to four-year colleges and universities.

To better describe this diverse set of institutions serving a variety of needs, the Carnegie Foundation for the Advancement of Teaching has clustered institutions with similar programs and purposes. (See sidebar, “Carnegie Classification of Institutions.”)

Long-Term Trends in Enrollment in U.S. Higher Education

The four-decade expansion in enrollment in U.S. higher education reached its peak in 1992, when more than 14.6 million students were enrolled, and then leveled off. This expansion first accelerated in the late 1940s and early 1950s; by 1950, higher education enrollment had surged to 2.7 million students (up from 1.2 million in 1944) as a result of the post-World War II influx of veterans supported under the GI Bill (U.S. HEW 1956).[3] After the influx of returning veterans subsided, the number of (nonveteran) college students grew steadily for several decades, from the 1960s to the early 1990s, reaching a peak of more than 14.6 million students in 1992. Following more than four decades of such growth in higher education, graduate enrollment began a slight decline in 1993; undergraduate enrollment began declining in 1995. (See “Undergraduate S&E Students and Degrees in the United States” and “Graduate S&E Students and Degrees in the United States.”)

From 1967 to 1992, enrollment in U.S. institutions of higher education expanded an average of 3 percent annually, but growth rates differed greatly by type of institution. For example, two-year colleges grew at twice this rate and accounted

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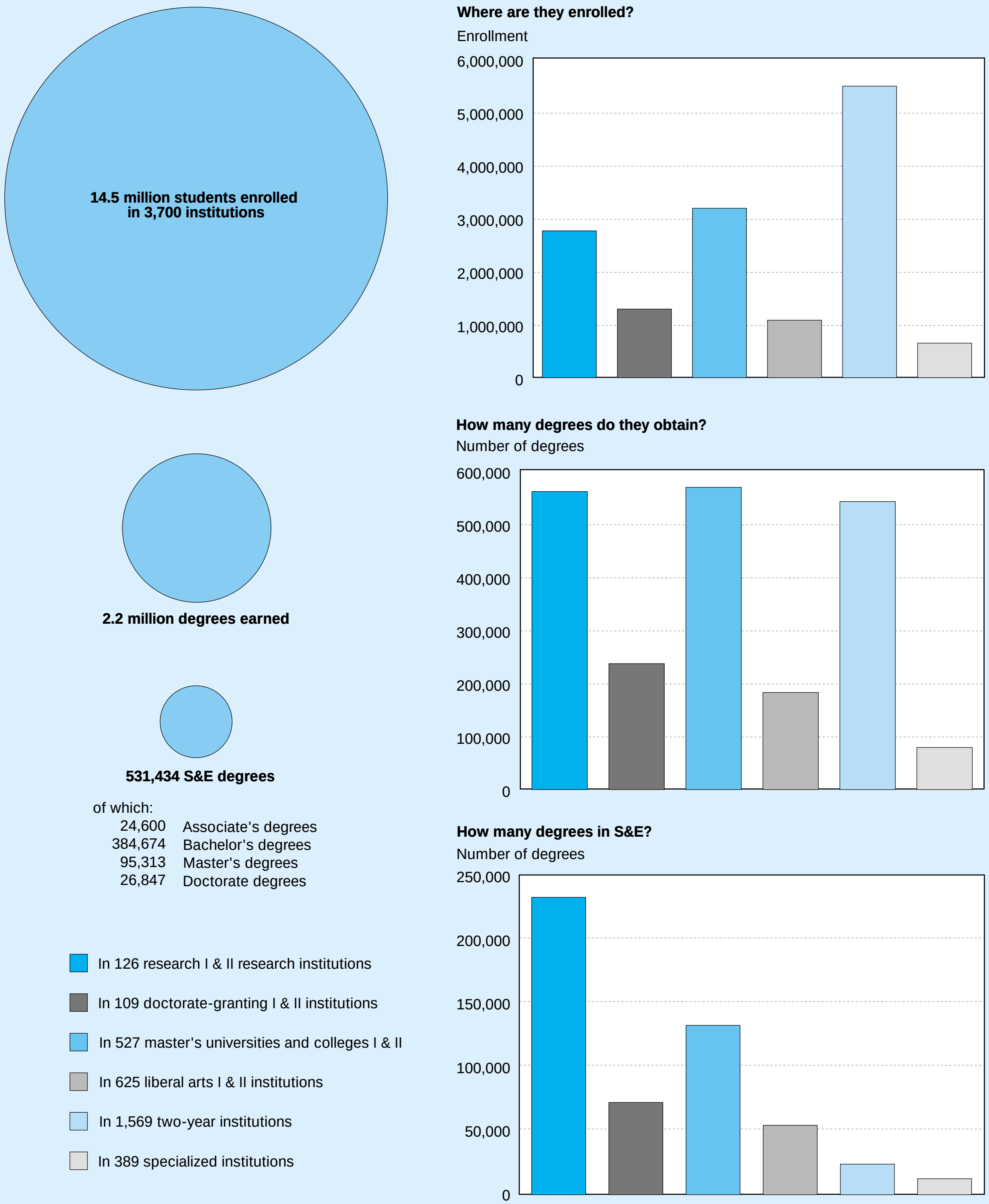
[3] In that year, 1950, veterans represented 35 percent of the students in higher education.

Figure 4-2.
U.S. higher education in 1996: students, institutions, and degrees at all levels



NOTE: The 355 institutions classified as "other" are not included.

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

Science & Engineering Indicators – 2000

Carnegie Classification of Institutions

Carnegie has classified higher education institutions into 10 categories based on the size of their baccalaureate and graduate degree programs, the amount of research funding they receive, and—for baccalaureate colleges—their selectivity.* Following is a brief description of these categories.

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

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*The Carnegie classification is not an assessment guide, nor are the distinctions between classification sublevels (for example, research I and research II) based on institutions' educational quality. Baccalaureate college I institutions exercise more selectivity regarding students than do baccalaureate colleges II, but in general the Carnegie categories are a typology, not a rank ordering.

for the largest share of the growth—from 0.2 million students in 1950 to 5.5 million students in 1996. (See appendix table 4-2 and U.S. HEW 1956.) In 1950, two-year college enrollment was 9 percent of overall higher education enrollment. By 1996, enrollment in two-year colleges was 38 percent of higher education's total enrollment. In contrast, student enrollment in research I universities grew more modestly, from 1.5 million students in 1967 to 2.1 million in 1991 (with slight declines since then).[4] 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 4-3 and appendix table 4-2.)

S&E Degree Production by Type of Institution

A diverse spectrum of institutions provides for relatively high access to higher education in the United States, but the research-intensive universities produce the majority of engineering degrees and a large proportion of natural and social science degrees at both the graduate and undergraduate levels. (See figures 4-4 and 4-5.) In 1996, the country's 126 research universities awarded more than 42 percent of all S&E degrees at the bachelor's level and 52 percent of all S&E degrees at the master's level. (See appendix table 4-3.) In addi-

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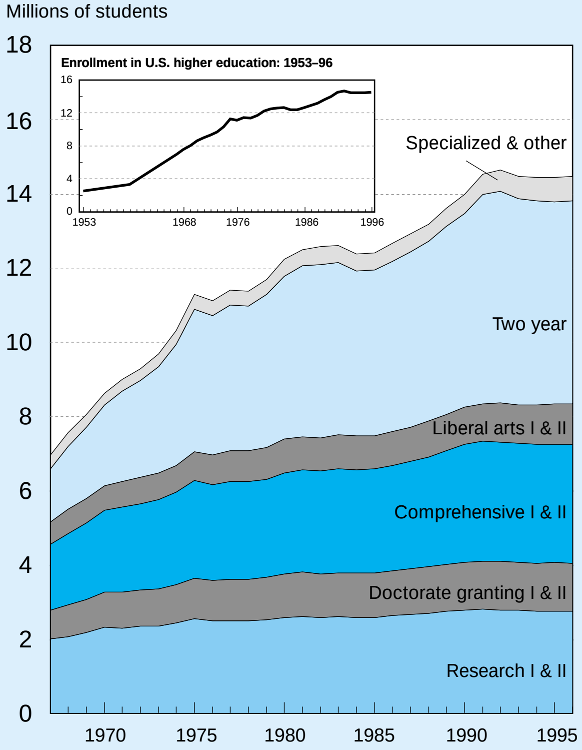
[4] Research institutions, however, account for significant numbers of S&E degrees; two-year colleges do not. (See figure 4-2 and "S&E Degree Production by Type of Institution.")

Figure 4-3.
Enrollment in U.S. higher education, by institution type: 1967–96



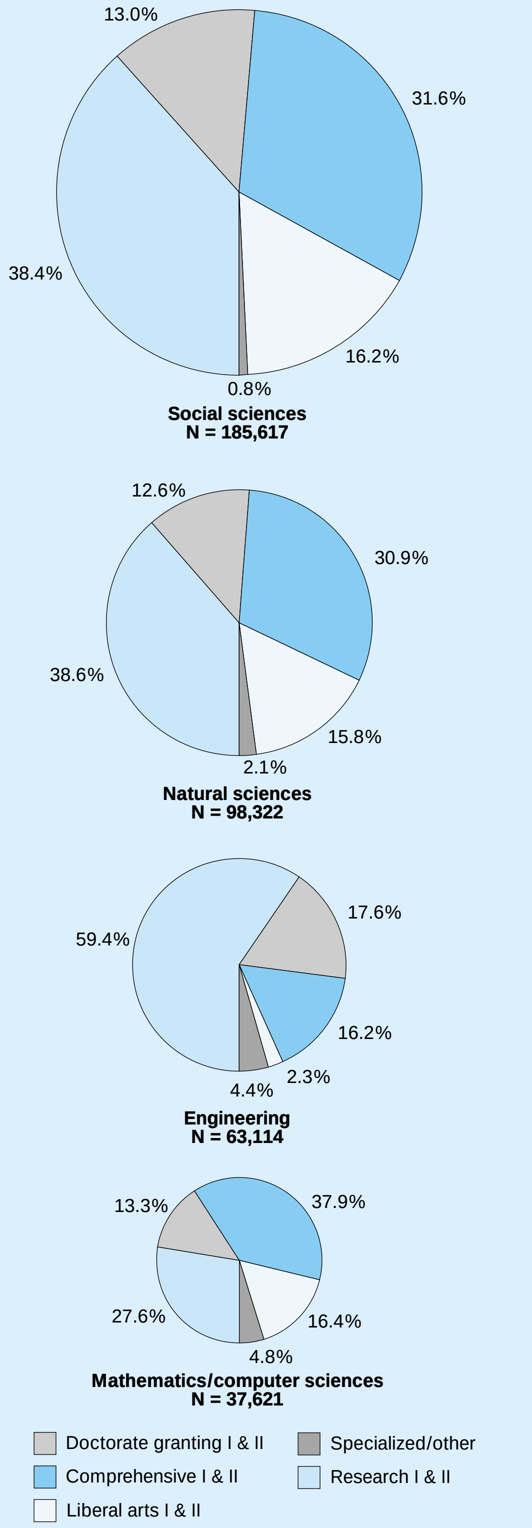
See text table 4-1 and appendix table 4-2.

Science & Engineering Indicators – 2000

tion, comprehensive and liberal arts I institutions produce significant numbers of bachelor's and master's degrees in science and engineering. (See appendix table 4-3.)

The proportion of S&E degrees earned by institution type in U.S. higher education, however, is not homogeneous for all groups. In contrast to the overall student population, S&E degrees earned by underrepresented minorities are less concentrated in research universities; minority-serving institutions still play a significant role in minorities' S&E education. These students earn a far smaller percentage of their bachelor-level degrees in the natural and social sciences at research universities, compared with their engineering degrees and with the percentage of such degrees earned by the overall student population. Over the past 20 years, underrepresented minority students have earned higher percentages of their degrees within research universities in social science and engineering fields, but not in natural science fields. By 1996, underrepresented minority students earned 44 percent of their bachelor-level engineering degrees at research universities, up from 32 percent in 1977. (See appendix table 4-5.) However, the relatively small percentages of degrees earned by underrepresented minority students within research universities have remained stable over the past 20 years. (See appendix table 4-5 and text table 4-2.)

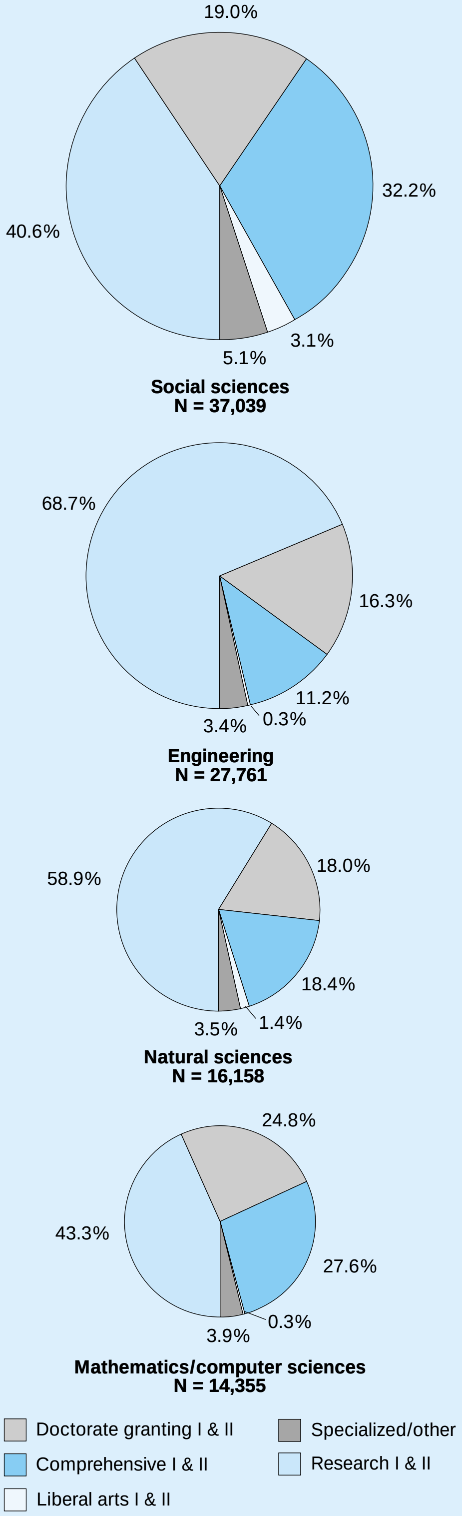
Figure 4-4.
Bachelor's degrees awarded in S&E, by institution type: 1996



NOTES: Natural sciences include physical, earth, atmospheric, oceanographic, biological, and agricultural sciences. Social sciences include psychology, sociology, and other social sciences.

See appendix table 4-3. *Science & Engineering Indicators – 2000*

Figure 4-5.
Master's degrees awarded in S&E, by institution type: 1996



NOTES: Natural sciences include physical, earth, atmospheric, oceanographic, biological, and agricultural sciences. Social sciences include psychology, sociology, and other social sciences.

See appendix table 4-3. *Science & Engineering Indicators – 2000*

Text table 4-2.
Percentage of S&E bachelor's degrees earned by underrepresented minorities within research universities: 1996

Field	Total student population	Underrepresented minorities
Total S&E	42	31
Natural sciences	39	25
Social sciences	38	32
Engineering	60	44

See appendix tables 4-3 and 4-5.

Science & Engineering Indicators – 2000

Black students have traditionally earned a large percentage of their S&E degrees within historically black colleges and universities (HBCUs)—mainly comprehensive universities and liberal arts colleges. HBCUs, originally established during the period of legalized segregation for the purpose of educating blacks, continue to produce large percentages of the S&E bachelor-level degrees earned by black students. These comprehensive universities and liberal arts colleges produce 30 percent of their engineering degrees, 44 percent of their natural science degrees, and 25 percent of their social science degrees. These percentages have remained relatively stable for the past 20 years. (See appendix table 4-5 and NSF 1999c.)

The associate of arts colleges, which enroll more than 5 million students, account for only a small percentage of S&E degrees. These two-year colleges, however, provide continuing education and flexibility in the U.S. higher education system, allowing students to complete required work-related courses or obtain coursework credits for transfer to a four-year college or university. An analysis of undergraduate careers in engineering in 1995 showed that one out of six students who received a bachelor's degree in engineering, engineering technology, or architecture started in a community college (USDE 1998).

Baccalaureate Origins of Ph.D.s

The 126 research universities provide the baccalaureate education of the majority (56 percent) of S&E doctoral recipients. However, liberal arts colleges and comprehensive universities also contribute a significant proportion of bachelor-level degrees among students who later complete doctoral S&E degrees. Each of these institution types provides 15 percent of the baccalaureate education of doctoral recipients; within individual fields they are even more prominent. For example, 23 percent of the students earning doctorates in chemistry received their undergraduate education within a liberal arts college, and an additional 23 percent received their undergraduate education within a comprehensive university. (See appendix table 4-6.)

Demographics and U.S. Higher Education

The U.S. college-age population has declined by more than 21 percent in the past two decades, from 21.6 million in 1980 to 17.0 million in the year 2000. This demographic decline is reflected in the trends presented in this chapter, including the declining number of bachelor's degrees in several fields of NS&E beginning in the late 1980s. (See figure 4-6.) This 20-year population decline of the college-age cohort reverses itself in the year 2000, and increases to 19.3 million by the year 2010. (See appendix table 4-7.) The increase in the college-age population by more than 13 percent in the first decade of the 21st century portends another wave of expansion in U.S. higher education—and growth in S&E degrees at all levels.

Undergraduate S&E Students and Degrees in the United States

Characteristics of American College Freshmen

Intentions to Major in S&E

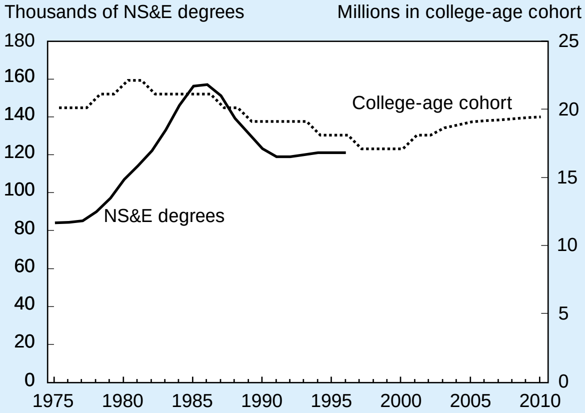
The issue of whether women and minorities are attracted to S&E majors is of national interest because they now make up the majority of the labor force. Their successful completion of S&E degrees will determine the adequacy of entrants into the S&E workforce in the United States. This section reports on two longitudinal surveys of student intentions to major in S&E, by race, ethnicity, and sex. (See "Bachelor's Degrees," "Trends in Earned S&E Degrees.") The Higher Education Research Institute's (HERI) Freshman Norms Survey annually surveys a nationally representative sample of first-year students in four-year colleges and universities about their intention to major in any S&E field (HERI 1998). The National Education Longitudinal Study of 1988 (NELS:88 unpublished tabulations) tracked a large, nationally representative sample of eighth graders and identified in a follow-up survey those who were enrolled in undergraduate S&E programs (NCES 1998b).

The Freshman Norms data show that, by 1998, 47 percent of the first-year college students reporting intentions to major in S&E were women; 53 percent were men (HERI 1998). These data also show increasing racial diversity among students choosing an S&E major. By 1998, underrepresented minority groups represented 19 percent of those intending an S&E major,[5] up from 8 percent in 1971. The trend is toward an increased percentage of black and Hispanic freshmen intending a natural science or engineering major. (See appendix table 4-9.) For example, from 1986 to 1998, the proportion of underrepresented minorities intending to major in the biological sciences rose from 10 percent of first-year college students to 18 percent.[6] (See appendix table 4-9.)

NELS:88 corroborated the findings of the Freshman Norms Survey and showed little difference between racial and ethnic groups with regard to choosing an S&E major. NELS:88 followed students from eighth grade through high school, college, and entry into the labor force. Students who reported being enrolled in an S&E program (generally as sophomores in college) were examined to identify differences by race and sex. Between 9 and 10 percent of all racial/ethnic groups of this cohort were enrolled in S&E programs in 1994. In contrast, the study found a significant difference in the percentage of males and females enrolled in S&E programs: 12 percent of males were enrolled in such programs, whereas only 7 percent of females were enrolled in S&E fields. The gap between males and females is particularly pronounced among (or attributable mainly to) the gaps among white and Asian/Pacific Islander students; among black and Hispanic students, women are essentially on par with men. (See figure 4-7.)

Of the relatively small percentage of students who enroll as S&E majors, less than one-half complete an S&E degree within 5 years. (See "Diversity Patterns in S&E Enrollment and Degrees in the United States.") Although there may be many reasons for this, the disparity between the percentage of students who aspire to study S&E fields and the percentage who complete an undergraduate S&E degree reflects, in part, the lack of readiness of U.S. students for college-level S&E coursework.

Figure 4-6.
Trends in U.S. college-age cohort and bachelor's degrees in selected NS&E fields: 1975–2010



NOTES: NS&E = natural science and engineering. College-age cohort = the 20–24-year-old population. Selected natural sciences include physical, earth, atmospheric, and oceanographic sciences, mathematics, and computer sciences.

See appendix tables 4-7 and 4-17, and National Science Foundation, Science Resources Studies Division, *Science and Engineering Degrees: 1966–96,* NSF 99-330, Author, Susan T. Hill (Arlington, VA, 1999).

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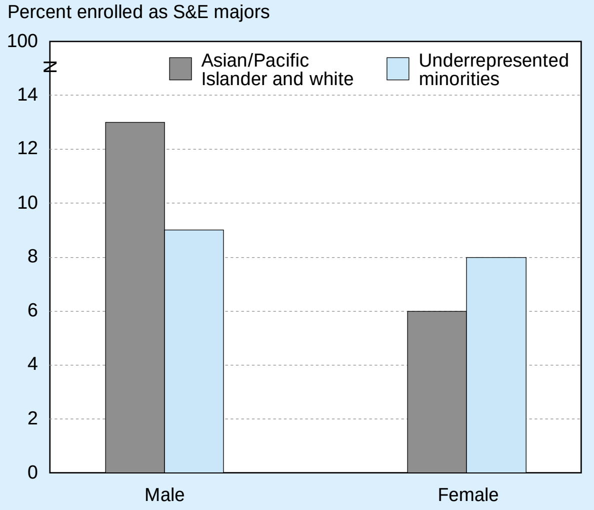
[5] In 1996, white students constituted 67 percent of the 18-year-old population in the United States; underrepresented minority groups constituted 29 percent (U.S. Department of Commerce, Bureau of the Census 1998).

[6] 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) and HBCUs. (See "S&E Degree Production by Type of Institution.")

Figure 4-7.
Enrollment in college as S&E majors, by race/ethnicity and sex



NOTE: 1988 eighth graders who later enrolled in college as S&E majors.

SOURCE: National Center for Education Statistics (NCES), National Education Longitudinal Study (NELS:88), unpublished tabulations.

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Quality of High School Graduates

Are U.S. freshmen ready for college-level coursework? Data from national longitudinal studies (HERI 1998; NELS:88 unpublished tabulations) and the 1994 High School Transcript Study (NCES 1997) provide some indicators of readiness: the increasing number of mathematics and science courses taken, the relatively low level of 12th-grade proficiency in science and mathematics, and the continuing need for remedial work in college.

Trend data from 1971 to 1998 on the number of high school mathematics and science courses that students have taken show that an increasing percentage of entering first-year college students have taken four years of high school mathematics and two to three years of science coursework (HERI 1998). These percentage increases have occurred across all racial groups, though they are somewhat lower among some minority groups. In 1998, between 64 and 75 percent of different subpopulations of entering first-year college students reported that they had completed four years of high school mathematics—a considerable increase from the figures reported in the previous decade. In 1984, between 37 and 65 percent of entering first-year college students reported having four years of high school math. In addition, first-year college students reported an increasing amount of high school coursework in the biological sciences. (See appendix table 4-10.) This increase in mathematics and science courses is corroborated in the 1994 High School Transcript Study, which showed that, from 1982 to 1994, rising percentages of male and female high school graduates had taken various mathematics and science courses. (See text table 4-3.)

Despite the additional mathematics and science coursetaking in high school, a relatively small percentage of 12th graders demonstrate a high level of proficiency in mathematics and science.[7] NELS:88 tracked a representative

Text table 4-3.
Percentage of high school graduates who report having taken mathematics and science courses, by sex: various years

Course	Total				Male				Female			
	1982	1987	1990	1994	1982	1987	1990	1994	1982	1987	1990	1994
Mathematics												
Algebra I	53.9	64.0	64.2	66.4	52.2	62.3	61.7	64.7	55.4	65.7	66.5	68.1
Geometry	45.5	59.7	63.4	70.4	45.0	58.8	62.4	68.3	45.9	60.4	64.4	72.4
Algebra II	32.2	48.1	51.7	58.6	32.4	47.3	50.0	55.4	32.0	48.9	53.3	61.6
Trigonometry	12.1	18.6	18.2	17.2	13.2	19.5	18.1	16.6	11.1	17.6	18.2	17.8
Analysis/precalculus	5.9	12.6	13.4	17.3	6.2	13.5	14.0	16.3	5.6	11.6	12.8	18.2
Calculus	4.6	6.0	6.5	9.2	5.1	7.4	7.5	9.4	4.1	4.6	5.6	9.1
Science												
Biology	76.4	87.8	91.3	93.5	74.2	86.3	90.0	92.3	78.4	89.4	92.5	94.7
Chemistry	30.9	43.7	49.0	56.0	31.9	44.3	47.9	63.2	30.0	43.2	50.0	58.7
Physics	14.2	19.2	21.5	24.4	18.8	24.0	25.4	26.9	10.0	14.6	18.0	22.0
Biology and chemistry	28.1	42.1	47.6	53.8	28.2	42.2	46.4	50.9	28.0	42.0	48.8	56.6
Biology, chemistry, and physics	10.6	16.4	18.8	21.3	13.4	20.1	21.8	23.1	7.9	12.8	16.1	19.6

SOURCE: National Center for Education Statistics (NCES), *The Condition of Education 1997* (Washington DC: 1997). (Data are based on the 1994 High School Transcript Study Tabulations.)

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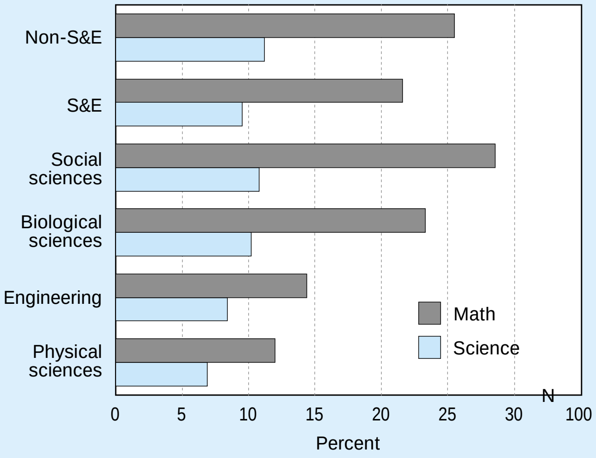
[7] The Third International Mathematics and Science Study shows similar findings. U.S. 12th graders scored below the international average and among the lowest of the 21 participating nations in both mathematics and science general knowledge.

sample of 25,000 students from eighth grade through high school, college, and entry into the labor force. This study included assessment of students' high school course-taking behavior and their mathematics and science proficiency. Analysis of the NELS data shows that in 1992 only about 37 percent of white and Asian/Pacific Islander students reached a high level of proficiency (level 4 or 5) in mathematics; an even smaller percentage of underrepresented minority students achieved this high proficiency (14 percent). In the sciences, only 25 percent of white and Asian/Pacific Islander students reached a high level (level 3) of proficiency in this exam, and even lower percentages of underrepresented minority students (8 percent) reached this level. (See appendix table 4-11.) This low level of science proficiency is also reflected in science literacy data collected with the National Science Foundation's (NSF) survey of public attitudes toward and understanding of science and technology (S&T) (see chapter 8).

Low mathematics and science proficiency is also evident among entering first-year college students. In 1997, 22 percent of first-year college students who intended an S&E major reported that they needed remedial work in mathematics; 10 percent reported they needed remedial work in the sciences. The percentages of students who need remedial work in mathematics and science have remained high over the past 20 years, with some differences by field of intended major. (See appendix table 4-12.) Students intending to major in the physical sciences and engineering report less need for remedial work. In contrast, students intending to major in the social and biological sciences, as well as in non-S&E fields, report more need for remedial work. (See figure 4-8 and appendix table 4-12.)

Figure 4-8.
Freshmen reporting need for remedial work in science or math, by intended major: 1997



See appendix table 4-12. *Science & Engineering Indicators – 2000*

Readiness for College-Level Mathematics

The American Mathematical Society's (AMS) surveys of mathematics courses (five-year incremental studies from 1970 to 1995) show an increasing percentage of remedial mathematics courses at two- and four-year colleges and a decreasing percentage of advanced-level course work at four-year institutions (NSB 1998). In the past decade, fewer students majored in mathematics (see "Bachelor's Degrees"), and universities decreased advanced-level coursework in mathematics. The forthcoming AMS survey of mathematics courses in the year 2000 should be monitored to see whether enrollment in remedial mathematics in four-year institutions continues to remain around 15 percent, or whether it decreases. (See text table 4-4.)

Engineering Enrollment

In contrast to intentions to major in S&E provided above, the annual fall survey of the Engineering Workforce Commission (EWC) obtains data on actual enrollment in graduate and undergraduate programs. Engineering programs generally require students to declare their major as first-year students, allowing enrollment to be used as an early indicator of undergraduate engineering degrees and interest in engineering careers.

The overall trend has been fewer students entering engineering (reflecting demographic declines in the college-age population), with a slight upturn in 1997 and 1998 (EWC 1999). At the undergraduate level, the EWC data show a declining trend in enrollment, from a high point of 441,200 students in 1983 to 356,000 students in 1996 (a 19-percent reduction). (See appendix table 4-13.) The decline was neither smooth nor continuous. Engineering enrollment stabilized for several years (1989–92) before resuming its declining trend until 1996. This declining trend turned around slightly in 1997 and 1998, with a 1.5-percent annual increase in undergraduate engineering enrollment. Trends in graduate engineering enrollment differ: graduate enrollment increased from 1979 to 1992 and then declined each year. (See figure 4-9.)

Associate's Degrees

The characteristics of the community college—flexibility, accessibility, links with industry, remediation, and low cost—contribute to its broad appeal. Many students who enroll in two-year colleges are seeking certificates or associate's degrees, but some find two-year colleges an inexpensive means of completing the first two years of a college education before transferring to a four-year institution. About 22 percent of 1989/90 beginning postsecondary students who began at two-year institutions transferred to four-year institutions[8] (NCES 1998a), thereby increasing access to higher levels of education. The majority of community colleges have links with industry; two-year engineering technology programs generally have cooperative programs with industry to train workers (Burton and Celebuski 1995). One-half of commu-

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[8] The source of these data is the U.S. Department of Education's Beginning Postsecondary Students Survey, reported in NCES (1998a).

Text table 4-4.
Estimated enrollment in undergraduate mathematics courses

	Four-year institutions					Two-year institutions				
Course level	1970	1980	1985	1990	1995	1970	1980	1985	1990	1995
Enrollment (in thousands)										
All math courses	1,188	1,525	1,619	1,619	1,469	555	925	900	1,241	1,384
Remedial	101	242	251	261	222	191	441	482	724	800
Precalculus	538	602	593	592	613	134	180	188	245	295
Calculus	414	590	637	647	538	59	86	97	128	129
Advanced	135	91	138	119	96	0	0	0	0	0
Other	NA	NA	NA	NA	NA	171	218	133	144	160
Percent										
All math courses	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Remedial	0.09	0.16	0.16	0.16	0.15	0.34	0.48	0.54	0.58	0.58
Precalculus	0.45	0.39	0.37	0.37	0.42	0.24	0.19	0.21	0.20	0.21
Calculus	0.35	0.39	0.39	0.40	0.37	0.11	0.09	0.11	0.10	0.09
Advanced	0.11	0.06	0.09	0.07	0.07	0.00	0.00	0.00	0.00	0.00
Other	NA	NA	NA	NA	NA	0.31	0.24	0.15	0.12	0.12

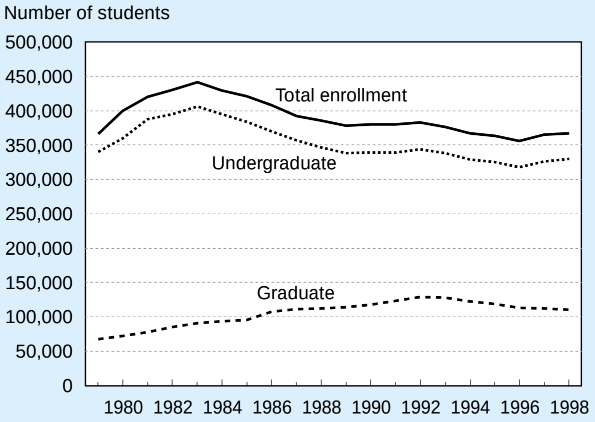
NA = not applicable

NOTE: Precalculus-level mathematics courses include algebra and trigonometry courses, as well as courses for nonscience majors, finite mathematics, non-calculus-based business mathematics, and mathematics for prospective elementary school teachers.

SOURCE: D.C. Rung, "A Survey of Four-Year and University Mathematics in Fall 1995: A Hiatus in Both Enrollment and Faculty Increases," *Notices of the AMS* 44, no. 8 (September 1997): 923–31.

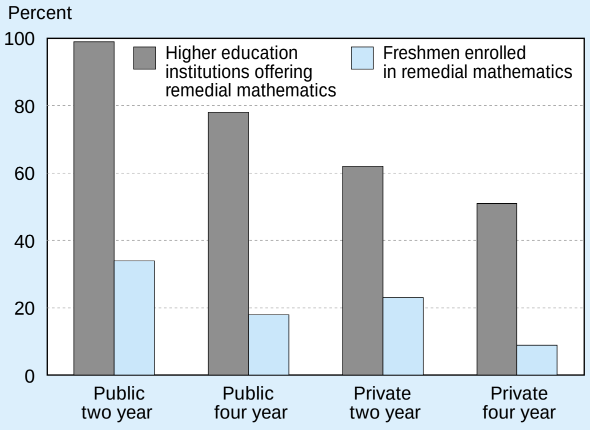
Science & Engineering Indicators – 2000

Figure 4-9.
Engineering enrollment, by level: 1979–98



See appendix table 4-14. *Science & Engineering Indicators – 2000*

Figure 4-10.
Course offerings in remedial mathematics, by type of institution: 1995



See appendix table 4-15. *Science & Engineering Indicators – 2000*

nity college students are enrolled on a part-time basis. Almost all public two-year institutions provide remedial coursework, and approximately one-third of the students in these institutions are enrolled in remedial mathematics courses. (See figure 4-10.)

Since 1990, student enrollment has leveled off in all institution types that produce large numbers of S&E degrees. In contrast, over the past several decades, student enrollment in U.S. higher education institutions has increased most in two-year colleges. These institutions produce relatively few degrees, however. In 1996, 38 percent of the 15 million students in U.S. higher education were enrolled in two-year colleges, but they earned only 500,000 associate's degrees. Among beginning students at two-year colleges in the 1989/90 school year, only 24 percent had earned an associate's or higher degree by 1994 (NCES 1998a). This large disparity between the number of students enrolled and earned degrees implies high attrition rates but also highlights one of the characteristics of community colleges—a large amount of coursetaking for specific skills not necessarily leading to an associate's degree. Part of this lack of persistence in completing an associate's degree is intentional; full-time students, as well as part-time, older, and night school students, may take a sequence of courses for specific skills to enter or change positions in the labor force. For a variety of other reasons, students can earn credentials below the level of associate's degree.

Among those who do earn associate-level degrees, relatively few (11 percent) earn them in S&E or engineering technology fields. In 1986–96, the number of associate's degrees in S&E fields has been modest and quite stable, ranging between 20,000 and 25,000 degrees out of approximately 450,000 to 540,000 total degrees. (See appendix table 4-16.) More numerous, however, are degrees earned in engineering technology programs (approximately 36,000 in 1996). Such engineering technology programs are mainly focused on electronics, computer technology, graphics, and mechanical engineering. (See Burton and Celebuski 1995.)

Although associate's degrees in engineering technology have been declining for about a decade—reaching a low of 36,000 in 1996 (Burton and Celebuski 1995)—enrollment in these programs is far higher than completed degrees would indicate. A survey of technical education in two-year colleges showed that course enrollment was about seven times higher than completed degrees (Burton and Celebuski 1995). The study also showed linkages with local industry that allow enrollees to acquire useful skills and familiarity with science, mathematics, engineering, and technology and join the industrial workforce without completing an associate's degree. Because of the importance of two-year colleges in preparing workers for high-technology employment, more needs to be known about the quality of education being provided and the attrition rates of their students.

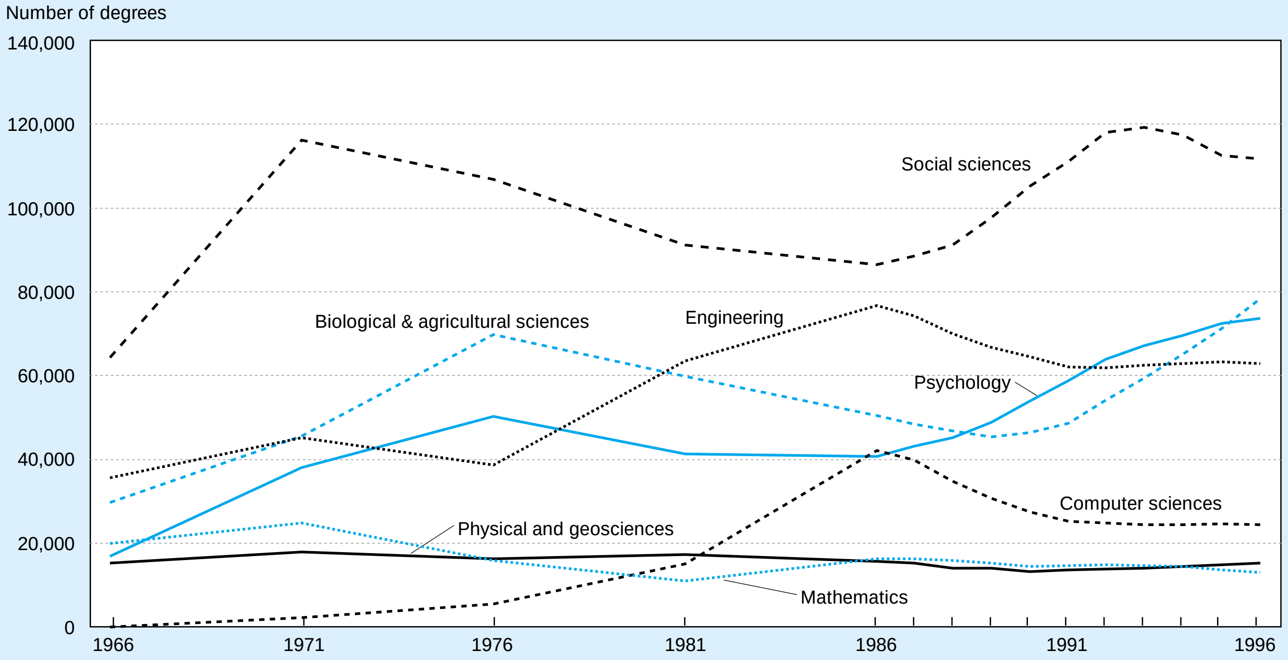
Bachelor's Degrees

Trends in Earned S&E Degrees

Since the 1950s, trends in total S&E degrees earned show continual upward growth, although several fields of NS&E show a declining number of degrees in the 1990s. (See figure 4-11.) The growth occurred in two waves: the first in the 1950s and 1960s and the second in the 1990s (U.S. HEW 1956). The first growth period was the strongest; the number of degrees in S&E fields increased at an average annual rate of eight percent. Then, during the decades of the 1970s and 1980s, the total overall degrees earned fluctuated and increased at an average annual rate of less than 1 percent, followed by a second and milder growth period in the 1990s. S&E degrees at the bachelor's level increased at an average annual rate of 2.6 percent from 1990 to 1996. (See appendix table 4-17.)

The increase seen in overall S&E degrees in the past four decades actually represents divergent trends in various fields.

Figure 4-11.
Bachelor's degrees earned in selected S&E fields: 1966–96



NOTE: Data are in five-year increments for 1966–86, and one-year increments for 1986–96. Geosciences include earth, atmospheric, and oceanographic sciences.

See appendix table 4-17.

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Different fields contributed to the expansion of S&E degrees at different time periods, and several fields show a declining number of degrees in the 1990s. The number of degrees in the physical and mathematical sciences peaked in the early 1970s, slowly declined in the 1980s, and then leveled off in the 1990s. In contrast, engineering and computer science degrees peaked in the mid-1980s, quickly declined, and leveled off in the 1990s. Trends in the biological sciences showed a long, slow decline in earned degrees in the 1980s but a reversal of this trend in the 1990s. The only fields with an increasing number of earned degrees in the 1990s are psychology and the biological sciences.

Curriculum Reform in Undergraduate Education

The Steelman report's concern for improving the quality of undergraduate education has been of recurring national interest and has gained momentum in the past 10 years. Individual faculty, departments, professional societies, and institutions of higher education are increasingly involved in reform to enhance undergraduate teaching and the curriculum in mathematics, the various fields of sciences, engineering, and technology. Since 1992, faculties from 700 institutions of higher education have participated in one or more workshops to strengthen student interest and success in mathematics and science (Project Kaleidoscope 1999). Reforms include, for example, infusing more investigative learning into the curricula, using innovative computer laboratories and learning technologies, increasing undergraduate research experiences, and encouraging interdisciplinary collaboration in team teaching.

Reforms are directed at both science and nonscience majors. Improved introductory and advanced courses that attract and retain science majors seek both to augment the S&E workforce needed in the U.S. economy and to prepare adequate numbers of students for advanced study. Designing successful introductory courses is also aimed at strengthening the understanding of the processes and methods of science for all college students. This broader attention to curricular reform in mathematics and science courses for all students is essential for improving future K–12 teachers, public understanding of scientific issues, and citizen participation in an increasingly technological society. (See sidebar, "Institution-Wide Reform.")

Institution-Wide Reform

Since curricular changes and facility improvements occur slowly without departmental and institutional backing, a major theme of undergraduate education reform in S&E courses is the so-called institution-wide reform. The aim of institution-wide reform is to revitalize undergraduate education on a more comprehensive, self-sustaining, and interdisciplinary basis. Recently initiated assessments of these initiatives will attempt to develop quantitative indicators on faculty, students, and institutions (Ruskus 1999). For example, faculty assessment will include the proportion of S&E faculty revising their curricula for best practices in teaching, collaborating with other faculty in developing courses, and publishing research on improved teaching and learning. Student outcomes will include the proportion of students completing S&E courses that reflect best practices, enrollment in follow-on courses, completion rates for S&E majors, and an undergraduate research experience or internship.

International Comparison of First University Degrees in S&E

Diffusion of Higher Education in S&E Fields

The worldwide expansion in advanced S&E education capabilities is particularly evident in Europe, Asia, and the Americas.[9] One indicator of this diffusion of S&E education capacity is the rapidly increasing number of students completing university degrees in S&E. (See appendix table 4-18 and NSB 1998.) Another indicator is the expansion of doctoral programs in S&E and graduate education reforms to improve the quality of research and build national innovation capacity. (See "International Comparison of Doctoral Degrees in S&E.[10])

In 1997, more than 2.7 million students worldwide earned a first university degree[11] in science or engineering. (Note that the worldwide total includes only countries for which recent data are available, primarily in the Asian, European, and American regions, and is therefore an underestimation.) These 2.7 million degrees are evenly balanced among the broad S&E fields: about 900,000 students earned degrees in each of the broad fields of natural sciences,[12] social sciences, and engineering. (See appendix table 4-18.)

From among reporting countries, more than 1 million of the 2.7 million S&E degrees were earned by Asian students within Asian universities. Students across Europe (including Eastern Europe and Russia) earned more than three-quarters of a million first university degrees in S&E. And students in the North American region earned one-half million bachelor-level degrees. These three regions, Asia, Europe, and North

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[9] Data in this section are primarily taken from the National Science Foundation, Science Resources Studies Division, *Global Database on Human Resources for Science,* and are based on national and international sources. (See appendix table 4-18.)

[10] For other indicators of the development of science and technology infrastructure in several world regions, see other chapters in this volume on research and development (chapter 2), bibliometrics (chapter 6), and patents and high-technology trade (chapter 7).

[11] A first university degree refers to completion of an undergraduate degree program. These degrees are classified as level 6 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.

[12] The natural sciences comprise the physical, earth, atmospheric, oceanographic, biological, and agricultural sciences; mathematics; and computer sciences.

America, account for the large majority (88 percent) of reported S&E bachelor's degrees earned worldwide. Students in Asia and Europe earn more first university degrees in engineering than in natural sciences and generally more in natural sciences than in social sciences, whereas in North America earned degrees show the reverse. (See figure 4-12 and appendix table 4-18.)

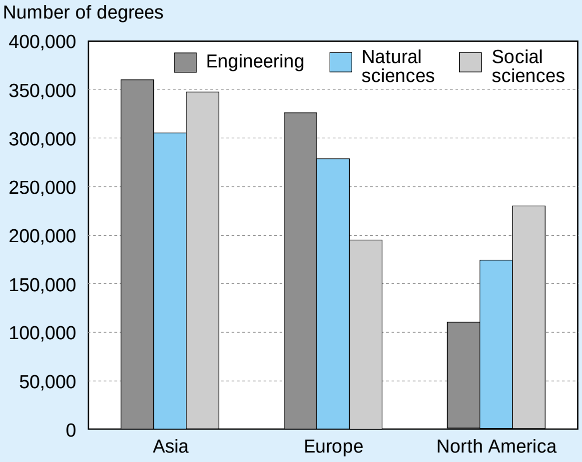
Growth Rates in S&E Fields

The higher growth rate in NS&E degrees in Asia and Europe than in North America has been reported earlier (NSB 1998; NSF 1993; NSF 1996a). For example, in the past decade, the average annual growth rate in earned NS&E degrees in the Asian and European regions was more than 4 percent. In contrast, in the North American region the number of NS&E degrees declined at an average annual rate of 0.9 percent during this same time period.

Trends in Asia

Recent changes in higher education in these regions, however, are less well known. These changes include a leveling off of bachelor-level S&E degrees and a shift in emphasis to doctoral S&E training. (See figures 4-13 and 4-14.) Bachelor-level engineering degrees peaked in Asia in 1995 at 324,500 and declined slightly in 1996. Similarly, natural science degrees peaked at 191,500 in 1995 and dropped slightly in 1996. (See "International Comparison of Doctoral Degrees in S&E" and sidebar, "Graduate Reforms in Europe, Asia, and Latin America.") Bachelor's degrees will again begin to increase around 2003–04, from the large expansion of undergraduate enrollment in China in 1999 (Plafker 1999).

Figure 4-12.
First university degrees in S&E in selected countries, by region: 1997 or most recent year



NOTES: Natural sciences include physical, biological, agricultural, earth, atmospheric, and oceanographic sciences, mathematics, and computer sciences. Social sciences include psychology, sociology and other social sciences.

See appendix table 4-18 for countries included within each region.

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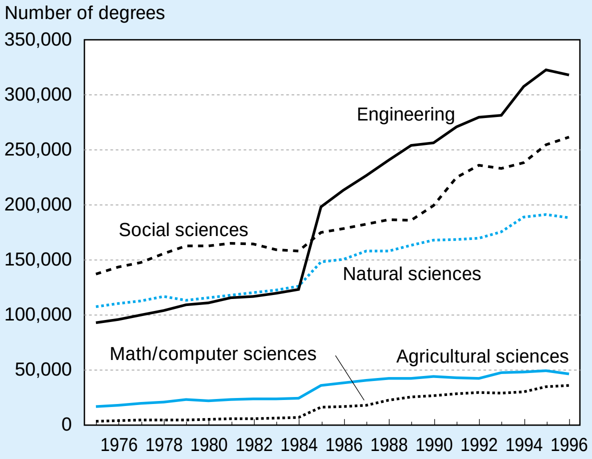
Figure 4-13.
Bachelor's degrees in S&E fields earned within selected Asian countries: 1975–96



NOTES: The steep rise in degrees in 1985 reflects the inclusion of Chinese data from that year on. Natural sciences include physical, biological, earth, atmospheric, and oceanographic sciences. Social sciences include psychology, sociology, and other social sciences.

See appendix table 4-19 for Asian countries included.

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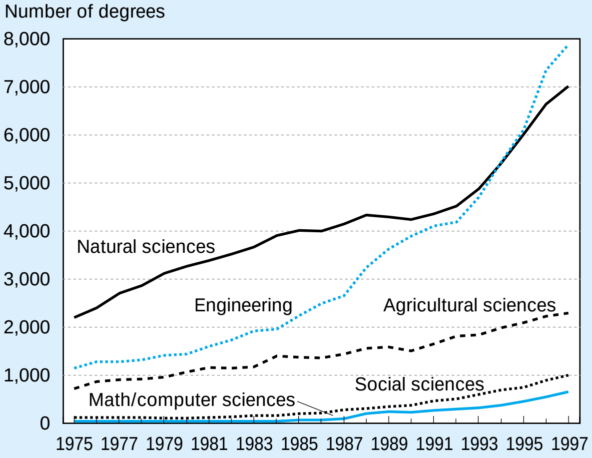
Figure 4-14.
Doctoral degrees in S&E fields earned within selected Asian countries: 1975–97



NOTES: Natural sciences include physical, biological, earth, atmospheric, and oceanographic sciences. Social sciences include psychology, sociology, and other social sciences.

See appendix table 4-19 for Asian countries included.

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In addition, Asian countries are reexamining the field mix of sciences within their universities, to balance the previous concentration on physical science and engineering and meet new needs. For example, Japan would like to increase study in the biological sciences and biotechnology for the health research needs of an aging population and for bioengineering industries of the future (see Government of Japan 1998a, 1998b, 1999). Text table 4-5 shows the number of biology and engineering degrees in Japan, their percent of total degrees, and comparative data from the United States. Within Japan, bachelor's degrees earned in the biological sciences are less than 1 percent of total degrees, while engineering degrees represent more than 19 percent of degrees earned at this level. Similarly, large differences exist at the master's and doctoral level. In contrast, in the United States, biology and engineering degrees represent a similar proportion of total degrees at both the bachelor's and doctoral levels. At the bachelor's level, biology and engineering each represent about 5 percent of total U.S. degrees; at the doctoral level, 14 to 15 percent of total degrees.

Trends in Europe

Recent European developments include a continually broadening access to higher education, more mobility for students and faculty among the countries of the European Union, and graduate education reform. European countries are introducing and expanding their short-cycle, three- to four-year undergraduate programs, alongside their traditional universities that require six to seven years for completion of the first university degree (equivalent to a master's). For example, Germany has increased the shorter cycle, four-year undergraduate institutions, called *Fachhochschulen,* and revised first university degree programs to shift more of the research training to the doctoral level (NSF 2000).

Comparison of Proportion of Degrees in S&E and non-S&E Fields Across Countries

How does the U.S. educational system compare with other countries in its emphasis on S&E in undergraduate programs? One indicator of focus on science and engineering is the proportion of degrees earned in S&E and non-S&E fields. Considering total degrees across all regions, the 2.7 million S&E degrees represent 42 percent of all first university degrees. (See appendix table 4-20.) However, some countries emphasize S&E fields in higher education more than others do. In several large countries—Japan, Russia, and Brazil—students earn more than 60 percent of their first university degrees in S&E fields, and in China, 72 percent do. In contrast, in the United States, students earn their degrees in a wide range of S&E and non-S&E fields: U.S. students earn about one-third of their bachelor-level degrees in S&E fields, mainly in the social sciences. (See appendix table 4-20.)

Of the first university degrees across all regions, approximately 14 percent are earned in each of the broad fields of natural sciences, social sciences, and engineering. There are strong differences in field emphases across countries, however. Engineering represents 46 percent of the earned

Text table 4-5.
Earned degrees in biology and engineering in U.S. and Japanese universities, by level: 1996

	Bachelor's			Master's			Doctoral		
Country and field	Total	Men	Women	Total	Men	Women	Total	Men	Women
				Number					
United States									
Total, all degrees	1,179,815	528,000	651,815	408,932	180,360	228,572	42,415	25,470	16,945
Engineering	63,114	51,798	11,316	27,763	23,009	4,752	6,305	5,529	776
Biology	62,081	29,216	32,865	6,286	2,945	3,341	5,723	3,308	2,415
Japan									
Total, all degrees	512,814	341,116	171,698	47,747	38,022	9,725	8,968	7,477	1,491
Engineering	99,428	92,097	7,331	22,622	21,454	1,168	2,127	2,016	111
Biology	1,875	1,139	736	794	572	222	192	159	33
				Percent					
United States									
Total, all degrees	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Engineering	5.3	9.8	1.7	6.8	12.8	2.1	14.9	21.7	4.6
Biology	5.3	5.5	5.0	1.5	1.6	1.5	13.5	13.0	14.3
Japan									
Total, all degrees	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Engineering	19.4	27.0	4.3	47.4	56.4	12.0	23.7	27.0	7.4
Biology	0.4	0.3	0.4	1.7	1.5	2.3	2.1	2.1	2.2

SOURCES: National Science Foundation, Science Resources Studies Division, *Science and Engineering Degrees 1966–96*, NSF 99-330, Author, Susan T. Hill (Arlington, VA: 1999); Government of Japan, Ministry of Education, Science, and Culture (Monbusho), *The Monbusho Survey of Education* (Tokyo: annual series, 1996).

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bachelor's degrees in China, about 30 percent in Sweden and Russia, and about 20 percent in Japan and South Korea. In contrast, students in the United States earn only 5 percent of bachelor-level degrees in engineering fields. Countries with high concentration of university degrees in the natural sciences include Ireland (34 percent), France and India (20 percent), and the United Kingdom (18 percent). (See appendix table 4-20.)

Participation Rates in University Degrees and S&E Degrees

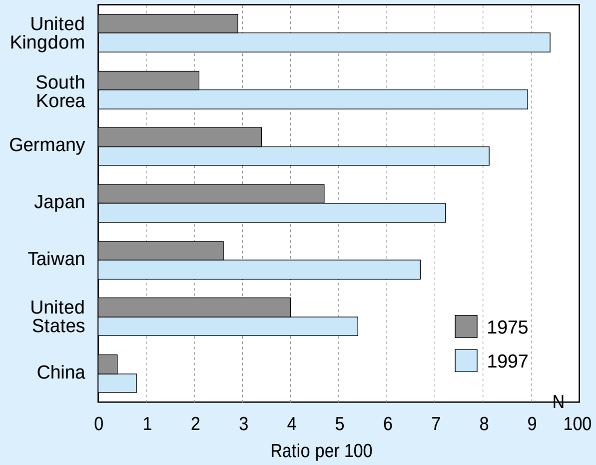
The concern raised by the Steelman report regarding the need to prepare a sufficient number of students for advanced graduate education and research in science not only has remained of national interest but has broadened. The issue has been broadened from ensuring adequate numbers of students willing and able to enter graduate S&E programs to preparing all citizens for life and employment in a high-technology economy. 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 an NS&E degree is an indicator of the technical skill level of those entering the workforce.

The ratio of U.S. bachelor's degrees to the college-age cohort is relatively high: 32 per hundred. Only a handful of countries (the United Kingdom, Canada, Australia, and New Zealand) have higher ratios. However, the ratio of NS&E degrees to the college-age population in more than a dozen Asian and European countries is higher than in the United States. South Korea and Taiwan dramatically increased their ratio of NS&E degrees to their 24-year-olds, from 2 per hundred in 1975 to 7 per hundred in 1997 in Taiwan and 9 per hundred in South Korea. Japan has maintained a high ratio of NS&E degrees to its 24-year-old population since the 1970s, with a slight decline in the late 1980s. The higher ratios after 1995 reflect an increasing number of NS&E degrees and the declining college-age population in Japan. Their college-age cohort will continue to decline until 2010. (See appendix table 4-18 for 1997 data and NSF 1993 for trend data on Asian countries, and appendix table 4-7 for the trends on declining college-age cohorts of major industrialized countries.)

Asia's two giants, India and China, have low participation rates in NS&E degrees. India, with its huge, growing population, is maintaining its participation rate of 1 per hundred. China, with an even larger population, has doubled its participation rate in the past decade, from 0.4 per hundred in 1985 to 0.9 per hundred in 1996. (See NSF 1993 for trend data, figure 4-15 and appendix table 4-18.)

A declining pool of college-age students in Europe has not resulted in declining numbers of NS&E degrees as in the United States. The size of the college-age cohort in Europe has declined 21 percent, from 29.7 million in 1985 to 23.5 million in the year 2000.[13] (See appendix table 4-7.) Among European countries, participation rates in NS&E degrees have grown to more than offset the declining population, most notably in Germany and the United Kingdom. For example, the ratio of NS&E degrees to the German college-age cohort has increased from 3 per hundred to more than 8 per hundred in the past 20 years. Similarly, in the United Kingdom, the ratio increased from 3 to more than 9 per hundred in this same time period. (See NSF 1996a and appendix table 4-18.)

Figure 4-15.
Ratio of NS&E degrees to the 24-year-old population, by country



NOTES: The ratio is the number of natural science and engineering degrees to the 24-year-old population, on a scale of 1 to 100. China's data are for 1985 and 1996. Other countries' data are for 1975 and 1997.

SOURCES: National Science Foundation, Science Resources Studies Division (NSF/SRS), *Human Resources for Science and Technology: The Asian Region,* NSF 93-303 (Washington, DC: 1993); NSF/SRS, *Human Resources for Science and Technology: The European Region,* NSF 96-319 (Arlington, VA: 1996); and appendix table 4-18.

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In contrast, overall participation rates have remained relatively constant in the United States; the ratio of NS&E degrees to the college-age population has remained between 4 and 5 per hundred for the past three decades. That is, students do not show less interest or achievement in earning natural science or engineering degrees; neither do they show more. Demographics have changed significantly, however. As discussed in "Demographics and U.S. Higher Education," the U.S. college-age population decreased by 21 percent from 1980 to 2000. (After this 20-year decline, the U.S. college-age cohort will begin to increase in 2001.) The effect of this demographic trend is partially offset by increasing participation rates for women and underrepresented minorities. Although the decreasing size of the college-age cohort resulted in a downturn in the number of degrees in several NS&E fields, fields in which women are very highly represented (biological sciences and psychology) have produced increasing numbers of degrees in the 1990s. (See appendix table 4-17.)

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[13] The European college-age cohort will begin to increase again in 2005.

Graduate S&E Students and Degrees in the United States

One of the indicators of national innovation capacity and potential international competitiveness is the size and growth of graduate programs in S&E (Porter 1999). This acknowledgment of the importance of education to economic growth is prompting countries to reform and expand graduate education. (See sidebar, "Graduate Reforms in Europe, Asia, and Latin America.")

Trends in Graduate Enrollment

The long-term trend of increasing enrollment in U.S. graduate programs of S&E persisted for more than four decades, followed by four years of declining enrollment, since 1993. The increase in enrollment occurred in two strong waves, reached a peak in 1993, and then subsequently declined in several S&E fields: natural sciences, social sciences, and engineering. (See appendix table 4-21.) The first wave of increasing graduate student enrollment began in the late 1950s and continued throughout the 1960s, with particularly strong Federal support for physics and engineering education and research. The second wave of increasing enrollment occurred in the late 1980s with strong Federal support for academic R&D. (See chapter 2.) A large influx of foreign students into U.S. graduate S&E programs also occurred in the late 1980s. (See appendix table 4-22.) Graduate S&E enrollment more than tripled, from approximately 140,600 students in 1963 (U.S. HEW 1963) to 435,900 in 1993, representing a 2-percent average annual increase over this period.[14] The subsequent drop in the number of graduate S&E students, from 1993 to 1997, represented an average annual decline of 2 percent. (See appendix table 4-21.)

However, the time period and intensity of growth and subsequent declines differ for various fields. Graduate enrollment in the social sciences grew in the 1960s and 1970s, dipped in the early 1980s, and then had a decade-long sharp increase until the mid-1990s. Recent slight decreases in enrollment began in 1995 in psychology and in 1997 in the social sciences. (See appendix table 4-21 and NSF 2000.)

Enrollment in the natural sciences, on the other hand, accelerated in the 1960s, echoing sharp increases in physical sciences support from several government agencies (National Aeronautics and Space Administration, Department of Defense, and Department of Energy), followed by modest growth from 1975 to 1990. The subsequent rapid growth in the early 1990s correlated with expanded research support in the biological sciences. Recent declines in enrollment in the natural sciences, however, are mainly from fewer students enrolling in physical and biological sciences. (See appendix table 4-21 and NSF 2000.)

Engineering followed an upward growth trend until 1992, with declining enrollment every year since then. Both U.S. and foreign students contributed to the rather sharp increase in engineering from 1986 to 1992; the decline since 1993 has been based on fewer U.S. and foreign students entering graduate engineering programs. (See appendix tables 4-21 and 4-22.)

Graduate enrollment in mathematics and computer sciences grew rapidly from 1980 to 1986, similar to engineering, with more modest growth until 1992, followed by a leveling off and slight decline (in mathematics). Foreign students accounted for much of the growth in the 1980s. The favorable U.S. job market after 1992 may account for some of the decline in graduate enrollment. (See appendix table 4-21 and 4-22 and NSF 1999a for disaggregated data on mathematics and computer sciences.)

Master's Degrees

Although graduate enrollment in S&E programs contracted in 1994, master's degrees in S&E continued to increase through 1996. (See appendix tables 4-21 and 4-23.) In fact, increases in S&E degrees at the master's level persisted for more than four decades, with accelerated growth in the first half of the 1990s and a leveling off in 1996. Master's degrees expanded from the modest number of 13,500 in 1954 to more than 95,000 in 1996.

At the master's level, growth in the number of students earning degrees occurred at different times for different fields. The increase in degrees in the physical and mathematical sciences peaked in the early 1970s and then declined, whereas growth in computer sciences continued to increase throughout the 1980s and 1990s. The number of earned degrees in the social and behavioral sciences peaked in the late 1970s, declined for more than a decade, and then showed a reversal of this trend in 1989 with continual annual increases. Biological and agricultural sciences followed this same pattern of a peak in the late 1970s and declined until 1990. Since then, agricultural sciences have increased even more sharply than the biological sciences (NSF 1999b). Engineering, on the other hand, has had almost continual growth over more than four decades, with slight declines in both 1995 and 1996. (See figure 4-16 and appendix table 4-23.)

Doctoral Degrees

The Steelman report's recommendation to train scientists and engineers in all fields of knowledge has been carried out. Doctoral S&E degree production in U.S. universities shows two waves of strong growth in the last half of the 20th century. The first upsurge of doctoral S&E degrees in the late 1950s and 1960s reflected the Cold War and the space race, as well as the result of the wave of GIs taking S&E-oriented bachelor's programs following World War II. (See appendix table 4-24.) This buildup of doctoral programs was followed by a long, slow decline in NS&E fields beginning in the early 1970s (from the cutback in the space program) and in the social sciences in the 1980s. In the 1980s, the second wave of growth occurred in NS&E fields with large increases in aca-

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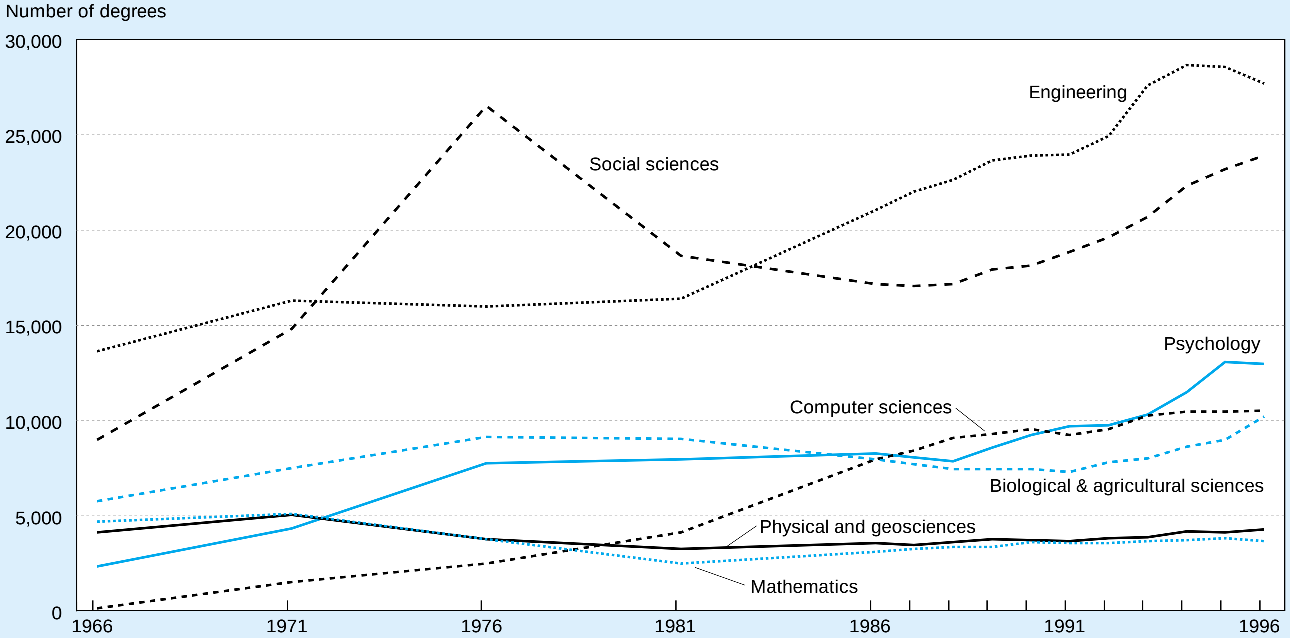
[14] The graduate student enrollment survey used by the U.S. Department of Health, Education, and Welfare in 1963 and that used by the National Science Foundation in 1993 have slightly different base populations, so only approximate comparisons can be made between the number of graduate students in these two periods.

Figure 4-16.
Master's degrees awarded in S&E, by broad field: 1966–96



NOTES: Data are in five-year increments for 1966–86, and one-year increments for 1986–96. Geosciences include earth, atmospheric, and oceanographic sciences.

See appendix table 4-23. *Science & Engineering Indicators – 2000*

demic R&D budgets. (See appendix table 4-25 and chapter 6.) From 1986 to 1992, increasing numbers of foreign students entered these expanded graduate NS&E programs. (See appendix table 4-26.)

Within the natural sciences, doctoral degrees in the biological and agricultural sciences had a long, steady, upward trend from 1970 to 1997, while degrees in the physical sciences peaked in the late 1960s, declined to 1980, grew quite steadily to 1995, and then leveled off. (See figure 4-17.) Doctoral degrees earned in the social sciences show a continual steady increase throughout the 1990s. The slight drop in doctoral degrees in NS&E fields in 1997 is mainly accounted for by the decline in the number of foreign doctoral recipients in that year. (A decline in foreign graduate enrollment in U.S. universities occurred from 1993 to 1996.) (See "Diversity Patterns in S&E Enrollment and Degrees in the United States" for doctoral degrees by race/ethnicity and citizenship.)

Steelman's concern for creating the "right" number of S&E doctorates to meet the needs of the workplace relates to the current issue of "overproduction" of doctoral degrees. The "right" number remains elusive. Attempts to model the complexity and change in the U.S. economy and predict demand for doctoral-level personnel by specific S&E fields have been unsuccessful. Rather than attempting to forecast demand or the "right number" of S&E doctorates, policymakers are recommending doctoral education that broadens career options. Because a larger proportion of S&E doctoral recipients than ever before have to seek employment outside academia (COSEPUP 1995), reforms are directed to broadening doctoral education for employment skills both within and beyond academia. (See sidebar, "Graduate Reforms in Europe, Asia, and Latin America.") For example, one large effort for better preparing doctoral students for teaching careers is "The Association of American Colleges and Universities' Preparing Future Faculty program." In addition, NSF has established Engineering Research Centers that provide more interdisciplinary learning and collaboration with industry for engineering students. (See the NSF Web site <<www.eng.nsf.gov/eec/erc.htm>>.)

International Comparison of Doctoral Degrees in S&E

The scale of doctoral programs has increased in several world regions, particularly Europe, Asia, and the Americas. This capacity building in doctoral S&E education is linked to national policies to develop an S&E infrastructure that more explicitly links universities to innovation and economic development. (See sidebar, "Graduate Reforms in Europe, Asia, and Latin America." at the end of this section.) By broad world region,[15] Western Europe produces more doctoral S&E degrees than North and South America (the Americas) and Asia.

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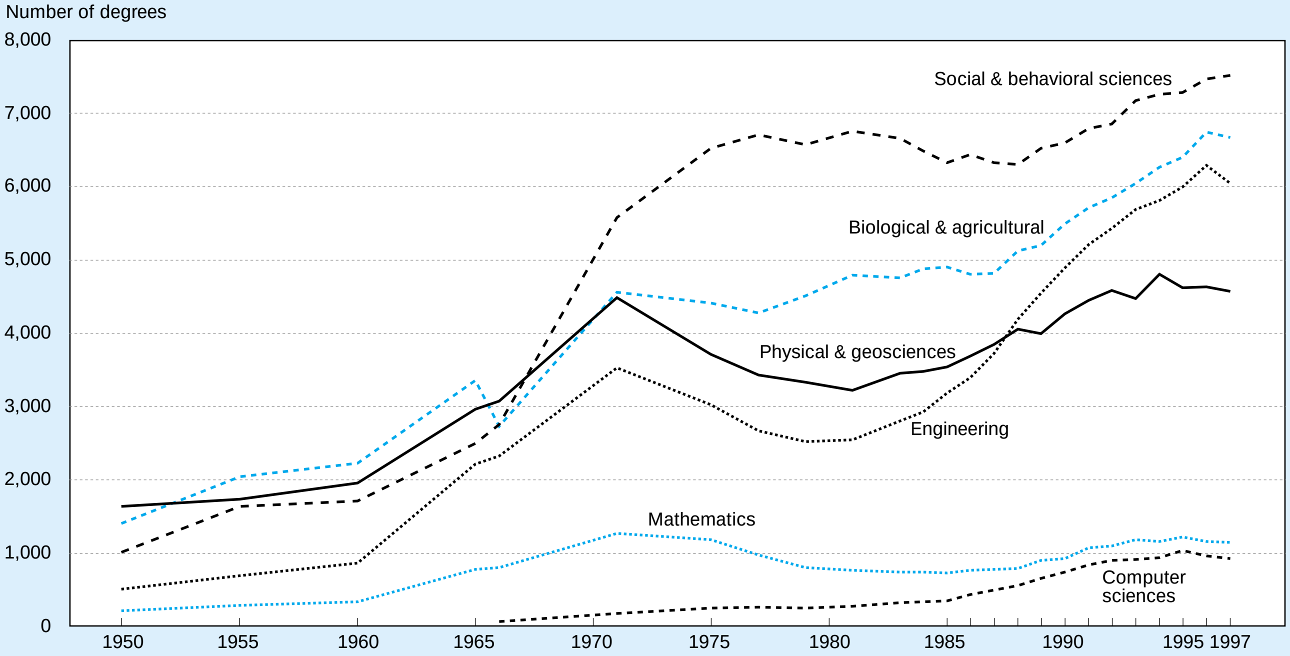
[15] This discussion of international comparisons presents data in terms of three world regions—Asia, Western Europe, and North America. The specific countries composing these regions are listed in appendix table 4-27.

Figure 4-17.
Doctoral S&E degrees earned in U.S. universities, by field: 1950–97



NOTES: Data are in five-year increments for 1950–85, and one-year increments for 1985–97. Geosciences include earth, atmospheric, and oceanographic sciences.

See appendix tables 4-24 and 4-25.

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In 1997, doctoral degrees awarded in S&E fields by Western European institutions totaled 40,000—about one-fifth higher than the number of such degrees earned in the American region and more than twice as many as the number recorded for Asian countries. (See appendix table 4-27 and figure 4-18.)

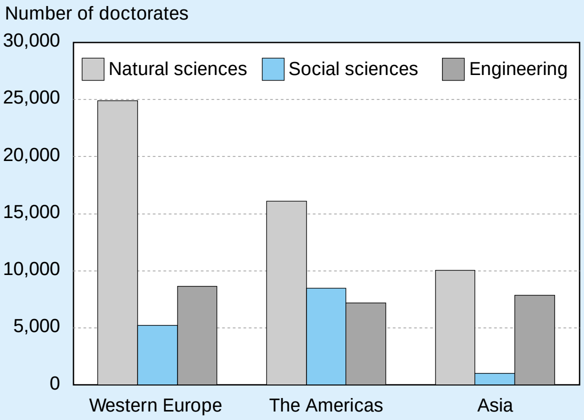
Considering broad fields of science, the largest number of natural science doctorates are earned within Western European universities, while the largest number of social science doctorates are earned within universities in the Americas. In contrast, in engineering, each region produces about one-third of the doctoral-level degrees.

Trends in Doctoral Degrees—Europe and the United States

By individual country, the United States has the highest number of doctoral degrees earned in S&E fields. In 1997, U.S. universities awarded about 27,000 S&E doctoral degrees—more than twice the number of S&E degrees awarded in any of the other major industrial countries. (See figure 4-19.) However, the combined doctoral S&E degrees of the three largest European countries (Germany, France, and the United Kingdom) recently surpassed the number of U.S. earned degrees. (See figure 4-19.)

S&E doctoral degrees in Germany grew faster than non-S&E doctoral degrees between 1975 and 1997. The number of S&E degrees increased 4.3 percent annually, engineering increased 5.0 percent annually, and non-S&E doctoral degrees increased 2.8 percent annually during this 22-year period. (See appendix table 4-28.) France undertook a reform of doctoral

Figure 4-18.
Doctoral S&E degrees by region and field: 1997



NOTES: Natural sciences include physical, biological, agricultural, earth, atmospheric, and oceanographic sciences, mathematics, and computer sciences. Social sciences include sociology, psychology, and other social sciences.

See appendix table 4-27 for countries included within each region.

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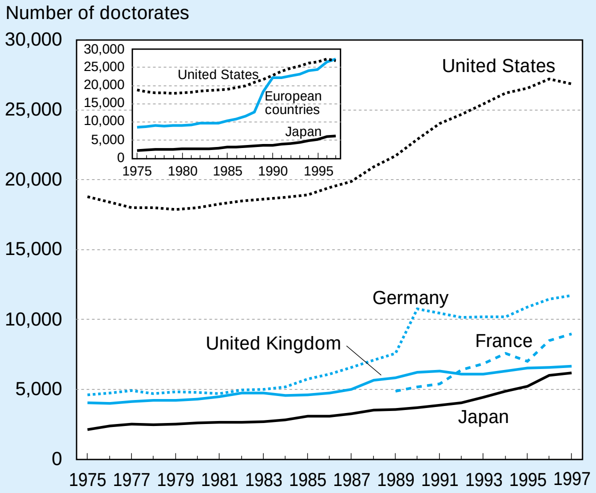
Figure 4-19.
Doctoral S&E degrees in selected industrialized countries: 1975–97



NOTES: The peak in the data from Germany in 1990 reflects the inclusion of degrees from former East Germany beginning in that year. The inset combines the three European countries.

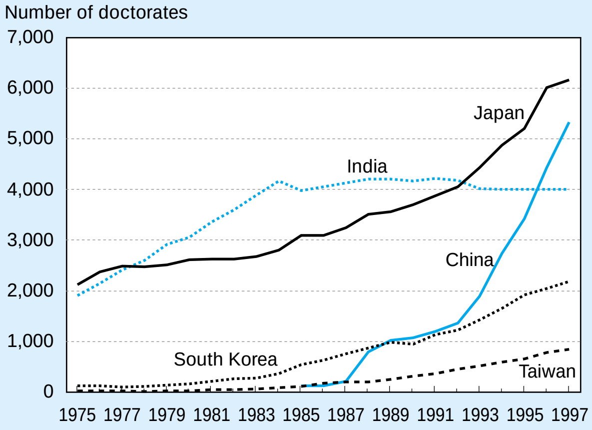
See appendix table 4-28. *Science & Engineering Indicators – 2000*

studies in 1988 in an effort to double the number and improve the quality of S&E doctoral degrees awarded within eight years. The effort has largely succeeded: the number of S&E doctoral degrees awarded in France increased from 5,000 in 1989 to 9,000 in 1997—more than an 83-percent increase (Government of France 1998a). In contrast to Germany, doctoral S&E degrees in the United Kingdom have not grown as fast as non-S&E doctoral degrees: S&E doctoral degrees grew 2.6 percent annually in the past two decades, while non-S&E fields grew 5.0 percent annually.

Trends in Doctoral Degrees—Asia

The scale of graduate education in Japan has been small by international standards. Until recently, most doctorates in NS&E in Japan were earned by industrial researchers after many years of research within Japanese companies. Doctoral reforms of 1989 called for the expansion and strengthening of graduate schools and the establishment of a new type of university exclusively for graduate study. The government has sharply increased support to universities to improve facilities and accelerate doctoral programs in NS&E fields. In 1994, Japanese engineers earned more doctoral degrees for research within university laboratories than within industrial research laboratories—53 percent and 47 percent, respectively (NSF 1997).

Figure 4-20.
Doctoral S&E degrees in selected Asian countries: 1975–97

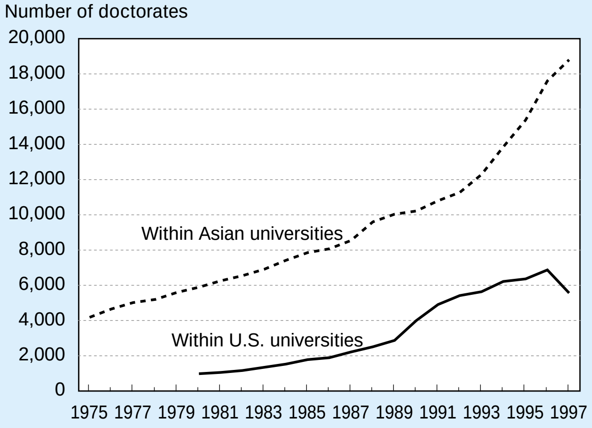


See appendix table 4-29. *Science & Engineering Indicators – 2000*

Asian graduate education reforms are also strengthening and expanding doctoral programs in China, Taiwan, and South Korea. (See figure 4-20.) In 1997, S&E doctoral degrees earned within major Asian countries (China, India, Japan, South Korea, and Taiwan) reached more than 18,000, representing a 12-percent average annual increase from 1993 to 1997. In contrast, such degrees earned by Asian students (from these five countries) within U.S. universities peaked at 6,900 in 1996 (representing less than a 5-percent average annual growth rate from 1993 to 1996) and declined in 1997. (See figure 4-21.)

China has invested heavily in graduate education to "embrace the era of knowledge economy" (*Nature* 1998). While still using the U.S. higher education system to absorb the rising demand for graduate education, Chinese universities have expanded graduate education to be able to absorb a larger proportion of the students seeking advanced S&E degrees. Although the number of S&E doctoral degrees earned by Chinese students within U.S. universities showed a decade-long increase until 1996, the number of such degrees earned

Figure 4-21.
Doctoral S&E degrees earned by Asian students within Asian and U.S. universities: 1975–97



See appendix table 4-30 for Asian countries included.
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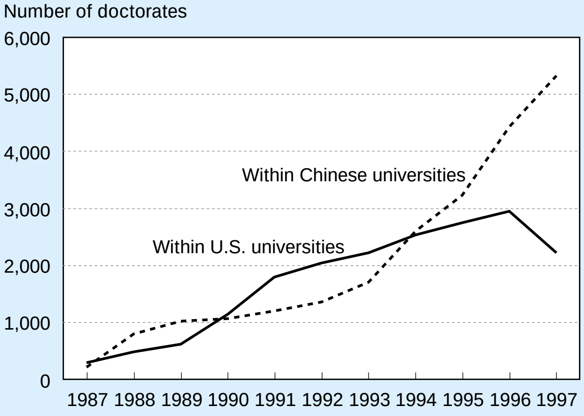
within Chinese universities continues to increase, and at a faster rate. (See figure 4-22.) By 1997, Chinese students earned more than twice as many S&E doctorates within Chinese universities as within U.S. universities.

Other Asian countries are also increasing their capacity to provide S&E graduate education. In the 1980s, the Korean Advanced Institute of Science and Technology was established to increase support for postgraduate training within the country. South Korean universities awarded almost 2,200 doctoral degrees in S&E in 1997, up from 945 such degrees in 1990. (See appendix table 4-29.) More recently, South Korea announced its plan, called “Brain Korea 21” to further strengthen graduate education in the natural sciences and provide university research funds for interdisciplinary programs such as biotechnology and materials science (Baker 1999).

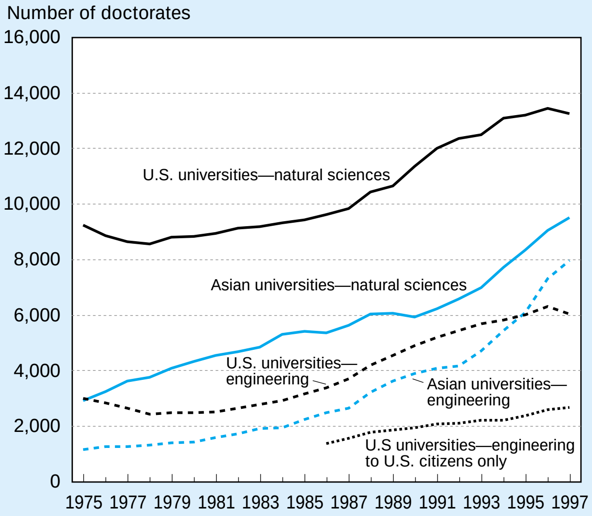
Universities within five Asian countries are now producing more engineering doctorates than universities within the United States. The gap is even larger, since half of the U.S. degrees are earned by foreign students, the majority of whom are Asian. (See figure 4-23.)

Figure 4-22.
Doctoral S&E degrees earned by Chinese students within Chinese and U.S. universities: 1987–97



See appendix table 4-31. *Science & Engineering Indicators – 2000*

Figure 4-23.
Doctoral NS&E degrees earned within U.S. and Asian universities: 1975–97



See appendix tables 4-25, 4-26, and 4-29 for Asian countries included.

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Graduate Reforms in Europe, Asia, and Latin America

As the world’s countries recast themselves as “knowledge-based” economies and attempt to build up “national innovation systems,”[*] interest in doctoral education—particularly in S&E—is increasing around the globe, occasioning a reexamination of its aims and structure. Reforms in doctoral programs in Asia, Europe, and the Americas are aimed at similar concerns—to strengthen and expand doctoral education and to develop the capacity for high quality or “breakthrough” research that would lead to technological innovation. No national assessments are available on how graduate reforms are improving economic competitiveness. There are, however, initial indicators of S&E capacity building: contributions to the world’s scientific literature (see chapter 6) and patents and high-technology trade (see chapter 7). Forces for graduate education expansion and reform include demographic, economic, technological, and social changes.

Forces for Change

Demographic

Recruitment pools for graduate education are rising from the so-called massification of higher education programs in industrialized countries (that is, the enlargement of the proportion of the population that undertakes a university degree). Across Europe, participation rates of the college-age cohort in first university degrees have more than doubled in the past 20 years, from 7 to 17 percent. Japan has more than one-quarter of its young people completing bachelor’s degrees, and the United States about one-third.

Economic

Among economic forces for reform in the United States and Europe are pressures from national and state funding

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[*] See, for example, recent journal articles on economic development through S&T by a member of the German parliament (Merkel 1998), by the French Minister of Education (Allègre 1998), and by the Chinese State Science and Technology Commission (*Nature* 1998).

sources and industry to produce graduate students who are better trained to contribute to economic development. In addition, students are demanding career information and broader skills for employment beyond academia. Asian countries—given their conviction that economic growth is dependent on S&T knowledge and its connection to production—are accelerating their within-country capacity to educate scientists and engineers at the doctoral level.

Technological

The pace of technological change is increasing in industrial R&D, and incremental improvement of products and processes (a particularly strong suit of Japanese industrial labs) is sometimes rendered ineffective by breakthrough innovations creating new commercial products. As current products and processes become obsolete more quickly, industries are motivated to partner with each other and with graduate research programs that augment their innovation capacity. Many inventions are increasingly linked to public science conducted in universities and national laboratories, and industry is increasing its investment in basic research performed in universities. Although still a small proportion of the total, industry is investing in graduate education to have access to some of the best students and encourage them into industrial careers.

Social

The growing demand for public accountability of governmental and academic institutions is forcing the introduction of assessments into higher education. Assessments are directed toward the quality of research and teaching, a reexamination of the balance between faculty research and teaching, the role of graduate students as research assistants, and how the mode of graduate support might affect the breadth of graduate education and the time to degree.

Different Emphases in Reforms Across Countries

Latin America

Within Latin America, countries such as Mexico, Chile, and Argentina have only recently begun to expand the scale of their doctoral programs. (Brazil greatly expanded the scale of its graduate programs in the 1980s to foster graduate S&T programs as a key instrument for knowledge creation and dissemination.) These developing Latin countries are motivated by a desire to have more of their university faculty trained at the doctoral level. For example, within Mexico, about 80 percent of the higher education faculty have only a first university degree (NSF 2000).

Europe and the United States

The criticism by industry of traditional graduate programs as too long, too narrow, and too campus-centered is particularly expressed in the United States, France, and Germany. With the expansion of graduate education and an ever-greater percentage of students who enter careers outside academia, the larger labor market is demanding broader training. For example, Germany is discussing shortening the time to degree and orienting doctoral recipients to industrial research, because doctoral recipients are considered too old to begin working in industry.

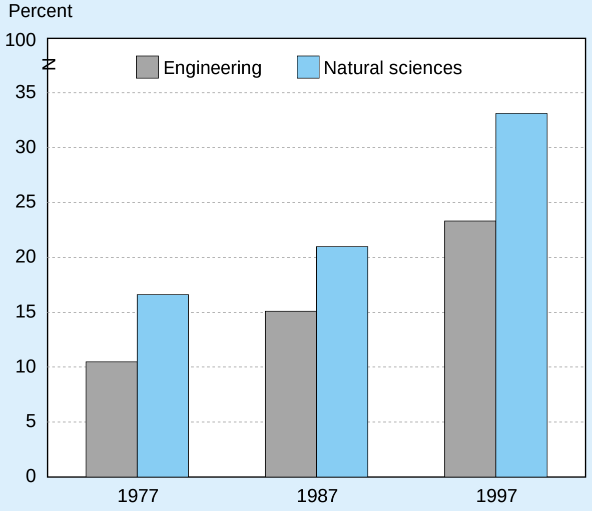
Within Europe and the United States, discussions of reform for broadening doctoral programs include providing off-campus internships and opportunities for interdisciplinary research experience, teaching skills to prepare future faculty, and increasing awareness of career opportunities in industrial research and management. Reforms also relate to lessening time-to-degree and to restraining costs from public funding sources of enlarged graduate programs. Within the United States, lessening time-to-degree is discussed more in terms of institutional accountability and varies by field.

Asian Countries

Within Asian developing countries, reforms are motivated by the belief that universities could be the engines of economic growth through research and innovation leading to high-technology products. Reforms are focused on establishing quality graduate schools, building university facilities and research infrastructure, and acquiring highly trained S&E professors, either at home or abroad. These attempts to expand graduate education and improve its quality are more accelerated in Asia than in Latin America and involve the building of whole new S&T universities. In Chinese Hong Kong and in South Korea, the establishment of S&T universities has been supported primarily by private industry. Chinese (People's Republic) research universities are expanding through more self-support from close alliances with, or ownership of, high-technology industries and through international loans (NSF 2000).

In Japan, industry for the most part had traditionally trained its own doctorate-level researchers. Japan is now concerned that such industrially trained scientists and engineers are not contributing breakthrough research for new and emerging industries. Japan is convinced that industries of the 21st century will require within-country or domestic innovation capacity. As part of its efforts to support future innovation through basic science, Japan is greatly expanding and reforming graduate education within its universities. By 1997, about one-third of Japanese students entered graduate school directly after completing a bachelor of science degree. (See figure 4-24.) Increased allocations for doubling the government's science budget are on schedule and will go mainly to universities to improve the environment for basic research. Institutional changes such as the integration of the Science and Technology Agency and the Ministry of Education (Monbusho) are also a response to this needed reform. Japan is greatly augmenting fellowships and traineeships for graduate students, and funding top-level foreign researchers to come to Japanese universities to upgrade basic research.

Figure 4-24.
Japanese students entering graduate school directly after completing bachelor of science degrees



SOURCE: Government of Japan, Ministry of Education, Science, and Culture (Monbusho), *Monbusho Survey of Education, 1998* (Tokyo: annual series). *Science & Engineering Indicators – 2000*

Diversity Patterns in S&E Enrollment and Degrees in the United States

The Steelman report recommended full utilization of human resources for science but did not explicitly address issues of equity for women and minorities entering S&E fields. As these groups now make up the majority of the labor force, their equal entry into S&E fields is of current national interest.

Enrollment in Undergraduate Programs, by Race/Ethnicity and Sex

Beginning in 1984 and lasting almost a decade, undergraduate enrollment in U.S. institutions of higher education showed strong growth, peaking in 1992 with nearly 12.7 million students. Undergraduate enrollment declined slightly each year until 1995 and leveled off in 1996. The decline is mainly from the decrease in the college-age cohort of the majority (white) population. White enrollment in undergraduate education leveled off in the early 1990s and has declined each year since 1992 for males and females, while enrollment for all minority groups increased. (See appendix table 4-32.)

This trend of increasing enrollment in undergraduate programs by underrepresented minorities has persisted over a decade. Black enrollment increased 3 percent annually from 1.1 million in 1990 to 1.4 million in 1996. Black males have had more modest gains than black females. In the same period, Hispanic enrollment in higher education increased at an even faster rate (7.7 percent) annually. The strongest growth, however, has been among Asians/Pacific Islanders (8.0 percent annually). Undergraduate enrollment of foreign students grew very modestly in the past two decades; in 1996, foreign students still represented only 2 percent of total undergraduate enrollment. (See appendix table 4-32.)

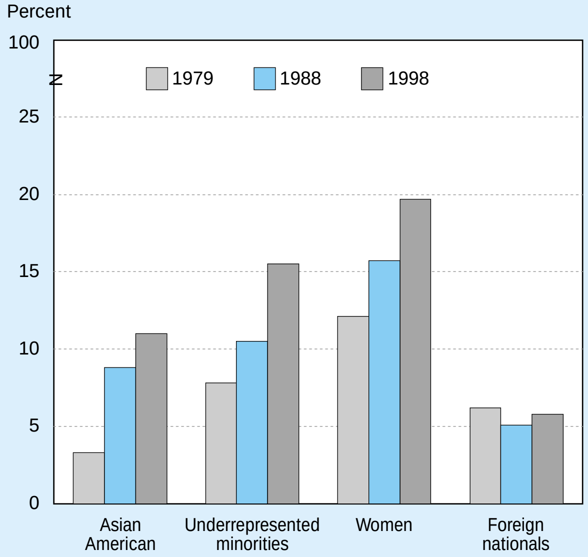
Enrollment in Engineering, by Race/Ethnicity and Sex

While total undergraduate engineering enrollment declined from 1983 to 1996, underrepresented minorities continually increased their enrollment during this period, and female students increased from 1987 to 1998. Female students enrolled in engineering increased from 60,000 in 1987 to 72,000 in 1998. For underrepresented minorities, the increases were greater over a longer period, from 37,000 in 1983 to almost 57,000 in 1998. (See appendix table 4-33.) By 1998, female students represented 19.7 percent of total undergraduate engineering enrollment, and underrepresented minorities represented 15.5 percent of such enrollment. (See figure 4-25.)

Persistence Toward a Bachelor's Degree, by Sex and Race/Ethnicity

There is a considerable gap between enrollment in S&E programs and successful completion of S&E degrees. National longitudinal data with high school and college transcripts provide some indicators of retention in S&E fields, as well as students' exploration and switching to other academic departments in undergraduate education. The Beginning Postsecondary Students (BPS) Longitudinal Study analyzed

Figure 4-25.
Representation of women and minorities in undergraduate engineering enrollment



See appendix table 4-33. *Science & Engineering Indicators – 2000*

completion rates of all beginning students in college, including nontraditional (older) students as well as traditional students (NCES 1996). The analysis on completion rates presented in *Women and Men of the Engineering Path* was restricted to engineering students who had reached the threshold of completing three required engineering courses (USDE 1998). Based on these national surveys, this section provides summary findings on differences in completion rates by race and sex.

Persistence in S&E majors of beginning college students can be examined, by race/ethnicity and sex, through the BPS of 1989/90 and 1995 follow-up. The transcripts of a subsample of 926 students who enrolled in S&E programs their freshmen year were examined over the next five years to identify the following outcomes: the proportion that completed a degree in an S&E field, those who still persisted in studying toward such a degree, students who switched to non-S&E fields, and those who dropped out of college. These data showed that less than one-half of the students intending an S&E major from any racial/ethnic group completed an undergraduate S&E degree within five years.[16] Further, females were more likely than males to complete an S&E degree within five years. In addition, about 22 percent of students from all racial/ethnic groups dropped out of college within five years.

Besides completions and dropouts, the study further showed the considerable percentage of students (16 percent to 27 percent) who persist in studying S&E fields five years after entering and the percentage who have explored and switched to other fields. The study found that, compared with the white and Asian/Pacific Islander groups, fewer underrepresented minority students completed an S&E degree within five years, but a higher percentage were still persisting in studying for an S&E degree. In addition, a higher percentage of underrepresented minority students switched to non-S&E fields. (See figure 4-26.)

An analysis of persistence in engineering reported in *Women and Men of the Engineering Path*[17] found that, of those students who reached the threshold of the engineering path (had completed three required engineering courses),[18] 59 percent earned a bachelor's degree in engineering by age 30. The analysis used an 11-year transcript history 1982–93 of the High School and Beyond/Sophomore Cohort Longitudinal Study.[19] The study found that women have a 20-percentage-point gap in their completion rate of undergraduate engineering programs: a 62-percent completion rate for males and 42 percent for females (USDE 1998).

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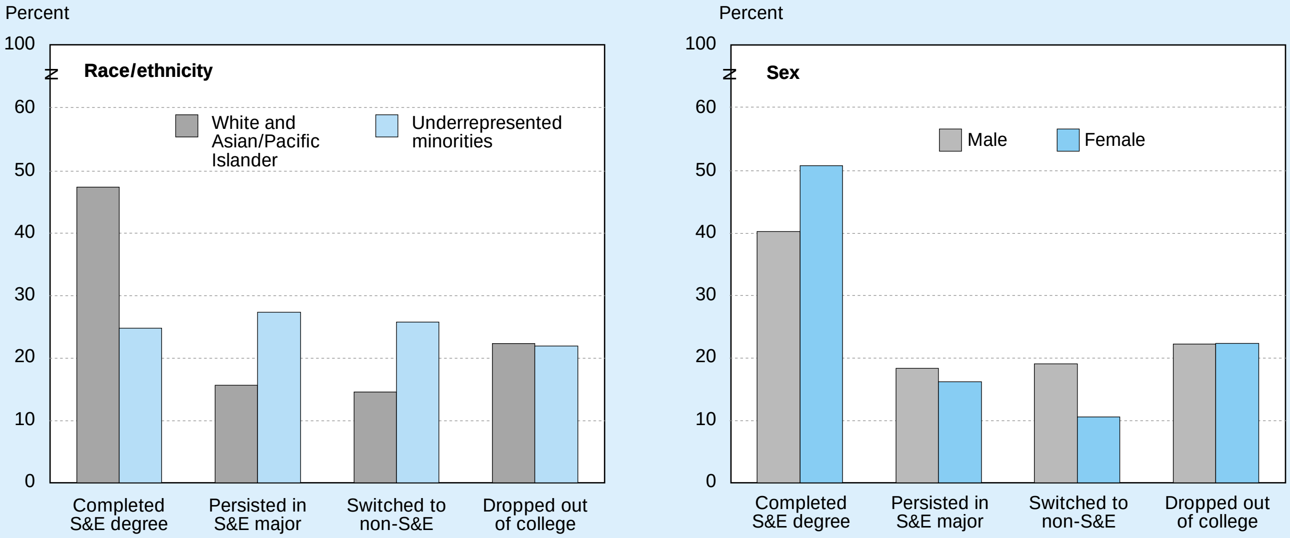
[16] The completion rate is somewhat higher for all fields of study, not just S&E fields. Among beginning students seeking bachelor's degrees in 1989/90, 57 percent of those who began in four-year institutions completed a bachelor's degree in five years (see NCES 1996 for completion rates by enrollment status).

[17] See the full study (USDE 1998) for the contents of the engineering core curriculum, secondary school background characteristics of those who reach the threshold, the "curricular momentum" of mathematics and science courses in high school and college for those who enter and complete engineering degrees, various institutional attendance patterns, field migration, classroom environments, and the role of community college.

[18] Approximately 9 percent of all freshmen reach the threshold of the engineering path.

[19] The study used a representative sample of more than 8,000 students.

Figure 4-26.
Completion and attrition rates five years after beginning an S&E major, by race/ethnicity and sex



SOURCE: National Center for Educational Statistics (NCES), Beginning Postsecondary Student (BPS) Longitudinal Study (Washington, DC: 1996). (Based on subsample of 926 first-year S&E students in 1990 and 1995 follow-up.)

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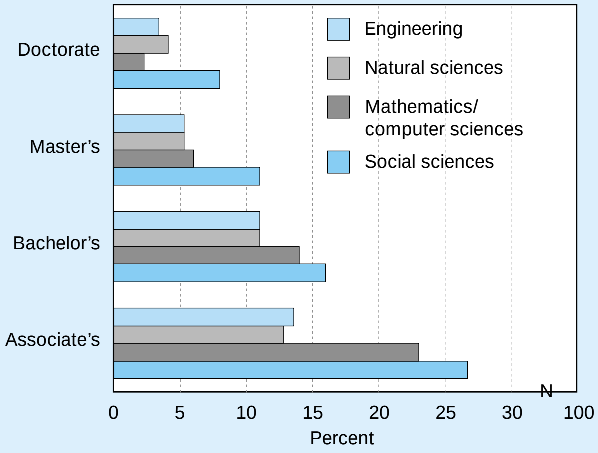
Associate's Degrees

Students from underrepresented minority groups earn a higher proportion of their S&E degrees at the associate's level than in four-year or graduate programs. In 1996, these students earned about 23 percent of the mathematics and computer science degrees at the associate's level, a far higher percentage than at the bachelor's or advanced levels of higher education. At advanced levels of higher education, the percentage of degrees earned by underrepresented minorities drops off precipitously in fields of NS&E. In contrast, in the social sciences and in non-S&E fields, the drop-off in percentage of degrees earned by underrepresented minorities at advanced levels is not as dramatic. (See figure 4-27 and appendix tables 4-34, 4-35, 4-38, and 4-39.)

Figure 4-27.
S&E degrees earned by underrepresented minority students, by level and field: 1996/97



NOTES: Doctoral-level degrees use 1997 data; all other levels use 1996 data. Natural sciences include physical, earth, atmospheric, oceanographic, biological, and agricultural sciences. Social sciences include psychology, sociology, and other social sciences.

See appendix tables 4-34, 4-35, 4-38, and 4-39.

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Bachelor's Degrees

Bachelor's Degrees, by Sex

The United States is among the leading countries in the world in the proportion of undergraduate S&E degrees earned by women. (See appendix table 4-37.) Trends for women show a smoother, steadier increase in their number of earned degrees in the past several decades than for men, but from a lower base. Male trends in earned S&E degrees show strong growth in the 1950s and 1960s, peaks and valleys in the 1970s and 1980s, and declining or level degrees in all fields except the biological sciences in the 1990s. (See appendix table 4-17.) By 1996, women represented 60 percent of the social and behavioral science degrees, 47 percent of natural sciences, 46 percent of mathematics, 28 percent of computer sciences, and 18 percent of engineering, up considerably from the percentages of 1954. (See text table 4-6.)

Text table 4-6.
Bachelor's degrees earned by women: 1954 and 1996

	1954			1996		
		Women			Women	
Field	Total	Number	Percent	Total	Number	Percent
Total, all fields	292,880	105,380	0.36	1,179,815	651,815	0.55
Science & engineering	117,575	22,743	0.19	384,674	181,333	0.47
Natural sciences	17,710	3,890	0.22	98,322	46,556	0.47
Physical sciences	8,155	1,194	0.15	15,396	5,702	0.37
Biological & agricultural	9,366	2,612	0.28	78,469	39,369	0.50
Earth, atm., & oceanographic	189	84	0.44	4,457	1,485	0.33
Math & computer sciences	4,090	1,368	0.33	37,621	12,764	0.34
Mathematics	4,090	1,368	0.33	13,076	5,992	0.46
Computer sciences	NA	NA	NA	24,545	6,772	0.28
Social & behavioral sciences	73,446	17,420	0.24	185,617	110,697	0.60
Psychology	5,758	2,673	0.46	73,828	53,863	0.73
Social sciences	67,688	14,747	0.22	111,789	56,834	0.51
Engineering	22,329	65	0.00	63,114	11,316	0.18

NA = not applicable

SOURCES: U.S. Department of Health, Education, and Welfare (HEW), *Statistics of Higher Education: Faculty, Students, and Degrees 1953–54* (Washington, DC: U.S. Government Printing Office, 1956), and appendix table 4-17.

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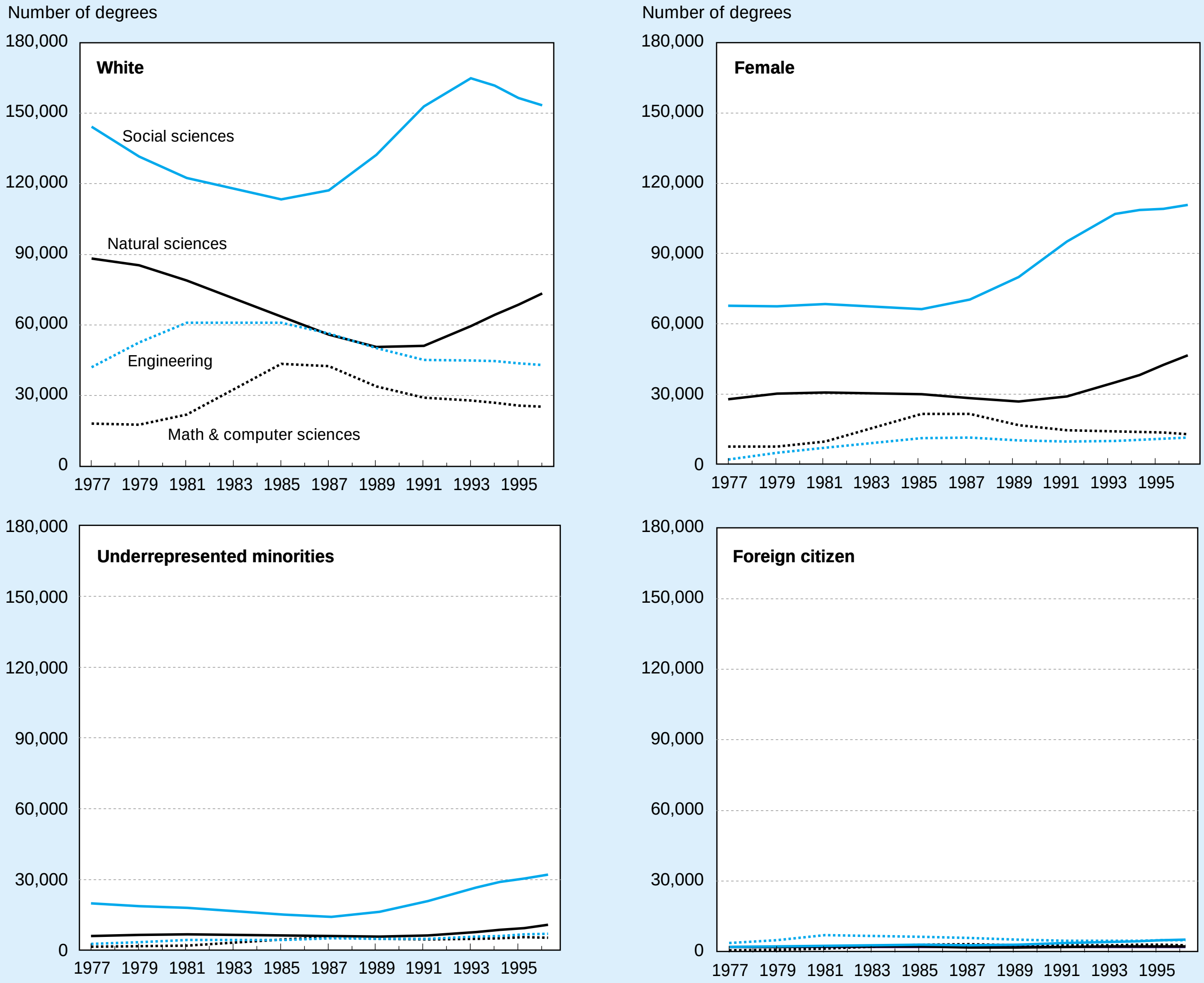
Bachelor's Degrees, by Race/Ethnicity and Citizenship

As discussed in "Trends in Earned S&E Degrees," the number of earned degrees has been increasing in the social and natural sciences and decreasing in engineering, mathematics, and computer sciences. Degrees earned by white and Asian/Pacific Islander students follow this overall pattern.

Trends for subpopulation groups, however, differ somewhat from this overall pattern. The number of degrees earned by the white majority population is declining in every field except the natural sciences. Asian/Pacific Islander students are sharply increasing their earned degrees in the natural and social sciences and leveling off in their number of earned degrees in engineering, mathematics, and computer science fields. Degrees to underrepresented minorities are increasing in all fields, but from a small base. (See figure 4-28.) From 1989 to 1996, degrees earned by underrepresented minority students increased by 10 percent annually in the social sciences, 9 percent in the natural sciences, 6 percent in engineering, and only 1 percent in mathematics and computer sciences.

Foreign students earn few degrees within U.S. universities at the bachelor's level. During the past two decades, S&E degrees earned by foreign students have remained between 3 and 4 percent of total S&E degrees. They are more concentrated, however, in engineering, mathematics, and computer sciences, representing 7 percent of degrees in these fields. Still, trends in these S&E fields are barely visible on a graph. (See figure 4-28.)

Figure 4-28.
Bachelor's degrees in S&E fields earned by selected groups



NOTES: Data for 1983 are estimated. Natural sciences include physical, earth, atmospheric, oceanographic, biological, and agricultural sciences. Social sciences include psychology, sociology, and other social sciences.

See appendix tables 4-17 and 4-35.

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Participation Rates, by Sex and Race/Ethnicity

The United States is among the leading nations in the world in providing broad access to higher education but ranks below many major industrialized countries in the proportion of its college-age population with an S&E background. The ratio of bachelor-level degrees to the college-level population was 32 per hundred in 1996, and the ratio of NS&E degrees to the 24-year-old population in the United States was about 5 per hundred in that same year. (See appendix table 4-18.) These national statistics, however, are not applicable to all minority groups within the United States. The ratio of college degrees earned by black and Hispanic groups to their college-age population was 14 to 18 per hundred, and the ratio of NS&E degrees to this college-age population was 2 per hundred. In contrast, Asians/Pacific Islanders have considerably higher than average achievement: the ratio of bachelor's degrees earned by Asians/Pacific Islanders to their college-age population was 40 per hundred, and their ratio of NS&E degrees to their college-age population was 12 per hundred.

Comparing participation rates in 1980 and 1996 shows some progress toward more diversity in higher education in general and S&E in particular. (See text table 4-7.) While low participation rates for blacks and Hispanics changed little throughout the 1980s, they improved considerably in the 1990s, particularly in the social sciences.

International Comparison of Participation Rates, by Sex

Among 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 1997, the ratio of first university degrees earned by women to the female 24-year-old population was 38 per hundred, slightly higher than this ratio in the United States and Canada (36 per hundred). Women in the United Kingdom and Canada also show high participation

Text table 4-7.
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 1996

Sex and race/ethnicity	Total 24-year-old population	Total bachelor's degrees	Degree field			Ratio of		
			Natural science degrees	Social science degrees	Engineering degrees	Bachelor's degrees	NS&E degrees	Social science degrees
						to 24-year-old population		
1980								
Total	4,263,800	946,877	110,468	132,607	63,717	22.2	4.1	3.1
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
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
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
1996								
Total	3,671,000	1,179,815	135,943	185,617	63,114	32.1	5.4	5.1
Male	1,864,000	528,488	76,623	74,920	51,798	28.4	6.9	4.0
Female	1,806,000	651,815	59,320	110,697	11,316	36.1	3.9	6.1
White	2,472,000	884,128	98,707	153,277	43,098	35.8	5.7	6.2
Asian/Pacific Islander	161,000	63,117	13,212	11,020	6,799	39.2	12.4	6.8
Black	505,000	89,554	8,670	17,385	3,000	17.7	2.3	3.4
Hispanic	500,000	71,015	6,764	13,296	3,731	14.2	2.1	2.7
American Indian/ Alaskan Native	33,000	6,813	741	1,324	243	20.6	3.0	4.0

NOTES: The ratios are the number of degrees to the 24-year-old population on a scale of 1 to 100. Population data are for U.S. residents only and exclude members of the armed forces living abroad.

SOURCES: Population data—U.S. Bureau of the Census, *U.S. Population Estimates by Age, Sex, Race, and Hispanic Origin: 1990 to 1997,* PPL-91R (Washington, DC), and previous editions; Degree data—National Center for Education Statistics (NCES), Earned Degrees and Completion Surveys (Washington, DC: 1997), unpublished tabulations, and National Science Foundation, Science Resources Studies Division, *Science and Engineering Degrees 1966–96*, NSF 99-330, Author, Susan T. Hill (Arlington, VA: 1999).

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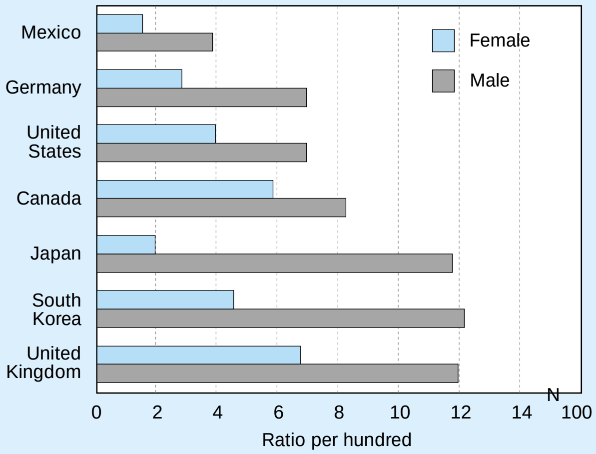
rates in NS&E degrees at the bachelor's level. In 1997, the ratio of NS&E degrees earned by women within the United Kingdom to the female 24-year-old population was 6.7 per hundred, about one-half the U.K. male participation rate. The participation rates for men and women in Canada are more similar. (See figure 4-29 and appendix tables 4-36.)

Among Asian countries, women earn first university degrees at a rate similar to or higher than many European countries. However, only in South Korea do women have high participation rates in NS&E degrees. In 1997, the ratio of their earned degrees in these fields to the female 24-year-old population was 4.5 per hundred, higher than the participation rate of women in other Asian countries, Germany, or the United States. (See figure 4-29.) Among all reporting countries, women earn the highest proportion of S&E degrees in the natural and social sciences. (See appendix table 4-37.)

Figure 4-29.
Ratio of NS&E degrees to the college-age population, by country and sex



See appendix table 4-36. *Science & Engineering Indicators – 2000*

Graduate Enrollment, by Citizenship, Race/Ethnicity, and Sex

Is the United States educating adequate numbers of bachelor-level S&E majors who are willing and able to pursue advanced degrees in S&E? This issue, voiced by Steelman in 1947, is still of interest to scientific and professional societies and to graduate programs of U.S. universities. The concern has been broadened, however, to ensuring access to women and underrepresented minorities in graduate S&E programs. The following section presents trends in graduate enrollment: strong growth of foreign students and the more modest growth in graduate enrollment of U.S. citizens for the period 1983–93, followed by declining graduate S&E enrollment for both U.S. and foreign citizens. It also provides data on increasing gender equity in graduate S&E fields.

For the period 1983–92, growth in enrollment in U.S. graduate programs in S&E depended on the entry of foreign students, particularly in programs of NS&E. During this period, foreign graduate student enrollment increased at an average annual rate of 5 percent. At the peak of their enrollment in U.S. graduate programs, 1992, foreign students represented one-fourth of all S&E students and an even larger percentage in some fields—one-third of the students in engineering, mathematics, and computer sciences. (See appendix table 4-22.) Recently, increased capacity for graduate S&E education within Asian countries and other career options for Asian students have contributed to the decreasing enrollment of foreign students in U.S. institutions. From 1993 to 1996, foreign graduate student enrollment declined at an average annual rate of 3 percent, with a slight upturn in 1997. Foreign student enrollment should be monitored to see whether the slight increase in enrollment in 1997 is a one-year fluctuation or a reversal of a trend toward fewer foreign graduate students in U.S. higher education.

In contrast, U.S. citizens, including the majority white population and Asians/Pacific Islanders, increased their enrollment in graduate S&E programs at a modest rate of 1 percent for the period 1983–93 and decreased their enrollment 3 percent annually since then. Underrepresented minorities, however, showed continual steady progress in increasing graduate enrollment. For the period 1983–95, underrepresented minority students increased their enrollment in graduate programs in fields of NS&E at an average annual rate of 6 percent, but from a low base. In the past two years, this growth rate slowed to less than 3 percent. By 1997, underrepresented minorities were 9 percent of graduate enrollment in S&E fields. (See appendix table 4-22.)

The long-term trend of women's increasing proportion of enrollment in all graduate S&E fields has continued during the past two decades. By 1997, women were 38 percent of graduate enrollment in the natural sciences, 19 percent in engineering, and 58 percent in fields of social and behavioral sciences. However, males are not as prevalent in fields of NS&E among underrepresented minority groups; women in these groups have a higher proportion of graduate enrollment compared with the overall average. For example, women are one-third of black graduate students in engineering and more than one-half of the black graduate students in fields of natural sciences. (See text table 4-8.)

Master's Degrees

Master's Degrees, by Sex

Gender equity in S&E degrees at the master's level has improved continually during the past four decades. Such degrees earned by women increased from 1,744 in 1954 to more than 37,000 in 1996, representing 39 percent of all S&E degrees at the master's level in 1996. By far the largest growth has been in the social sciences. Gender equity has been reached in the biological sciences. Modest increases have occurred in engineering, physical sciences, mathematics, and computer sciences.

Text table 4-8.
Percentage of female enrollment in graduate S&E programs among racial and ethnic groups and foreign students: 1997

Status/race and ethnicity	Natural sciences	Social sciences	Engineering
Total	38	58	19
White	38	59	18
Asian/Pacific Islander	42	61	22
Black	53	66	32
Hispanic	44	61	23
American Indian/ Alaskan Native	44	61	24
Foreign students	33	42	17

NOTE: Natural sciences include physical, biological, agricultural, earth, atmospheric, and oceanographic sciences, mathematics, and computer sciences. Social sciences include psychology, sociology, and other social sciences.

SOURCE: National Science Foundation, Science Resources Studies Division, *Graduate Students and Postdoctorates in Science and Engineering: Fall 1997*, NSF 99-325, Project Officer, Joan Burrelli (Arlington, VA: 1999).

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By 1996, women earned 58 percent of the master's degrees in the social and behavioral sciences and 49 percent in the biological sciences. However, they earned only 27 percent of computer science degrees and 17 percent of those in engineering. Degrees to males have declined in engineering for the past two years, mainly accounted for by declining engineering enrollment of foreign students. (See appendix table 4-23.)

Master's Degrees, by Race/Ethnicity

Minority groups continued to increase their proportion of S&E degrees earned at the master's level. Asians/Pacific Islanders have been increasing the number of master's degrees earned in all fields of S&E for two decades, except for the recent leveling off in engineering fields. (See appendix table 4-38.) The number of master's degrees earned by underrepresented minority graduate students increased modestly in all fields of S&E (especially in the social sciences) from 1990 to the present. (See figure 4-30.) In 1996, underrepresented minorities earned 7.4 percent of the S&E degrees at the master's level. (See appendix table 4-38.)

Master's Degrees, by Citizenship

The number of master's degrees earned by U.S. citizens and permanent residents declined or leveled off in engineering, mathematics, and computer science degrees. (See appendix table 4-38.) The number of master's degrees increased only in the natural sciences, particularly in the agricultural and biological sciences. U.S. citizens earned increasing numbers of master's degrees in the biological sciences. Along with engineering, agriculture is a popular major for foreign students in U.S. as well as Japanese universities. Until 1991, foreign students on temporary visas earned 25 percent of the master's degrees in agricultural science. Chinese foreign students, who shifted to permanent resident status with the 1992 Chinese Student Protection Act, may account for the sharp jump in agricultural degrees recorded between 1992 and 1996 for U.S. citizens and permanent residents (NSF 1999b).

Master's degrees earned by foreign students (on temporary visas), which had increased for two decades, slightly declined in fields of S&E in 1996. Fewer foreign graduate students enrolling in engineering since 1994 account for the fall-off in master's degrees in engineering. (See appendix table 4-38.)

Doctoral Degrees

Doctoral Degrees, by Sex

Women have made continual progress toward gender equity in S&E degrees earned at the doctoral level. The proportion of doctoral S&E degrees earned by women increased from 6 percent in 1954 to 33 percent in 1997. The largest gains were made in the social sciences, from approximately 9 percent in 1954 to 51 percent in 1997, and in the natural sciences, from 5 percent in 1954 to one-third in 1997. In engineering, however, doctoral degrees earned by women increased from 0 percent in 1954 to 12 percent in 1997. (See figure 4-31.)

Among countries with disaggregated data on doctoral degrees by sex, women in France have the highest representation in S&E fields. More than 41 percent of the doctoral degrees in the natural sciences are earned by women and almost 23 percent of the engineering degrees. In comparison, women in the United States earn about 34 percent of the S&E degrees at the doctoral level, almost 35 percent of the natural science degrees, and 12 percent of the engineering degrees. (See text table 4-9 and appendix table 4-40.)

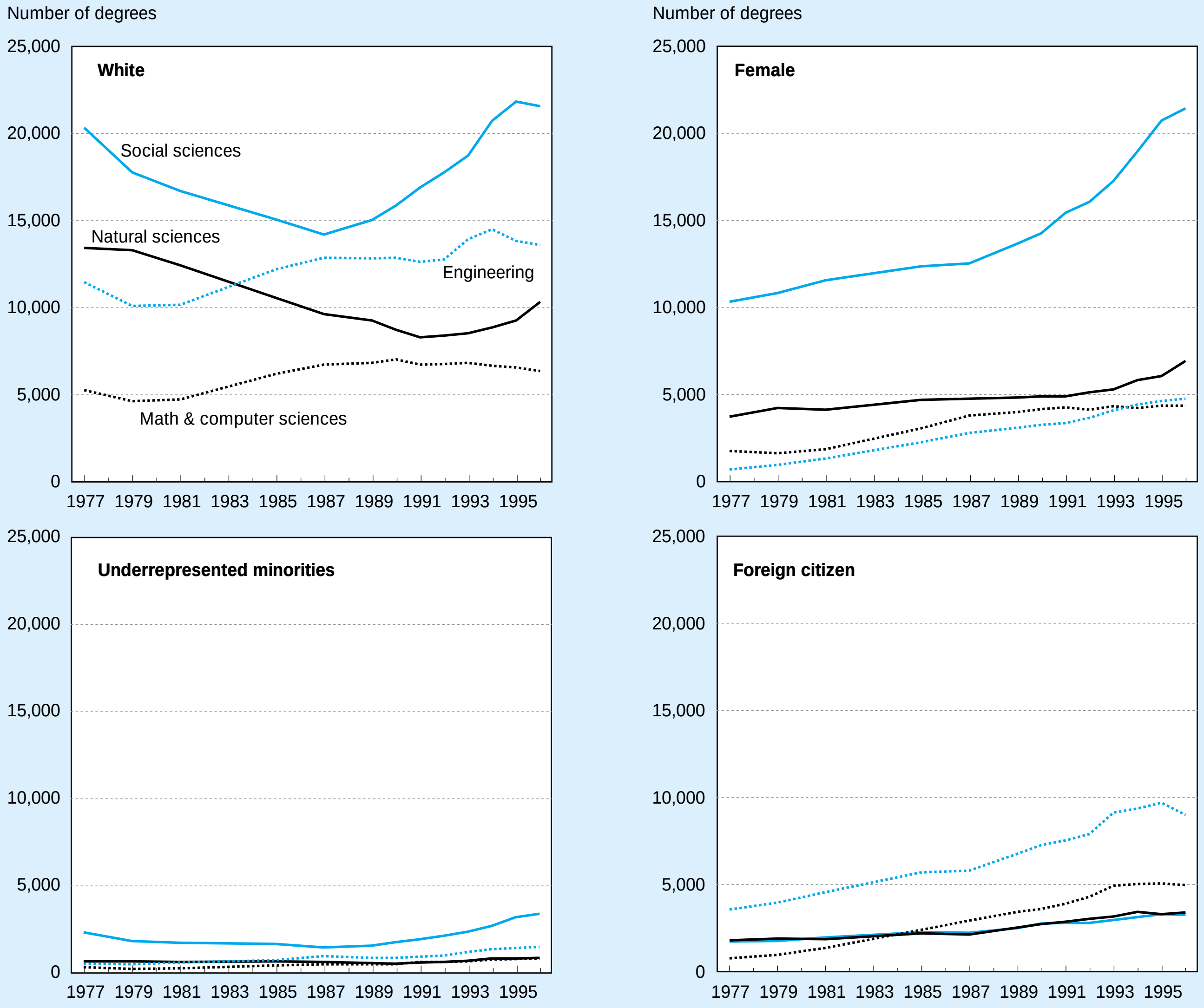
Doctoral Degrees, by Race/Ethnicity

In the period 1977–97, the majority white population earned a stable number of degrees in all fields of science, but an increasing number in engineering fields from 1985 until 1995. After 1995, engineering doctoral degrees earned by whites also leveled off. Underrepresented minorities made steady progress in earned doctoral degrees in NS&E from 1985 to 1997, but maintained a low and level number of degrees in the mathematics and computer science fields. Their doctoral degrees are barely visible on a graph that uses the same scale to compare S&E degrees earned by various groups. (See figure 4-32.) In the 1990s, very steep increases in doctoral degrees in all S&E fields among Asians/Pacific Islanders who were citizens and permanent residents mainly reflect the Chinese foreign students on temporary visas shifting to permanent resident status from the 1992 Chinese Student Protection Act.

Doctoral Degrees, by Citizenship

Each year from 1986 to 1996, an ever-larger number of foreign students earned S&E doctoral degrees from U.S. universities. The number of such degrees earned by foreign stu-

Figure 4-30.
Master's degrees in S&E fields earned by selected groups



NOTES: Data are estimated for 1983. Natural sciences include physical, earth, atmospheric, oceanographic, biological, and agricultural sciences. Social sciences include psychology, sociology, and other social sciences.

See appendix tables 4-23 and 4-38.

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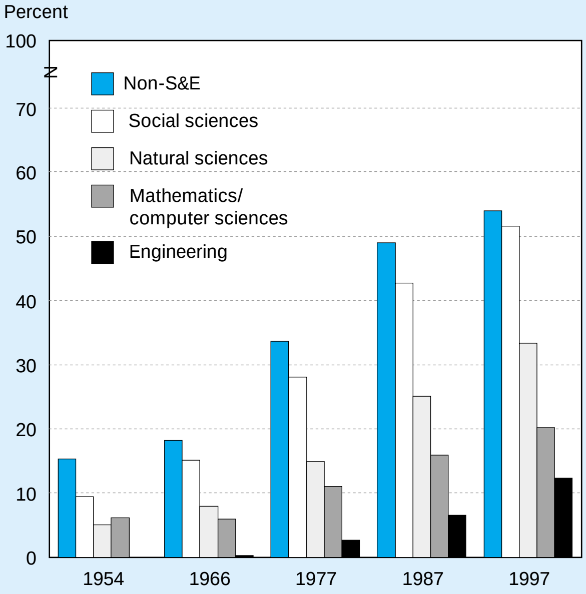
dents increased far faster (7.8 percent annually) than those earned by U.S. citizens (2 percent annually). (See appendix table 4-26.) This decade-long trend of increasing number of S&E doctoral degrees earned by foreign students halted in 1997. In that year, the number of degrees earned by foreign doctoral students dropped by 15 percent (see figure 4-33); their enrollment in U.S. graduate S&E programs had declined from 1993 to 1996 and slightly increased in 1997. Students in several Asian countries are becoming somewhat less dependent on U.S. universities for advanced training, particularly in NS&E. (See “International Comparison of Doctoral Degrees in S&E.”)

Foreign students earn a larger proportion of degrees at the doctoral level than in any other degree level. (See figure 4-34.) This concentration increased for a decade, from the mid-1980s to the mid-1990s, peaked in 1996 at 40 percent of all S&E doctoral degrees, and declined in 1997 to 34 percent.

International Comparison of Foreign Doctoral Recipients. Like the United States, the United Kingdom, Japan, and France have a large percentage of foreign students in their doctoral S&E programs. In 1997, foreign students earned 45 percent of the doctoral engineering degrees awarded within U.K. universities, 43 percent within Japanese universities, and 49 percent within U.S. universities. In that same year, foreign students earned more than 21 percent of the doctoral degrees in the natural sciences in France, 29 percent in the United

Figure 4-31.
Proportion of doctoral degrees earned by women in U.S. universities, by field



NOTES: Natural sciences include physical, earth, atmospheric, oceanographic, biological, and agricultural sciences. Social sciences include psychology, sociology, and other social sciences.

SOURCES: U.S. Department of Health, Education, and Welfare, *Statistics of Higher Education: Faculty, Students, and Degrees 1953–54* (Washington, DC: U.S. Government Printing Office); National Science Foundation, Science Resources Studies Division, *Science and Engineering Degrees, 1966–96.* NSF 99-330, Author, Susan T. Hill (Arlington, VA); and appendix table 4-25.

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Kingdom, and 36 percent in the United States. (See text table 4-10.)

Stay Rates of Foreign Doctoral Recipients. Historically, about one-half the foreign students who earned S&E doctoral degrees within U.S. universities planned to locate in the United States, and a smaller proportion, about 40 percent, had firm offers to do so. In the 1990s, however, foreign doctoral recipients from Asia, Europe, and North America increasingly planned to stay in the United States and received firm offers to do so. By 1997, 69 percent of foreign doctoral recipients in S&E fields planned to stay in the United States following the completion of their degrees, and 50 percent had accepted firm offers to do so. (See appendix tables 4-42 and 4-43.)

In a recent study of foreign S&E doctoral recipients from 1988 to 1996, 39 percent reported they had firm work or study offers in the United States at the time the survey was conducted. Of the 39 percent who received firm offers to stay, 22 percent were for postdoctoral positions, and 17 percent were for employment offers. The primary work activity identified in these offers from industry was R&D. Industry was more likely to make offers to new foreign Ph.D.s who majored in engineering, the physical sciences, and computer science than to those who majored in other fields (NSF 1998).

The decision of foreign doctoral recipients in S&E fields to remain in the United States has implications for the U.S. economy and the concentration of scientists and engineers in the United States, as well as for the economies of the nations from which these students come. For example, in the 1990s, the number of South Korean and Taiwanese S&E doctoral recipients reporting plans to remain in the United States declined because the economies of South Korea and Taiwan increased those countries' capacities to absorb the majority of

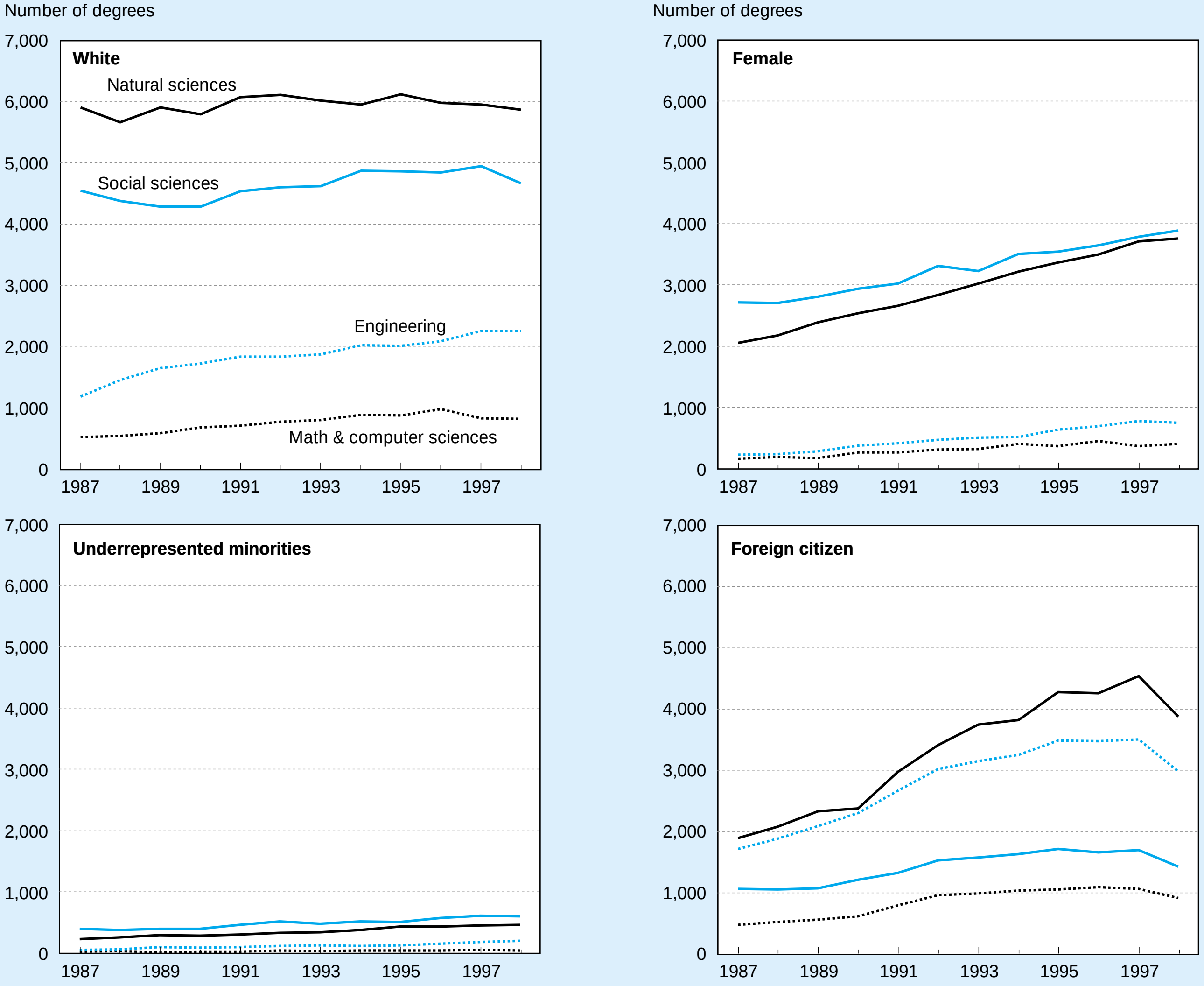
Text table 4-9.
Percentage of doctoral S&E degrees earned by women, by country: 1997 or most current year

		Degree field				
Region/country	All S&E degrees	Natural sciences	Math/ computer sciences	Agricultural sciences	Social sciences	Engineering
Asia						
Japan	10.4	10.2	7.7	15.7	23.4	5.5
South Korea	10.5	18.8	31.0	14.0	13.4	3.0
Taiwan	10.8	15.2	14.3	38.5	25.8	2.3
Europe						
France	35.0	41.4	22.9	51.2	36.3	22.5
Germany	22.5	25.9	17.1	35.5	27.5	8.3
United Kingdom	27.7	34.4	18.4	31.6	32.7	13.4
North America						
Canada	26.7	22.4	14.2	36.9	50.2	9.1
Mexico	33.8	32.7	18.2	27.1	43.3	18.5
United States	33.7	34.9	20.2	26.4	51.6	12.3

See appendix table 4-40.

Science & Engineering Indicators – 2000

Figure 4-32.
Doctoral degrees in S&E fields earned by selected groups



NOTES: Natural sciences include physical, earth, atmospheric, oceanographic, biological, and agricultural sciences. Social sciences include psychology, sociology, and other social sciences.

See appendix tables 4-25, 4-26, and 4-39.

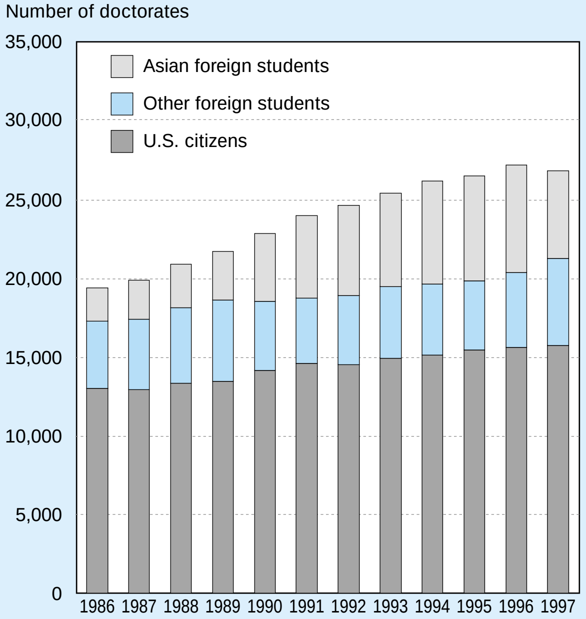
Science & Engineering Indicators – 2000

the U.S.-trained doctoral scientists and engineers. In 1997, however, a larger percentage of foreign students from all Asian countries sought to remain in the United States, possibly reflecting the Asian economic crisis. However, since the S&E doctoral degrees earned by foreign students dropped 15 percent in 1997 (see appendix table 4-26), the numbers actually staying also decreased by 8 percent in that year. (See appendix table 4-42; for the decrease in doctoral recipients from the major countries of origin in North America, Europe, and Asia and the decreasing numbers planning to stay, see figure 4-35 and appendix table 4-43.)

A recent study of foreign doctoral recipients working and earning wages in the United States (Finn 1999) shows that about 53 percent of the foreign students who earned S&E doctorates in 1992 and 1993 were working in the United States in 1997. The stay rates are higher in physical and life sciences and in engineering and lower in the social sciences. For example, 61 percent of the foreign students who earned a doctorate in computer sciences in 1992 and 1993 were employed in the United States four to five years later, while only 32 percent of those in the social sciences were employed in the United States. (See chapter 3.)

Stay rates differ more by country of origin than by discipline, however. The large majority of 1992 and 1993 engineering doc-

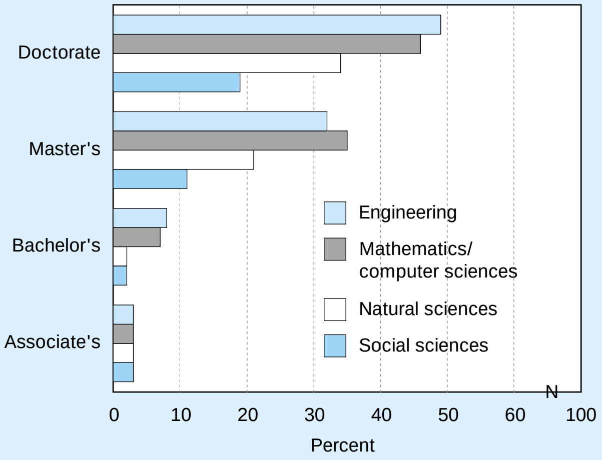
Figure 4-33.
U.S. doctoral S&E degrees earned by U.S. and foreign citizens: 1986–97



See appendix table 4-41 for Asian countries included.

Science & Engineering Indicators – 2000

Figure 4-34.
S&E degrees earned by foreign students, by level and field



NOTES: Associate’s, bachelor’s, and master’s degree data are for 1996; doctoral degree data are for 1997. Natural sciences include physical, earth, atmospheric, oceanographic, biological, and agricultural sciences. Social sciences include psychology, sociology, and other social sciences.

See appendix tables 4-34, 4-35, 4-38, and 4-39.

Science & Engineering Indicators – 2000

Text table 4-10.
Percentage of NS&E doctoral degrees earned by foreign students in selected countries: 1997

Country	Natural sciences[1]	Engineering
United States	36.2	49.4
France	21.1	31.5
Germany	6.9	12.0
Japan[2]	25.8	42.6
United Kingdom	28.9	44.7

[1] Natural sciences include mathematics, computer sciences, and agricultural sciences.

[2] Percentage of NS&E doctoral degrees earned by foreign students within Japanese universities only; not those earned within industry.

SOURCES: **France**—Ministère de l’Éducation National, de la Recherche, et de la Technologie, *Rapport sur les Études Doctorales* (Paris: 1998); **Germany**—Statistisches Bundesamt, *Prüfungen an Hochschulen* (Wiesbaden: 1998); **Japan**—Ministry of Education, Science, and Culture (Monbusho), *Monbusho Survey of Education* (Tokyo: annual series); **United Kingdom**—Higher Education Statistical Agency, *Students in Higher Education Institutions, 97/98* (Cheltenham: 1999); **United States**—National Science Foundation, Science Resources Studies Division, *Science and Engineering Doctorate Awards: 1997,* NSF 99-323 (Arlington, VA: 1999).

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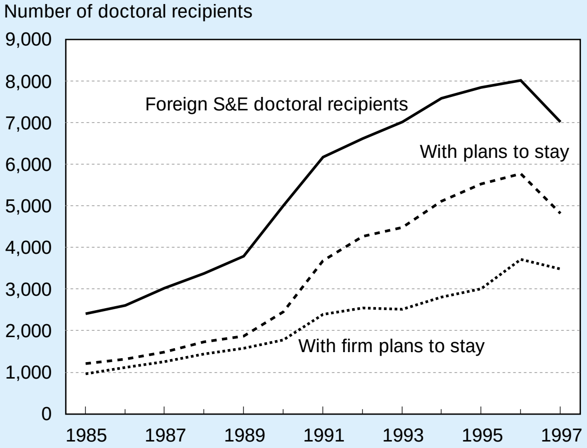
toral recipients from India (90 percent) and China (97 percent) were working in the United States in 1997. In contrast, only 8 percent of South Koreans who completed engineering doctorates from U.S. universities in 1992 and 1993 were working in the United States in 1997. (See appendix table 4-44.)

Stay rates for foreign students are not static. Because China is now the main country of origin of foreign S&E doctoral recipients in the United States, the trend toward increasing stay rates in the 1990s should be followed to see whether it is temporary. Should China succeed in implementing economic reforms that rely heavily on scientific and technological progress, the demand for high-level specialized personnel and the number of new Ph.D.s returning to China may increase substantially.

Postdoctoral Appointments

Postdoctoral researchers play an important role in the dissemination of S&E knowledge and new techniques, and Japan and European countries are introducing more postdoctoral researchers as a way to improve the vitality of their science (AAAS 1999 and Frijdal and Bartelse 1999.) By 1997, postdoctoral researchers in the United States numbered more than 38,000. Postdoctoral appointments for research are made primarily in fields of science and medicine, rather than in engineering. In 1997, postdoctorates in engineering made up only 8 percent of the 38,000 postdoctorates in all surveyed fields. In that year, foreign researchers performed a slight majority (53 percent) of S&E postdoctoral research. These percentages differ, however, in fields of science versus engineering. Postdoctoral appoint-

Figure 4-35.
Foreign S&E doctoral recipients (from North America, Europe, and Asia) with plans to stay in the United States: 1985–97



See appendix table 4-43 for countries included in each region.

Science & Engineering Indicators – 2000

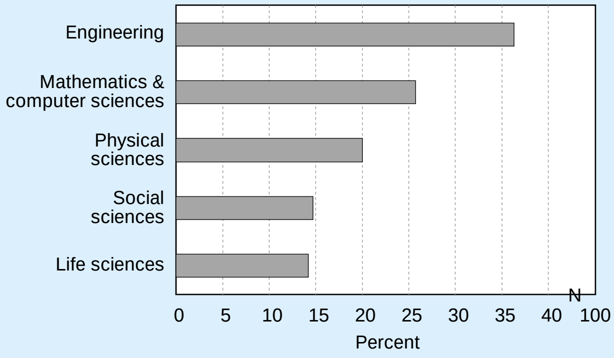
ments in fields of science are filled by approximately equal numbers of U.S. and foreign researchers; engineering postdoctorates are filled more often by foreign researchers (63 percent). (See appendix table 4-45 and chapter 3 for further discussion of postdoctoral appointments.)

International Dimension of U.S. Higher Education Faculty

One indicator of mobility of S&E personnel in the world is the proportion of foreign-born faculty in U.S. higher education. The United States has been a magnet for trained scientists and engineers because of a well-developed economy able to absorb high-level personnel. (See chapter 3 for the proportion of immigrant scientists and engineers in the overall U.S. labor force.)

The U.S. university system has been able to employ considerable numbers of foreign-born scientists and engineers.[20] In 1997, of the 225,000 faculty teaching S&E in four-year institutions, 45,000 are foreign-born scientists and engineers. Foreign-born faculty in U.S. higher education represent more than 36 percent of the engineering professors and more than one-quarter of the mathematics and computer science teachers. (See figure 4-36.) These faculty are mainly from Asian and European countries, with the largest numbers coming from India, China, and England. (See text table 4-11.) The vast majority of these faculty earned their doctoral education in U.S. universities. However, those who received their doctoral education outside the United States and began teaching in U.S. universities after 1993 are not captured in the NSF's SESTAT database. Therefore, the percentages of foreign-born faculty are underestimations, particularly from the countries of the former Soviet Union. Faculty from these countries are most likely to have obtained their doctoral degrees before immigrating to the United States and may have come after 1993. (See appendix tables 4-46, 4-47, and 4-48.)

Figure 4-36.
Foreign-born S&E faculty in U.S. higher education, by field: 1997



See appendix table 4-46. *Science & Engineering Indicators – 2000*

Text table 4-11.
Major countries of origin of foreign-born S&E faculty members in U.S. universities: 1997

Place of origin	Number	Percentage
Total S&E faculty	224,707	100.0
U.S.-born	179,698	80.0
Foreign-born	45,009	20.0
Total S&E faculty from major countries of origin	21,545	9.6
India	6,876	3.1
China	4,830	2.1
United Kingdom	3,426	1.5
Taiwan	1,820	0.8
Germany	1,309	0.6
South Korea	1,218	0.5
Greece	1,044	0.5
Japan	1,022	0.5
Other	23,464	10.4

NOTE: Data include scientists and engineers whose first job is in S&E postsecondary teaching at four-year colleges and universities in the United States; it excludes scientists and engineers who may teach as a secondary job.

See appendix table 4-48. *Science & Engineering Indicators – 2000*

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[20] These data are based on the integrated data files of the NSF SESTAT system, a system of data about the S&E workforce.

Conclusion

The capacity to provide higher education in S&E is expanding throughout the world, with multiple poles of concentration in Europe, Asia, and the Americas. The expansion of S&E higher education in these and other regions, and the consequent decline in the U.S. proportion of S&E degrees, is likely to continue. This increasing global capacity in S&E education, with recent growth in graduate education capacity, has implications for the United States as well as for all nations. Higher participation rates in S&E degrees and a greater focus on S&E fields in higher education in other countries contribute to their potential pool of scientists and engineers. Such human capital is important for addressing complex societal needs and for technological innovations.

These world regions are attempting to create important additional factors for innovation besides S&E degrees and recognize a lag time between S&E degree production and other needed S&E infrastructure that would contribute to their economic competitiveness. Creating graduate S&E departments has proven easier than creating jobs to employ the recent graduates, particularly in developing countries. Nonetheless, a larger global capacity for S&E education implies U.S. needs for (1) S&T information on other world regions and (2) consideration of heightened levels of international scientific cooperation in emerging regions. In addition, the global expansion of S&E knowledge has potential benefits of quickening the pace of development in other world regions.

This global diffusion parallels some limited domestic progress; U.S. higher education in S&E is becoming more diverse, particularly at the undergraduate level. In the 1990s, white enrollment in undergraduate education leveled off and began to decline, while enrollment for all minority groups increased. Similarly, while overall undergraduate engineering enrollment has been declining, enrollment of women and minorities has been increasing, particularly in the 1990s. At the bachelor's level, the number of degrees earned by underrepresented minorities is increasing slightly in NS&E fields and very rapidly in the social sciences. Compared with a decade ago, recent participation rates, disaggregated by race/ethnicity and sex, show considerable progress toward increasing diversity by sex in S&E fields and more limited progress in increasing diversity by race/ethnicity.

The constancy of the ratio of NS&E degrees to the college-age population (5 per hundred) and the declining college-age population have accounted for the decade-long decline in NS&E degrees. This relatively low U.S. participation rate in NS&E degrees compared with other countries may be inadequate for the current and future economy, as reflected in the high number of foreign-born skilled workers who have been provided special visas to attempt to meet the needs of U.S. high-technology industries and services. In addition, the lower participation rates of underrepresented minority groups, currently 28 percent of the U.S. college-age population (see "Diversity Patterns in S&E Enrollment and Degrees in the United States") should be monitored as these groups increase their proportion of the U.S. workforce.

At the graduate level, there have been considerable progress for women and limited progress for minorities in S&E programs. At the master's level, women have made significant progress in earned degrees in the natural sciences, but underrepresented minority groups showed only modest growth in these fields. At the doctoral level, the share of S&E degrees earned by women has more than doubled, from 15 percent in 1975 to 33 percent in 1997. Underrepresented minority students have slightly increased their proportion of doctoral S&E degrees to 7 percent in 1997, from 5 percent in 1987.

The large capacity of U.S. graduate S&E programs in the late 1980s was increasingly met through foreign students, but S&E graduate programs have recently seen a slightly lower concentration of foreign students. The rate of growth in S&E master's degrees earned by foreign students slowed in the 1990s. The declining graduate enrollment of foreign students in engineering since 1993 has resulted in the 1996 fall-off of the number of master's degrees in engineering earned by foreign students. At the doctoral level, the proportion of NS&E degrees earned by foreign citizens reached 47 percent in 1994, but declined to 40 percent by 1997.

Despite these declines, graduate education in the United States will continue to have a large proportion of foreign students in S&E fields, as do France and the United Kingdom. As countries attempt graduate education reforms to improve the quality of their research universities, they will continue to send their students to U.S. research universities and encourage them to remain for postdoctoral training and an industrial research experience. This combination of doctoral education and research experience provides valuable skills to the home country, even in an advisory capacity if the young scientists and engineers remain in the United States for employment.

The U.S. university system has accelerated the diffusion of S&E knowledge in the world through teaching foreign doctoral students who have contributed to the S&T infrastructure in the United States and in their home countries. Besides the global good of enhancement of scientific knowledge and world development, U.S. higher education is itself enriched by the network of former doctoral students and faculty in key research centers in Asia and Europe. The benefits include enhanced cooperative research opportunities, expanded opportunities for U.S. graduate and undergraduate students to study abroad, and international postdoctoral research positions for young U.S. scientists and engineers.

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Chapter 5
Elementary and Secondary Education

Highlights

The quality of mathematics and science education in the United States has been an ongoing concern of scientists, engineers, and decisionmakers. Following World War II, scientists, engineers, and mathematicians expressed grave concerns in the Bush and Steelman reports about the quality of pre-college instruction in their fields as well as the number of students who go on to college and study these subjects. They saw the curriculum as badly out of date, too broad for teachers to master—let alone students—and instruction as too passive for children to develop a genuine understanding of the key concepts and ideas in their fields. The perception of a crisis in education was further created by the launching of Sputnik in 1957 and by the publication of international comparative studies of student achievement starting in the 1970s. Pre-college math and science education is today still a national, state, and local concern. The following highlights point out that some improvements have occurred on a national scale, but that these are not uniform. Additionally, international comparisons show that U.S. achievement is especially low at the end of secondary school, well below the international average.

U.S. Achievement Compared with Other Countries

- ♦ **U. S. student achievement in mathematics and science compared least favorably with that of their peers in other countries at the end of high school, was at or above the international average in middle school, and was above the international average in elementary school in the 1995 Third International Mathematics and Science Study (TIMSS).**
- ♦ **U.S. students in the final year of secondary school scored below the international average on assessments of general science and mathematics.** On an assessment of general mathematics, students in 14 of 21 nations outperformed U.S. students, and on an assessment of general science, students in 11 of 21 countries outperformed U.S. students. The United States performed better than 2 countries, Cyprus and South Africa, in both subjects.
- ♦ **U.S. 12th grade advanced science students performed below 14 of 16 countries on the TIMSS physics assessment. Advanced mathematics students scored below 11 of 16 countries on the advanced mathematics assessment.** Advanced mathematics and science students did not outperform students in any country on either the physics or advanced mathematics assessment.
- ♦ **Eighth grade U.S. science students performed above the 41-country international TIMSS average.** They performed at the international average in chemistry and physics, and above average on life sciences, earth sciences, and environmental issues.
- ♦ **Eighth grade U.S. mathematics students performed below the 41-country international average overall as well as in geometry, measurement, and proportionality.**
- ♦ **The science and mathematics performance of fourth grade students in the United States was among the highest of those countries participating in the TIMSS assessment at that level.** In science, fourth grade students scored well above the international average for 26 countries overall as well as in the four content areas assessed. Fourth grade students scored above the international mean in mathematics overall and in all content areas except measurement.

National Trends in Achievement

- ♦ **U.S. students in the 1990s were generally performing better in mathematics and science as measured by the National Assessment of Educational Progress (NAEP) than did their counterparts in the late 1970s.** The "benchmarks" selected for this report are scores on NAEP trends assessment of 200, 250, and 300, respectively, for ages 9, 13, and 17.
- ♦ **The science and mathematics achievement of both male and female students has increased in the last two decades at all ages tested (9, 13, and 17).**
- ♦ **No significant difference in mathematics performance was observed between boys and girls at ages 9 and 13 between 1978 and 1996.** Differences in mathematics performance for 17-year-old males and females were observed in NAEP between 1978 to 1986, but not between 1990 and 1996.
- ♦ **No gender differences in mathematics were observed at any grade in the international assessment administered for the TIMSS.**
- ♦ **Gender differences in science achievement continue to exist in the 1996 NAEP for students at ages 13 and 17.** Differences between boys and girls in science achievement in the United States were generally small compared with differences for students in other countries (TIMSS).
- ♦ **The percentage of white, black, and Hispanic students that reached the benchmark levels of science achievement at ages 9, 13, and 17 increased between 1977 and 1996.** The change was particularly noteworthy for

9-year-old black students, who increased by 25 percentage points over that period.

- **White, black, and Hispanic students in the three age groups demonstrated upward trends for mathematics proficiency between 1978 and 1996.** Differences in achievement levels of racial and ethnic groups persist, however.

Advanced Course Taking by High School Students

- **More students took advanced mathematics and science courses in 1994 than in 1982.** More than 90 percent of the high school class of 1994 completed biology, more than one-half completed chemistry, and about one-quarter completed physics. Approximately 70 percent of the class of 1994 completed geometry, 58 percent completed algebra 2, and 9 percent completed calculus.
- **Students from racial/ethnic groups that are typically underrepresented in science and mathematics made substantial gains in the proportions taking advanced mathematics and science courses.** For example, the proportion of black students completing chemistry doubled between 1982 and 1994; the completion rate for Hispanic students nearly tripled; and for American Indian/Alaskan Natives, the proportion increased by more than one-half. More students in all racial/ethnic groups completed physics between 1982 and 1994, although the proportion of students from black, Hispanic, and American Indian/Alaskan Native groups remained lower than for white and Asian students in 1994.

Curriculum and Instruction

- **Access to technology in schools grew rapidly in the 1990s.** Hand-held calculators are in common use in both U.S. homes and classrooms. Computers are seemingly ubiquitous and Internet connectivity is on the increase. By 1998, nearly all schools reported having at least one computer linked to the Internet and half of individual classrooms had access to the Internet. However, at present, only about one teacher in five felt “very well prepared” to integrate education technology into the subjects they taught.
- **A “digital divide” persists in access to technology in schools.** Black and Hispanic students and less affluent students continue to have less access to high-end technology at school.
- **Curriculum and textbooks used in U.S. schools are highly repetitive, contain too many topics, and provide inadequate coverage of important topics, according to a curriculum analysis conducted as a part of TIMSS.** Independent judges determined that none of the 9 U.S. science texts that were evaluated and only 6 of the 13 U.S. mathematics texts were satisfactory based on 24 instructional criteria.
- **Instruction in U.S. eighth-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 while 87 percent of lessons from U.S. classrooms were judged to be of low quality.

Teachers and Teaching

- **There are few adequate indicators of the quality of teachers to describe teaching in the United States.**
- **It is common for students to be taught mathematics and science by teachers who do not hold degrees in these subjects.** For example, a 1996 study showed that more than a third of eighth graders were taught mathematics by teachers who had neither a degree in mathematics nor a degree in mathematics education. This mismatch was even larger in science.

Alternative Forms of Schooling

- **Charter schools now serve approximately 170,000 students out of 48 million students in the United States.** From school year 1992/93 to 1997/98, the number of charter schools increased from 2 (in Minnesota) to approximately 1,000 nationwide.
- **More low-income students have access to privately funded vouchers and scholarships.** In school year 1992/93, close to 4,100 low-income students in four urban districts received privately funded vouchers or scholarships to attend better schools. In school year 1996/97, approximately 11,000 low-income students in 28 urban districts received private scholarships.
- **Increased numbers of parents are choosing to educate their children at home.** Home schooling has increased from an estimated 250,000 to 350,000 nationwide in 1991/92 to approximately 700,000 to 750,000 in 1995/96.

Introduction

The U.S. education system encompasses over 15,000 school districts and 88,000 public schools (NCES 1999a). Under the Constitution, educational matters are the province of the states, which delegate certain decisions to school districts or other local education agencies. Local decision making gives rise to local differences in instructional practices, which in turn yield differences in achievement. It is useful to keep this point in mind throughout the following discussion.

The statistical information presented in this chapter has been selected from representative national surveys, most of which were collected and published by the National Center for Education Statistics (NCES), an agency of the U.S. Department of Education.

Chapter Organization and Sources of Data

This chapter begins with a brief discussion of education-reform efforts that began in the 1950s. The remainder of the chapter is organized into four main sections, each addressing a critical aspect of mathematics and science education reform.

Student Achievement. This section discusses student achievement from both national and international perspectives. It is based on two primary sources of data: National Assessment of Educational Progress (NAEP) trends studies, which provide the Nation's only continuous comparable measures of student performance in four core subjects in the United States—reading, writing, mathematics, and science. They have been administered to nationally-representative samples of 9-, 13-, and 17-year-old students every two to four years since 1969. NAEP results have been reported in terms of performance levels only since 1977, which is the point where this chapter begins tracking NAEP achievement. Second, the Third International Mathematics and Science Study (TIMSS) provides information about representative samples of students in the primary and middle grades as well as students in their final year of secondary school. TIMSS includes several components: assessments in science and mathematics from 41 nations, student and teacher surveys, an analysis of curriculum guides and textbooks from 26 nations, and an observational-video study conducted in eighth grade mathematics classrooms in the United States, Germany, and Japan.

Patterns of Course Taking. This section describes the extent to which students of different gender and ethnicity completed higher-level mathematics and science courses in 1994 as compared to earlier years. The data are taken from the 1994 High School Transcript Study (HSTS). Results are based on the records of over 25,000 seniors who graduated between 1982 and 1994 (NCES 1998e).

Curriculum and Instruction. This section of the chapter discusses instructional time, curriculum and textbooks, instructional practice, and technology. Information is drawn from the curriculum and component of TIMSS as well as NCES Fast Response Surveys on telecommunications technology and classroom implementation of educational reforms.

Teachers and Teaching. This section provides an overview of teacher characteristics and qualifications, estimates of the proportion of teachers with classes outside their fields, and a discussion of new directions in teacher preparation, licensing, and professional development. Primary sources for this discussion are a recent NCES Fast Response Survey on teacher qualifications and recent educational literature pertaining to the policy aspects of teaching.

Educational Reform from the 1950s to the Present

As the National Science Foundation (NSF) celebrates its 50th year and the new millennium approaches, the Nation has identified educational reform as one of its highest priorities. Large-scale education reform in the United States has been attempted many times. However, it is quite a difficult undertaking—much more so than in other nations—due to the greater size and complexity of the U.S. system and the greater diversity of our students.

The roots of current reform efforts can be traced to developments that took place in the 1950s and 60s. Early in that era, even before the launching of Sputnik in 1957, scientists and mathematicians expressed grave concerns about the quality of precollege instruction in their fields. Among other things, they saw curricula as badly out of date and instruction as too passive for children to develop genuine understanding of the key concepts and ideas in their fields. (See sidebar, "View of Mathematics and Science Education in Elementary Schools in 1947.") With support from NSF, small groups of scientists and mathematicians began designing radically different curricula. The University of Illinois Committee on School Mathematics, under the leadership of Max Bebberman, began work on a new curriculum for high school mathematics. The Physical Science Committee, under the leadership of Jerald Zacharias, began working on new science curricula in their field (Bybee 1997, Dow 1997, and Rutherford 1997). Later, other groups of scientists came together to work on curricula for biology and chemistry.

With the launching of Sputnik, concerns about mathematics and science education reached crisis proportions. The American public joined scientists and educators in calling for reform, believing that U.S. schools were graduating too few talented scientists and engineers to assure the security of the Nation. There were two dominant views how instruction should be overhauled. Mathematicians and scientists thought the solution involved elevating academic standards and curriculum. Others argued for a return to past educational practices—reflecting a "back to basics" philosophy. The latter position was argued perhaps most vocally by Admiral Hyman Rickover, here cited by Dow (1969, 59):

> We are engaged in a grim duel. We are beginning to recognize the threat to American technical supremacy, which could materialize if Russia succeeds in her ambitious program of achieving world scientific and engineering supremacy by turning out vast numbers of well-trained scientists and engineers.

> We have let our educational problem grow far too big for comfort and safety. We are beginning to see now that we must solve it without delay.

NSF responded to the perceived crisis by expanding its work in curriculum development. With NSF support, curriculum projects proliferated in the early 1960s. (See sidebar, "National Science Foundation Support of Post-Sputnik Reforms in Science and Mathematics Education.") According to Shymansky, Kyle, and Alport (1983), the science programs were successful. By the early 1970s, NSF-funded science curricula for grades 7 through 12 were used in 60 percent of school districts and materials for elementary grades were used in 30 percent of the school districts. Because the new curricula were difficult to implement, by 1976/77, only 30 percent of districts continued to use one or more of the new science programs. New mathematics curricula fared less well, used in only 30 percent of districts in the early 1970s and in only 9 percent in 1976/77 (Bybee 1997).

The United States turned its attention to other matters until another crisis in education was declared early in the 1980s. During those years, numerous reports were published that were highly critical of the U.S. educational system. The most influential of the reports was *A Nation at Risk* (NCEE 1983):

> Our nation is at risk. Our once unchallenged prominence in commerce, industry, science, and technological innovation is being taken over by competitors throughout the world….While we can justifiably take pride in what our schools and colleges have historically accomplished and contributed to the United States and the well-being of its people, the educational foundations of our society are being eroded by a rising tide of mediocrity that threatens our very future as a nation and as a people. What was unimaginable a generation ago has begun to occur: others are matching and surpassing our educational attainments.

A Nation at Risk provided several recommendations for improving the nation's schools including increasing the requirements for graduation, increasing instructional time in core subjects, lengthening school days and school years, significantly improving teaching, and developing and implementing rigorous and measurable standards. Different initiatives were undertaken in response to these recommendations. State policy makers implemented the "new core" curriculum proposed in *A Nation at Risk*, which required four years of English, three of mathematics, three of science, three of social studies, and one-half year of computer science. High school students were required to pass exit examinations in order to receive diplomas and assure that they had command of fundamental academic skills. In the 1970s, only a handful of states required exit exams. By 1990 at least 40 states had adopted this practice (Geisinger 1992). Schools were required to develop and monitor their progress on improvement plans. More stringent screening and certification requirements were put in place in an effort to upgrade the quality of teaching (Popkewitz 1992).

Other reform initiatives focused on the structure of decisionmaking and power relationships among teachers, principals, district administrators, and parents. In many school districts, decision making was decentralized based on the assumption that those closest to the children in a school were best equipped to identify and meet the children's learning needs. School-based management and a variety of other approaches to restructuring schools were tried (Peterson 1992). New models of professional development were proposed (Sparks and Loucks-Horsley 1990, Darling-Hammond 1994) and initiatives to "professionalize" teaching were promoted, many of which focused on empowerment strategies.

The development of standards ushered in the current decade of educational reform, one that has been centered on content and instructional strategies. The National Council for Teachers of Mathematics was first to develop new standards for student learning (NCTM 1989) and teaching (NCTM 1991). The standards provided guidelines for instruction and

View of Mathematics and Science Education in Elementary Schools in 1947

It is better to teach a few things for mastery than to spread the effort over a larger number of goals, some of which are doubtful.

Present-day textbooks in arithmetic are thick and include a wide range of materials, and the unskilled teacher has difficulty determining the things that are important. The teacher may not have a clear notion (1) of the new mathematical terms that should be mastered in a given semester, (2) of the new principles that should be learned, (3) of the skills that should be gained, (4) of the concepts that should be carefully taught, and (5) of the attitudes that should be established.

[The] practical limitations to the teaching of arithmetic are

(1) the oversized classes of 30, 40, or even 50, when they should probably be held to approximately 20,

(2) failure of teachers to have and to utilize classroom materials and equipment,

(3) the tendency of teachers to forget the long trail that they themselves have traveled to arrive at generalizations and at the meaning of symbolism,

(4) the fact that many teachers undertake the teaching of arithmetic with no training in arithmetic beyond what they had in elementary school,

(5) the utilization of conflicting methods by teachers in the same school system or in the same building,

(6) the lack of specific objectives in arithmetic, and

(7) the failure of the teacher to take each pupil where he is and to provide experiences in accord with his normal growth and development.

SOURCE: Steelman, J.R. 1947. *Science and Public Policy*. Washington, DC: U.S. Government Printing Office. Reprinted 1980. The University of California, Irvine. New York: Arno Press.

National Science Foundation Support of Post-Sputnik Reforms in Science and Mathematics Education

One of the primary forces shaping the science reforms of the 1950s and 1960s was the National Science Foundation. Founded in 1950, the NSF's education effort prior to Sputnik had been confined to promoting science fairs and clubs and funding summer institutes for teachers. In 1955, the NSF annual report expressed growing concern about the shortage of high school students entering scientific careers, but was reluctant to lobby Congress for funds given the nation's historic aversion to federal influence in school matters. While the Foundation had cautiously supported Jerrold Zacharias' early planning work on PSSC Physics at M.I.T., it took the launching of Sputnik to release a torrent of federal funds.

In 1958, the NSF increased its support for curriculum development at a rapid pace; in addition to supporting PSSC, the organization funded the School Mathematics Study Group at Yale and the Biological Sciences Curriculum Study of the American Institute of Biological Sciences. Within the next two years, the organization also launched two programs in high school chemistry: the Chemical Bond Approach Project and the Chemical Education Materials Study of the American Chemical Society. By 1960, the programs of the Education Directorate represented 42 percent of the NSF annual budget. Each of these projects, at NSF's insistence, was guided by a steering committee of prominent scientists and engineers....

If the movement had lasted longer, it may have had a wider impact on schools. Unfortunately, by the end of the decade, federal support for curriculum innovation was beginning to wane … What finally killed the science reform movement, however, was the Apollo moon landing in 1969. When the world saw Neil Armstrong unfurl the American flag on the surface of the Moon, our 'education gap' seemed as mythological as the so-called 'missile gap,' and ironically congressional support for science education began to fade. Before the mid-seventies, the Education Directorate of the National Science Foundation had shrunk to 10 percent of the agency's budget, and following election of President Reagan in 1980, the Directorate closed altogether. The Sputnik reforms were to prove as ephemeral as the technological threat that spawned them.

SOURCE: Dow, P. 1997. "Sputnik Revisited: Historical Perspectives on Science Reform. Prepared for the symposium, "Reflecting on Sputnik: Linking the Past, Present, and Future of Educational Reform." Washington, DC. October 4.

learning, building upon earlier reports issued by the Mathematics and Science Education Board (MSEB) of the National Research Council (NRC) and the Mathematical Association of America (MAA). The science standards followed several years later (NRC 1996). Although not formally released by the NRC until 1995, the science education standards reflected a consensus arrived at earlier and built upon work of the National Science Teachers Association (NSTA) and the American Association for the Advancement of Science (Rutherford and Algren 1990). The seminal reports of these associations are included in the list of references (NSTA 1992, NRC 1996, and AAAS 1999a,b).

Central to standards in both subjects is the idea that students must become what Robert Glaser has described as "mindful architects of their own knowledge" (cited in Maloy 1993). In this constructivist view, students play a proactive role in their learning, rather than passively receiving information doled out by teachers or textbooks. The teacher's primary role is to facilitate and support the process by creating opportunities for students to engage in higher-level processes—solve novel problems, integrate information, and actively build their own understanding of a particular idea or situation (Anderson 1996). The standards for mathematics and science, share several basic tenets, including:

- promoting high expectations for all students;
- emphasizing depth rather than breadth of content coverage; and
- emphasizing tasks that provide students the opportunity to become actively engaged with the subject matter, problem solving, and applying skills learned in new, broader contexts.

Many of the core ideas underlying new educational standards in science and mathematics are legacies of the 1960s reform agenda, but there are important differences. One such difference is that the factor motivating change during the post-Sputnik years was the perceived need to expand the pool of potential scientists. Consequently, curricula developed during that period targeted students at the higher end of the achievement spectrum. By contrast, as educational reform evolved in the late 1980s and early 1990s, there was a genuine interest in providing a high quality education for all students. In contemporary reforms, equity and excellence are treated as equally important goals (DeBoer 1997 and Rutherford 1997).

Current reform efforts differ from earlier attempts in the breadth of their activity. From the 1960s through the 1980s, many reform strategies were pursued in isolation: some approaches focused solely on curriculum, some focused solely on structural change, and some focused exclusively on teachers. In the 1990s, the idea that all parts of the education system must be changed to meet new standards and goals was formalized in an often-cited publication by Smith and O'Day (1991), which put forward the notion of "systemic" approaches to reform. Such methods are grounded in three core ideas:

promotion of high standards for all students, purposeful alignment of policies to support good instructional outcomes, and restructuring of governance systems around the goal of improved achievement (Smith and O'Day 1991).

The sidebar, "Systemic Reform: Complex Solutions to Complex Problems," describes the intricacies involved in systemic reform, as conceptualized by NSF in the late 1970s, although the term "systemic reform" was not yet in common use.

Federal agencies have actively supported systemic reform, with the systemic initiatives funded by NSF among the best known efforts. In the first cycle of the program, NSF awarded grants to support state level reforms aimed at improving instruction and raising academic achievement. Later, the program was extended to support systemic reform in urban communities, then in rural communities, and most recently, local reform at the school district level. The U.S. Department of Education's Eisenhower Initiatives complemented these efforts, providing funds for the kind of high quality professional development needed to achieve high standards.

Legislation, particularly the "Goals 2000: Educate America Act," has bolstered the idea of large-scale reform. At the core of Goals 2000 are the eight National Education Goals that grew out of educational summits organized by the nation's governors, then-President Bush and later, President Clinton. The national goals as they appear in the legislation are presented in the sidebar, "The National Education Goals."

The legislation provides funds for states to pursue national goals through comprehensive reform efforts that encompass development and implementation of challenging standards, content, and assessments; strengthening professional development; and aligning governance strategies and accountability systems to be consistent with academic goals (Landess 1996).

The Social Context of Education

Learning experiences in schools, as elsewhere, are conditioned by the social context in which they occur. For schools, social context is greatly influenced by characteristics of the children in attendance. School enrollment is viewed as an indicator of the demand for teachers, facilities, and resources. In 1950, approximately 25 million students were enrolled in public elementary and secondary schools (NCES 1998a). The 1999 enrollment is expected to include 33.7 million elementary school students and 13.5 million secondary students. Public school enrollment is projected to be 48 million students by the year 2009 (NCES 1999a). (See figure 5-1 and text table 5-1.)

The composition and diversity of the school population have increased in the last several decades and projections suggest that these trends will continue into the 21st century. Hispanic students made up 7 percent of the school population in

Systemic Reform: Complex Solutions to Complex Problems

….[T]here are too many complex, interconnected problems present for any one, simple solution to alter the fundamental dynamics of teaching and learning in the overall education system or even a single classroom…. Clear standards for science education…that give life and meaning to classroom practice are an important part of the answer, but real, sustainable change demands much more:

- A transformation of people's beliefs about science education well informed by the processes of science and by our evolving understanding of children's ability to learn complex, thought-provoking material;
- The creation in each district and school of a clear vision of effective science teaching and a set of goals that reflects this evolving knowledge;
- High-quality instructional materials that support a coherent presentation of important science concepts—and the resources necessary to make those materials available to every student;
- New kinds of tests that more accurately measure students' deep understanding of ideas, not just their short-term recall of facts;
- A long-term commitment of professional development to a generation of educators capable of turning this vision of teaching and learning into reality;
- A broadening of public understanding and support for effective science education and the development of community partnerships that spur schools, universities, museums, foundations, and corporations to work toward common goals;
- Steadfast support from district administrators and policymakers who recognize the crucial importance of local school-based initiatives;
- Enlightened leadership that understands how all of these factors affect and depend upon each other; and
- The need for all of these changes to occur at the same time.

This is the soul of a systemic approach to science education reform: a wide-angle view of school change that sees all aspects of the system as a whole. It recognizes that if changes are to be long lasting, each and every component part of the system must be irreversibly and permanently altered.

SOURCE: National Science Foundation (NSF). 1997a. "Foundations: A Monograph for Professionals in Science, Mathematics, and Technology Education." In *The Challenge and Promise of K-8 Science Education Reform, Volume 1*. NSF 97-76. Washington, DC.

The National Education Goals

By the year 2000:

1) All children in America will start school ready to learn.

2) The high school graduation rate will increase to 90 percent.

3) American students will leave grades 4, 8, and 12 having demonstrated competency in challenging subject matter…including mathematics and science.

4) The Nation's teaching force will have access to programs for the continued improvement of their professional skills and the opportunity to acquire the knowledge and skills needed to instruct and prepare all American students for the next century.

5) U.S. students will be first in the world in mathematics and science achievement.

6) Every adult American will be literate and will possess the knowledge and skills necessary to compete in a global economy and exercise the rights of citizenship.

7) Every school in the United States will be free of drugs, violence, and the unauthorized presence of firearms and alcohol and will offer a disciplined environment conducive to learning.

8) Every school will promote partnerships that will increase parental involvement and participation in promoting the social, emotional, and academic growth of children.

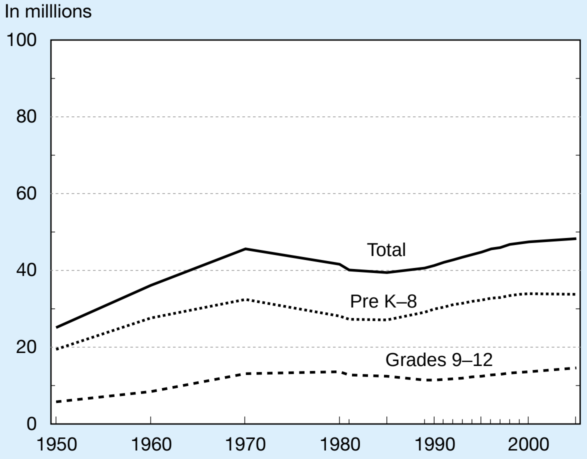
SOURCE: U.S. Department of Education. 1999. Educational Excellence for All Children Act of 1999. Fact sheet. Available from <<http://www.ed/gov/offices/OESE/ESEA/factsheet.html>>. Accessed August 12, 1999.

1979 and 14 percent in 1996. Growth in the percentage of black students in the public school population was more modest: 15 percent in 1970, 16 percent in 1979, and 17 percent in 1995, with concentrations of both ethnic groups much higher in central city schools. In 1996, approximately 32 percent of students in central city schools were black and 25 percent were Hispanic (NCES 1999c). (See text table 5-2.)

More language diversity has been introduced into schools as the number of immigrant and Hispanic students has increased. Recent data show more school-aged children now live in non-English speaking homes than ever before. That number has increased steadily from 2.9 million in 1980 to 4.2 million in 1990 (NCES 1998b).

Several family characteristics associated with school success also have changed in recent years. Mothers of younger children were better educated in 1997 than in 1972. Fewer mothers had less than a high school diploma, a decrease from 34 percent to 16 percent over that period, and more mothers were employed, 38 percent in 1972 vs. 66 percent in 1997. Fewer children lived in large families (four or more siblings),

Figure 5-1.
Total enrollment in public elementary and secondary schools: 1950–2005



SOURCE: U.S. Department of Education, National Center for Education Statistics, Statistics of State School Systems; Statistics of Public Elementary and Secondary School Systems; Statistics of Nonpublic Elementary and Secondary Schools; Projections of Education Statistics to 2007; Common Core of Data. National Center for Education Statistics (NCES). 1999. *Digest of Education Statistics,* 1998. NCES 1999-036. Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement.

See appendix table 5-1. *Science & Engineering Indicators – 2000*

Text table 5-1.
Total enrollment in public elementary and secondary schools: 1981–2009, selected years

Year	Total	Prekindergarten through grade 8 (in thousands)	Grades 9 through 12
Fall 1981	40,044	27,280	12,764
Fall 1985	39,422	27,034	12,388
Fall 1990	41,217	29,878	11,338
Fall 1995	44,840	32,341	12,500
Fall 1999[a]	47,244	33,701	13,543
Fall 2000[a]	47,533	33,875	13,658
Fall 2005[a]	48,392	33,723	14,669
Fall 2009[a]	48,126	33,427	14,699

[a] Projected.

SOURCE: National Center for Education Statistics (NCES). 1999. *Projections of Education Statistics to 2009.* NCES 1999-038. Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement.

Science & Engineering Indicators – 2000

Text table 5-2.
Percentage of students in grades 1–12 who are black or Hispanic in all public schools and public schools within central cities: 1970–96, selected years

	Black		Hispanic	
Year	Total	Central cities	Total	Central cities
1970	14.8	32.5	—	—
1979	16.1	35.8	6.8	14.0
1985	17.0	36.0	10.1	21.5
1990	16.5	33.1	11.6	19.8
1994	16.8	33.0	13.4	24.7
1995	17.1	31.8	14.0	24.3
1996	17.0	31.9	14.3	25.0

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

— Not available

Science & Engineering Indicators – 2000

a decrease from 24 percent to 6 percent. (See appendix table 5-4.)

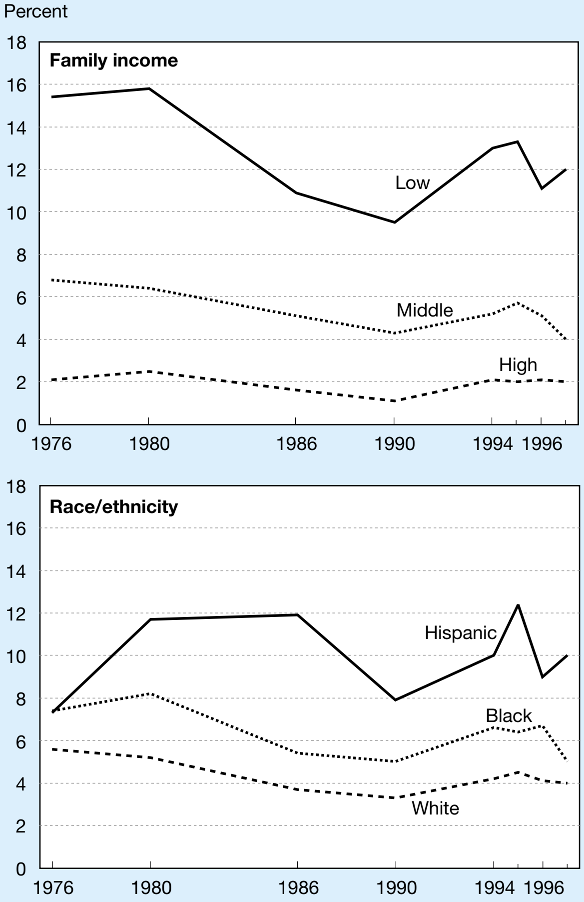
Not all changes reflected improved circumstances. Median family income[1] dropped from $38,000 in 1989 to approximately $35,000 in 1995 and 1996 (Peterson 1992) and the number of poor children has increased. In 1970, approximately 10 million children under 18 years of age (15 percent) lived in families with earnings below the poverty level. In 1996, 14 million children (20 percent) lived in poverty. (See appendix table 5-1.) Black and Hispanic children were more likely to live in poverty than white children. For example, in 1996, approximately 40 percent of black and Hispanic children (4.4 and 4.1 million, respectively) lived below the poverty line, compared to 16 percent of white children (8.5 million).

Although diversity adds richness to the learning environment, it also presents special challenges. Poor and minority children and children with limited English proficiency are more likely to experience difficulty in the early grades, to repeat a grade, or to need special education services (NCES 1998b). Black, Hispanic, and low-income students also are more likely to leave school without a high school diploma. (See figure 5-2.) Of those who complete high school, black students and low income students are less likely to enroll in college following graduation (NCES 1999c).

Additionally, families are more mobile, another factor related to poor school outcomes. The National Center for Education Statistics (NCES) estimates that one in three students changes schools more than once between first and eighth grades (NSB 1999). These moves sometimes seriously disrupt the continuity of learning, making it difficult for teachers in the new schools to identify and meet the academic needs of these highly mobile students (Kelly, Suzuki, and Gaillard 1999; NSB 1999).

As the National Science Board (1999) pointed out, responding to these challenges may be the most difficult task faced by schools and teachers in the next century. In their view, it is no longer acceptable for race, ethnicity, gender, language, or

Figure 5-2.
Percentage of 15 to 24-year-olds (grades 10–12) who dropped out of school, by family income and race/ethnicity: 1976–97



SOURCE: National Center for Education Statistics (NCES). 1998. *The Condition of Education 1998.* NCES 98-013. Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement.

See appendix tables 5-2 and 5-3.

Science & Engineering Indicators – 2000

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[1] Median incomes are computed in 1996 dollars adjusted by the Consumer Price Index.

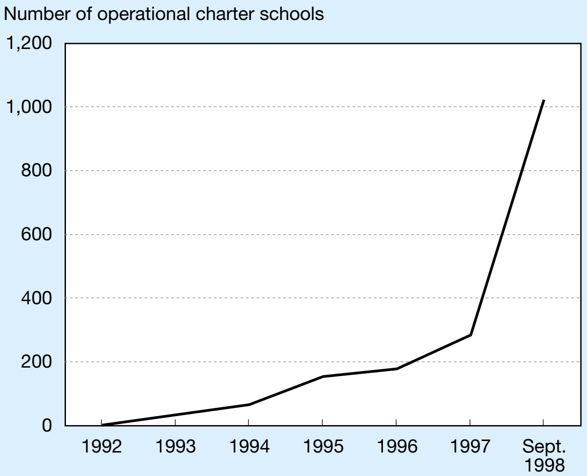
economic disadvantage to be used as excuses for the poor academic achievement of particular groups of children.

Schooling and School Choice in the 21st Century

Even with the thrust toward national standards and national goals—and perhaps in some cases *because* of that thrust—the balance of control over education is changing rapidly as the 21st century approaches. Where the option is available, many parents are enrolling their children in charter schools. Charter schools operate under a contract (or charter) with a public agency, most often a local school district. The charter frees the school from state and local regulations that might otherwise limit their use of innovative approaches to instruction. In return, the school agrees to meet specific achievement goals within a specific time period, usually three to five years. If the targets are not met, the charter is not renewed.

The number of charter schools varied considerably over states in 1998, from 5 or less in Mississippi, Hawaii, Rhode Island, Nevada, New Mexico, Delaware, and South Carolina, to over 100 in California, Michigan and Arizona (CSU 1998). In the years since the first two charter schools opened in Minnesota in 1992, the number of schools operating by charter has grown steadily. (See figure 5-3 and appendix table 5-5). Currently, the number of charter schools in operation is estimated at between 1,022 (Berman 1998) and 1,200 (Hadderman 1998 and CER 1999) nationwide. According to recent estimates, these schools serve 170,000 students, still a small proportion of the approximately 47 million elementary and secondary students in the United States.

Figure 5-3.
Charter schools by year



SOURCE: California State University (CSU). 1998. *Charter Schools: National Concept, California Experience.* Proceedings of a roundtable discussion sponsored by the California Education Policy Seminar and the California State University Institute for Education Reform. Sacramento, CA. October 1.

See appendix table 5-5. *Science & Engineering Indicators – 2000*

Educational vouchers are another mechanism for choice. The idea was first proposed in the 1950s by economist Milton Friedman, who argued that schools would upgrade the quality of their offerings (or go out of business) if they had to compete for students and resources (Hadderman 1998). Today, vouchers are promoted as a way to move central city children from failing schools to more successful schools. But vouchers remain controversial on several fronts. One of the most contentious issues is whether large-scale voucher systems will deplete much needed resources from public schools. Another point of dispute centers on the appropriateness and legality of using public funds to send children to private and religious schools. A number of privately-financed voucher plans, generally given in the form of scholarships, also have made an appearance in recent years. According to estimates, in 1992/93 approximately 4,100 privately-financed scholarships were offered to low-income students in four urban districts; in 1996/97, close to 11,000 needy students in 28 urban districts received private scholarships (Hadderman 1998).

Home-schooling also has increased in recent years—from an estimated 250,000 to 350,000 students nationwide in 1991/92 to approximately 700,000 to 750,000 students in 1995/96 (Lines 1996). Home schooling is generally seen as the ultimate form of school choice. In the 1970s, home schooling was a prevalent choice among families committed to a philosophy of child-led learning. Later, families chose to educate their children at home for religious reasons. Currently, issues of school safety and local control over curriculum also are prompting more parents to choose this alternative (Lines 1996). Students taught at home generally attend a campus-based school at least part-time for special subjects and special activities. Community resources and nearby colleges are drawn on to round out home programs of study (Lines 1996).

Although almost all states require families to register their children as "home schoolers," other regulations vary by state. Some states require parents to submit instructional plans for home-schooled students to the local or state education agency. Some require home-schooled children to participate in state testing programs. Few regulations exist, however, to assure that parents have some minimal level of educational experience in order to teach their own children at home. In most states, parents are not required to have teaching certificates to educate their own children at home**.** Michigan, which has the most stringent regulations, only requires the involvement of a certified teacher.

To date, few systematic studies have been conducted to determine achievement outcomes in charter schools. Published results have not been consistent from place to place or from one study to another. By contrast, home schooling has shown consistently positive results. In virtually every comparative study undertaken, home-schooled students outperformed their public schools counterparts. This finding is viewed with some caution however, because by necessity, data are available only from states that require home-schooled children to participate in testing programs (Lines 1996). No large-scale studies of voucher programs have been conducted, but that situation will soon change. In response to a request by the U.S. Department of Education, the National Research Council has proposed a comprehensive study that will not only examine the achievement of students whose education is financed or supplemented by vouchers, but will also examine the policy consequences, such as the impact vouchers have on the public school system (White 1999).

Student Achievement

Trends in National Achievement

The National Assessment of Educational Progress (NAEP) has monitored educational performance through its trends series (which is distinguished from other NAEP series) since 1969. To facilitate comparisons, the same instruments have been used in every trend assessment since that time. NAEP trend results are reported in terms of average scale scores and in terms of five proficiency levels or anchor points. The five anchor points correspond to five levels of performance, ranging from the basic skills and knowledge to be mastered in the earliest years (Skill Level 150) to the fluency needed to solve challenging problems (Level 350). Most of the NAEP results included in this chapter are based on the latter. (See sidebar, “Proficiency Levels Used in NAEP Science and Mathematics Trends Assessments.”)

NAEP trends results from the last 20 years indicate that, for the most part, students are performing at higher levels in mathematics and science than did their counterparts in the late 1970s. However, the data also suggest that performance falls below expectations based on new educational standards (NCES 1997a).

Elementary and Middle School Science and Mathematics

At the high school level, the primary function of the mathematics and science curricula is to begin the preparation of future scientists, mathematicians, and engineers, which was the goal of educational reforms in the 1960s. In turn, the primary function of elementary and middle school science and mathematics is to lay the groundwork for high school curricula in these areas. In other words, elementary and middle schools are expected to provide the building blocks that students will need in order to progress through the science and engineering pipeline in later years. These early years are quite critical, particularly for mathematics. According to several respected educators, it is in elementary school that young children begin constructing a knowledge base to build upon as they progress to higher levels of knowledge, skill, and understanding (Campbell and Johnson 1995). This section of the chapter examines the adequacy of elementary, middle, and high school preparation, as reflected by NAEP achievement results.

The science and mathematics achievement of both 9- and 13-year-old students has improved significantly since 1977/78. In science, about two-thirds of 9-year-olds reached Level

Proficiency Levels Used in NAEP Science and Mathematics Trends Assessments

Level	Science	Mathematics
350	**Integrates Specialized Scientific Information** Can infer relationships and draw conclusions using detailed scientific knowledge.	**Multistep Problem Solving and Algebra** Can solve multistep problems and use algebra.
300	**Analyzes Scientific Procedures and Data** Has some detailed scientific knowledge and can evaluate the appropriateness of scientific procedures.	**Moderately Complex Procedures and Reasoning** Can compute with decimals, fractions, and percents; recognize geometric figures; solve simple equations; and use logical reasoning to solve problems.
250	**Applies General Scientific Information** Understands and applies general information from the life and physical sciences.	**Numerical Operations and Beginning Problem Solving** Can add, subtract, multiply, and divide using whole numbers and can solve one-step problems.
200	**Understands Simple Scientific Principles** Understands some simple principles and has some knowledge, particularly about physical sciences.	**Beginning Skills and Understanding** Can add and subtract two-digit numbers and recognize relationships among coins.
150	**Knows Everyday Science Facts** Knows some general science facts.	**Simple Arithmetic Facts** Knows some addition and subtraction facts.

SOURCE: National Center for Education Statistics (NCES). 1997. NAEP 1996 Trends in Academic Progress. NCES 97-985. Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement.

200 in 1977, showing that they could understand some simple scientific principles. Between 1977 and 1996, the proportion reaching this level increased so that on the most recent assessment, roughly three-quarters of students demonstrated that capacity. Approximately 26 percent of 9-year-olds met or exceeded Level 250 in 1977, showing that they could apply general information from the life and physical sciences. That number increased to 32 percent in 1996.

The proportion of 13-year-old students reaching achievement Levels 200 and 250 in science also increased between the first and the most recent trends assessments. Eighty-six percent or more of 13-year-olds showed understanding of simple scientific principles (Level 200) in 1977, while 92 percent performed at the level in 1996. Level 250 performance demonstrates some capability to apply life- and physical-science concepts. Approximately 49 percent of 13-year-olds reached or exceeded that level in 1977 and about 58 percent did so in 1996. (See figure 5-4.)

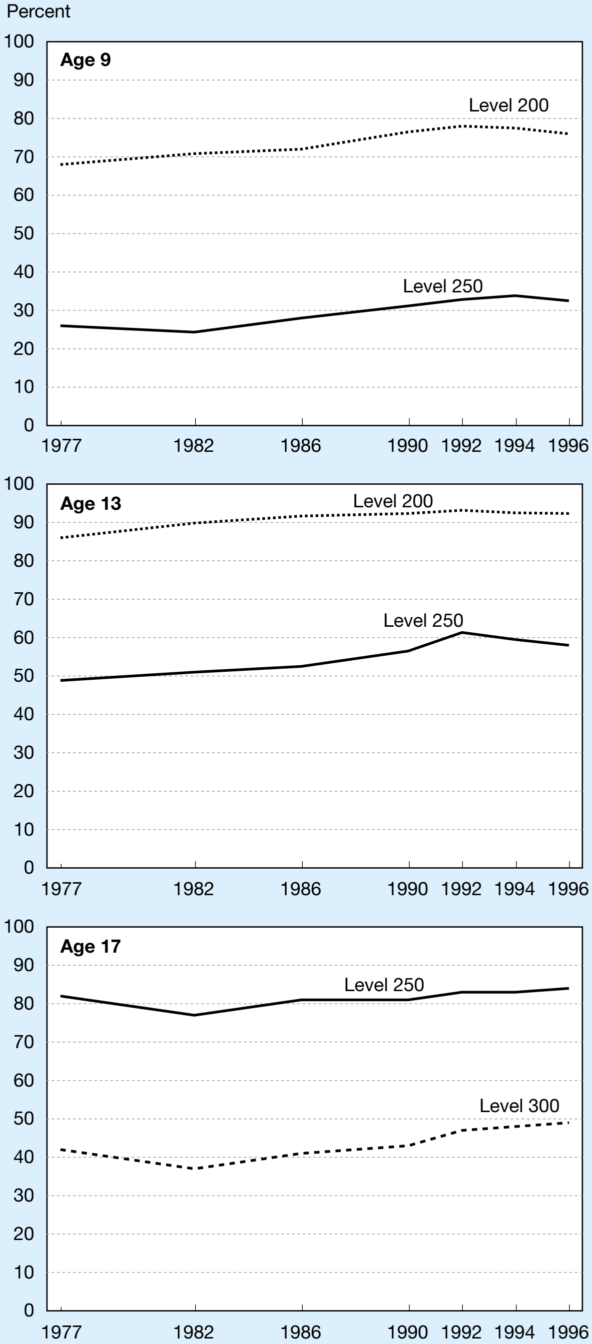
The mathematics achievement of elementary and middle school aged children also improved between 1978 and 1996. (See figure 5-5.) At Level 200, students are able to add and subtract two-digit numbers and recognize some coins. The percentage of 9-year-olds achieving that level was 70 percent in 1978 and increased to 82 percent in 1990, after which it remained stable through 1996. At Level 250, students can perform the basic four mathematical operations (addition, subtraction, multiplication, and division) and can solve one-step problems. In 1978, approximately 20 percent of 9-year-olds performed at this level. The numbers grew to 30 percent in 1996.

The number of 13-year-olds demonstrating command of the basic operations of mathematics (Level 250) grew from 65 percent in 1978 to 79 percent in 1996. At Level 300, students are able to compute with decimals and fractions, recognize geometric figures, solve simple equations, and use moderately complex reasoning. Approximately 18 percent of students demonstrated these skills in 1978 compared to 21 percent in 1996, which was not significantly higher.

High School Achievement

There were also some gains among 17-year-old students in science and mathematics from 1977 to 1996. (See figures 5-4 and 5-5.) In 1977, 82 percent of 17-year-olds met or exceeded Level 250 on the science assessment, the stage at which students can apply principles of life and physical sciences. There was an upward trend in the performance of students achieving at this level between 1977 and 1996, but the 84 percent in 1996 was not significantly different from the 1977 findings. Forty-two percent of 17-year-olds achieved Level 300 in 1978, where students are presumed to have some detailed scientific knowledge and the capacity to evaluate the appropriateness of scientific procedures. The percentage of high school students demonstrating benchmark performance ranged from 37 percent in 1982 to 48 percent in 1996. The overall pattern of science performance increase between 1977 and 1996 performance was significant. (See figure 5-4.)

Figure 5-4.
Trends in the percentage of students at or above benchmark levels of NAEP science performance, by age: 1977–96



NAEP = National Assessment of Educational Progress

SOURCE: National Center for Education Statistics (NCES). 1997. *NAEP 1996 Trends in Academic Progress.* NCES 97-985. Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement.

See appendix tables 5-6, 5-7, and 5-8.

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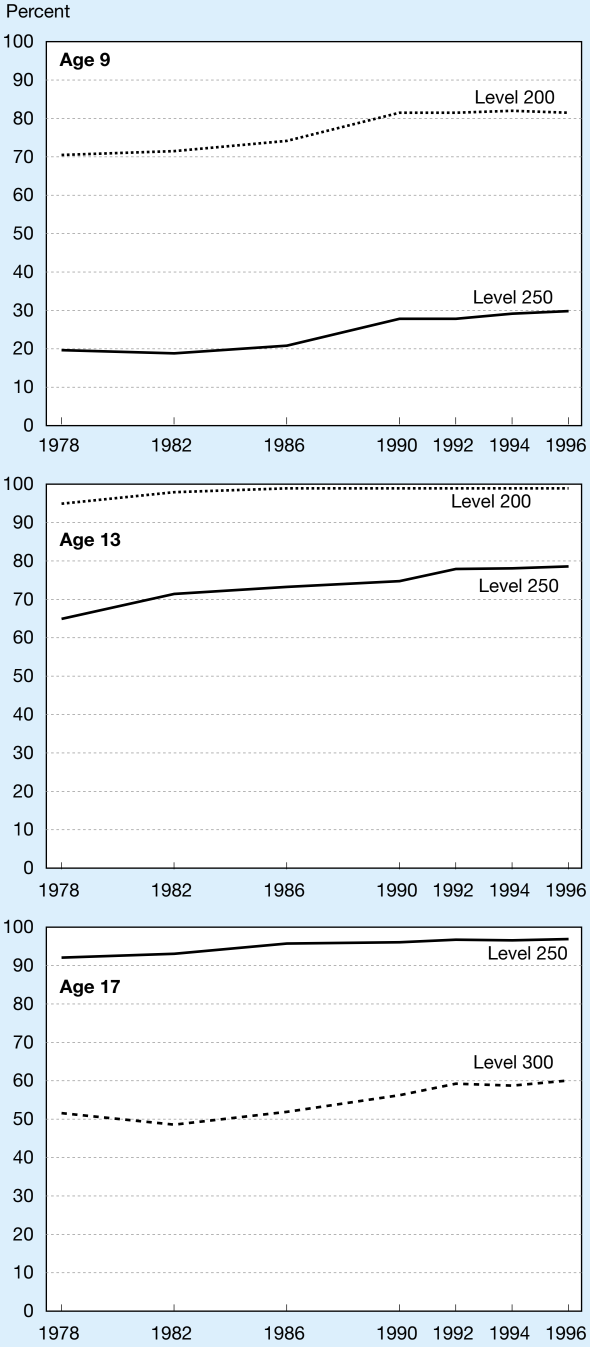
Figure 5-5.
Trends in the percentage of students at or above benchmark levels of NAEP mathematics performance, by age: 1978–96



NAEP = National Assessment of Educational Progress

SOURCE: National Center for Education Statistics (NCES). 1997. *NAEP 1996 Trends in Academic Progress.* NCES 97-985. Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement.

See appendix tables 5-9, 5-10, and 5-11.

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In 1978, approximately 92 percent of 17-year-old students functioned at or above Level 250 in mathematics, showing that they could solve one-step problems. (See figure 5-5.) The 5 percentage-point difference between the 1977 numbers and the overall upward trend were statistically significant. Approximately 52 percent of 17-year-old students functioned at a higher complex reasoning stage (Level 300) in 1978 and 60 percent in 1996, a statistically-significant increase in the change of percentage points.

Achievement Trends by Demographic Group

The proportion of females and underrepresented minorities still remains low at every point along the science, mathematics, and engineering pipeline. For these reasons, it is of interest to monitor mathematics and science performance of these demographic groups from elementary school through high school.

Gender Differences in Performance. The chapter on higher education reports that the number of females who receive bachelor's degrees in natural science fields has increased in the past ten years but that the number of women in mathematics and computer science fields has not increased since 1985. Therefore, the performance of students on mathematics tests in elementary and secondary school is of concern as an indicator of the preparation of students for college performance in mathematics and science.

NAEP performance levels for male and female students are presented for science in text table 5-3 and for mathematics in text table 5-4. A higher proportion of both male and female 9-year-olds reached benchmark science performance in 1996 than in 1978. Between 1977 and 1996, the performance levels of boys and girls were not distinguishable. For 13-year-olds, significant increases also occurred for both boys and girls between 1977 and 1996; however, at this age, boys have slightly higher proportions with performance in science above 250 (62 percent of boys and 54 percent of girls). At age 17, the performance of both males and females increased between 1977 and 1996 but males were more likely than females to get scores of 300 or more in 1996. (See text table 5-3.) By 1996, the difference in the proportion of males and females scoring at 300 or more was about 9 percentage points. Thus, in science performance, the tendency of males to perform at higher levels than females at older ages continues to exist.

In mathematics, differences between males and females are much more difficult to detect than for science. At ages 9 and 13, the percentage of males and females reaching the benchmark on the mathematics assessment (Level 200 at age 9 and 250 at age 13) increased from 1978 to 1996. There had been no significant difference for boys and girls age 13 since 1978. For 17-year-olds, the mathematics performance of both genders increased significantly from 1978 to 1996 but the differences in the performance of male and female students has not formed a consistent trend. The figures in text table 5-4 suggest a closing of the gap between males and females (males were a few percentage points higher in 1978, 1982,

Text table 5-3.

Trends in the percentage of students at or above benchmark levels of science performance, by age and sex: 1977–96, selected years

Years	Male	Female
Age 9	Level 200	
1977	70	67
1982	70	72
1986	74	70
1990	76	76
1992	80	76
1994	78	77
1996	77	76
Age 13	Level 250	
1977	52	45
1982	56	46
1986	57	48
1990	60	53
1992	63	60
1994	62	57
1996	62	54
Age 17	Level 300	
1977	49	35
1982	45	30
1986	49	34
1990	48	39
1992	51	42
1994	53	42
1996	53	44

SOURCE: National Center for Education Statistics (NCES). 1997. *NAEP 1996 Trends in Academic Progress*. NCES 97-985. Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement.

See appendix tables 5-6, 5-7, and 5-8.

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Text table 5-4.

Trends in the percentage of students at or above benchmark levels of mathematics performance, by age and sex: 1977–96, selected years

Years	Male	Female
Age 9	Level 200	
1978	69	72
1982	69	74
1986	74	74
1990	81	82
1992	82	81
1994	82	82
1996	83	81
Age 13	Level 250	
1978	64	66
1982	71	71
1986	74	73
1990	75	74
1992	78	78
1994	79	77
1996	80	77
Age 17	Level 300	
1978	55	48
1982	52	45
1986	55	49
1990	58	55
1992	61	58
1994	60	57
1996	63	58

SOURCE: National Center for Education Statistics (NCES). 1997. *NAEP 1996 Trends in Academic Progress*. NCES 97-985. Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement.

See appendix tables 5-9, 5-10, and 5-11.

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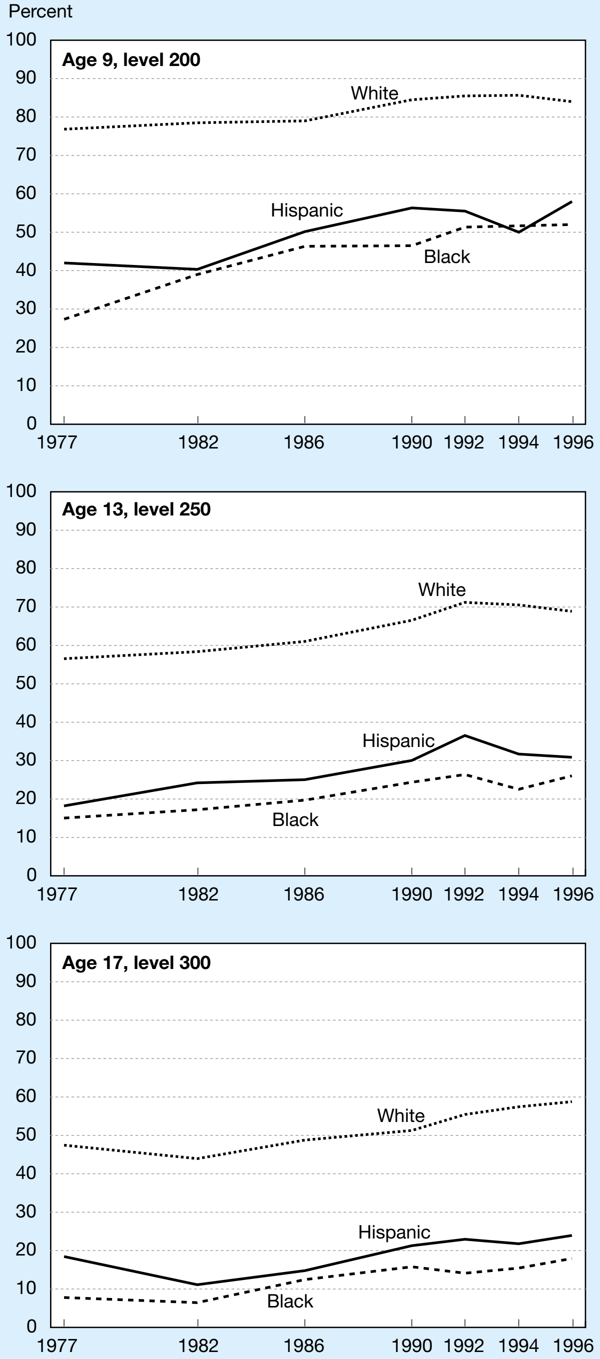
and 1986), but no evidence of a further closing of the gap was observed between 1990 and 1996. Among 17-year-olds, males increased their achievement in the 1990s whereas females did not have significant increases in performance between 1990 and 1996. The apparent difference between male and female 17-year-olds in 1996 was not statistically significant.

Gender differences in student performance on mathematics and science assessments were also examined globally in the reports of Third International Mathematics and Science Study for grades 4, 8, and 12. The comparative performance of boys with that of girls depends on the subject and grade level for most countries. In science, boys outperform girls in most countries in middle school (28 out of 39 countries) and in high school (in 20 out of 21 countries), but not in as many countries at elementary levels (10 out of 25). In mathematics, boys are much less likely to outperform girls in elementary school (3 out of 25 countries) or middle school (8 out of 39 countries), but at high school age, boys outperformed girls in 18 out of 21 countries. Interestingly, U.S. performance on the TIMSS assessments revealed no gender differences at any grade in mathematics. There were some differences detected between U.S. boys and girls in science at elementary and high school grades (not at middle school), but the differences were very small compared with other countries (Beaton et al. 1996a,b; Martin et al. 1997, 1998; and Mullis et al. 1997.)

Ethnic Differences in Performance. Comparisons of performance by racial/ethnic group are presented in figures 5-6 and 5-7. In science, more white, black, and Hispanic 9-year-olds reached benchmark (Level 200) in 1996 than in 1977. The change was particularly noteworthy for black students, who showed a 25 percentage-point increase from the initial assessment (27 percent) to the most recent one (52 percent). By comparison, the percentage of Hispanic students increased from 42 percent to 58 percent and the percentage of white students increased from 77 percent to 84 percent. As these numbers show, white students started off well ahead of black and Hispanic students in 1977 and remained well ahead through 1996. The disparity between white and black students at the 200 benchmark declined from 50 percentage points in 1977 to 32 percentage points in 1996. Changes in the white-Hispanic

Figure 5-6.
Trends in the percentage of students at or above benchmark levels of NAEP science performance, by age and race/ethnicity: 1977–96



NAEP = National Assessment of Educational Progress

SOURCE: National Center for Education Statistics (NCES). 1997. *NAEP 1996 Trends in Academic Progress.* NCES 97-985. Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement.

See appendix tables 5-6, 5-7, and 5-8.

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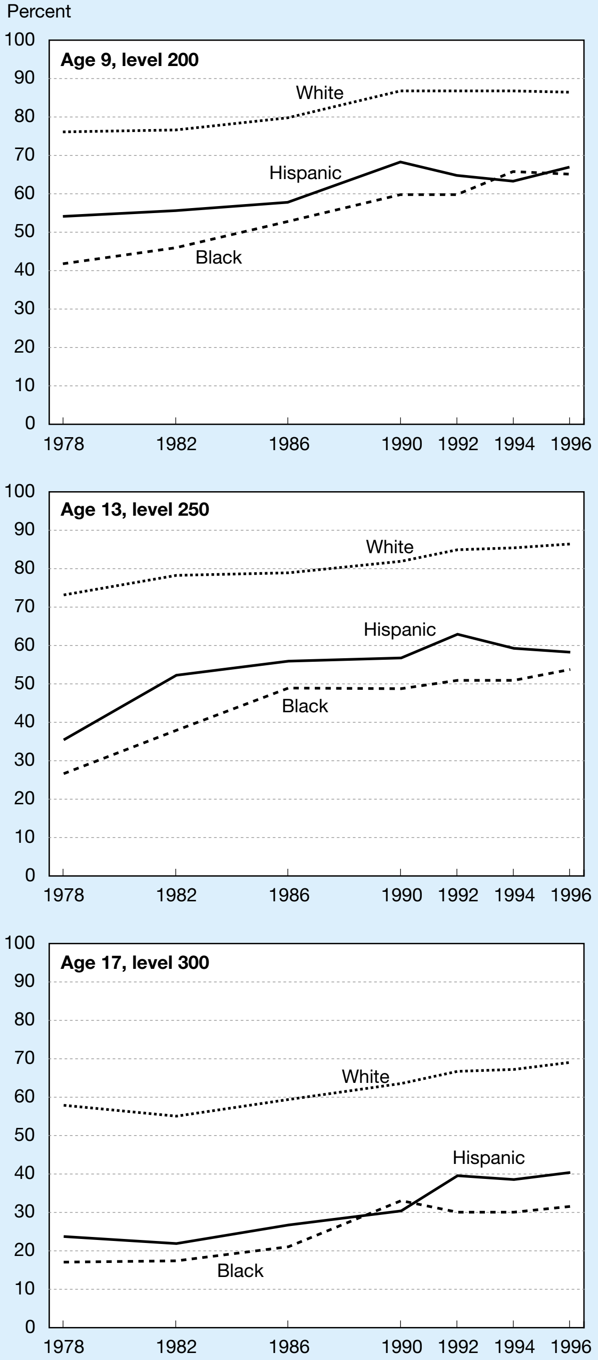
Figure 5-7.
Trends in the percentage of students at or above benchmark levels of NAEP mathematics performance, by age and race/ethnicity: 1978–96



NAEP = National Assessment of Educational Progress

SOURCE: National Center for Education Statistics (NCES). 1997. *NAEP 1996 Trends in Academic Progress.* NCES 97-985. Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement.

See appendix tables 5-9, 5-10, and 5-11.

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performance differences were more modest over that time period. The initial difference was 35 percentage points, while the difference in 1996 was 26 percentage points.

More 13-year-olds in all three racial/ethnic groups reached the benchmark (Level 250) on the science assessment in 1996 than in 1977. White students demonstrated a 12 percentage-point increase in reaching benchmark performance, black students a 10-point increase, and Hispanic students a 13 percentage-point increase. Again, white students started off well ahead of black and Hispanic students and this comparison continued through the years. Among 13-year-olds, performance differences between white-black and white-Hispanic groups did not narrow significantly over time.

Greater percentages of white and black 17-year-olds reached Level 300 in science in 1996 than in 1977, increasing by 11 and 10 percentage points, respectively. The proportion of 17-year-old Hispanic students achieving Level 300 increased by 5 percentage points. The upward trend in all three groups was statistically significant. As is the established pattern, more white students than black and Hispanic students attained Level 300 throughout the assessments.

In mathematics, significantly more 9-year-olds reached Level 200 in 1996 in all three racial/ethnic groups than in 1978. Black students showed the greatest improvement (from 42 to 65 percent) in reaching benchmark performance levels. White and Hispanic students showed increases of 11 and 13 percentage points, respectively. The disparity between white and black students but not that between white and Hispanic students decreased over this interval. The difference between white and black students reaching benchmark performance was 34 percentage points in 1978 and 22 percentage points in 1996.

There were improvements in the percentage of white, black, and Hispanic 13-year-old students reaching Level 250 between the first and most recent mathematics assessment. The differences between white and Hispanic students decreased from 37 percentage points in 1978 to 28 percentage points in 1996. The difference in performance between black and white students also decreased, from 44 to 32 percentage points. Major differences remained between the groups in 1996. About 86 percent of white students, 54 percent of black students, and 58 percent of Hispanic students scored at the benchmark level.

White, black, and Hispanic 17-year-olds functioned at significantly higher levels of mathematics performance in 1996 than in 1978. The increase for white students was from 58 percent to 69 percent; for black students, from 17 percent to 31 percent; and for Hispanic students, from 23 percent to 40 percent. As these numbers also reveal, white students held the edge from the first to the most recent assessment and no significant reduction in performance differences occurred from the first to the most recent assessment.[2]

Summary of NAEP Performance

Science and mathematics achievement in the early and middle grades have improved during the years in which trends assessments were conducted. Compared to 1977/78 performance levels, more 9- and 13-year-olds demonstrated understanding of simple scientific principles and could understand and apply general information from life and physical sciences in 1996. Mathematics achievement for these age groups also has improved since 1978. More 9- and 13-year-old students could perform two-digit addition and subtraction in 1996 than in 1978. More students also had command of the four basic arithmetic operations and could solve simple mathematical problems.

More 17-year-olds showed evidence of detailed scientific knowledge and evaluation of scientific procedures in 1996 than in 1977. More students also demonstrated mastery of one-step problems in 1996—a small but significant improvement. More 17-year-olds showed that they could compute with decimals and fractions and use moderately complex reasoning in 1996.

There also are negative aspects to these findings. Many 9-year-olds lack a good cognitive foundation on which to build future knowledge and understanding. About 70 percent of these students could not compute using whole numbers or could not solve one-step problems. More than 40 percent of 13-year-olds could not apply information from the life and physical sciences. About half of 17-year-olds could not evaluate scientific procedures and 40 percent were deficient in computation or in the use of moderately complex reasoning. Taken as a whole, the data suggest that, while definite improvements in achievement have occurred, the situation remains disappointing for black and Hispanic students. On average, black and Hispanic groups continued to score well below white students, even where there was some success in narrowing the gaps.

U.S. Achievement in an International Context

International assessments provide another perspective on U.S. achievement. The most recent study, the Third International Mathematics and Science Study (TIMSS), conducted in 1995, included assessment of fourth and eighth grade students as well as students in their final year of secondary school. The study included several components: the assessments, analyses of curricula for various countries, and an observational-video study of mathematics instruction in eighth grade classes in Germany, Japan, and the United States.

Achievement of Fourth and Eighth Grade American Students

TIMSS results for fourth and eighth grade students have been widely reported, including in the previous volume of S&E Indicators (NSB 1998). Often observers have expressed grave concern about the implications of TIMSS results for the science and mathematics education being provided to the

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[2] Appendix table 5-12 presents comparable trends information based on average scale scores.

Nation's students. The National Science Board reports TIMSS' results in *Preparing Our Children: Math and Science Education in the National Interest* (NSB 1999). Among other issues critical to precollege education, the report recommended collaborative review of instructional materials by mathematics and scientists employed in knowledge-based industries, parents, and others. The report also recommended the partnership of teacher education instruction with relevant state and local agencies to create constructive alignment of teacher preparation, certification, and hiring practices and policies.

TIMSS findings are outlined here in only general terms. U.S. fourth grade students performed at competitive levels in both science and mathematics. In science, they scored well above the 26-country international average overall as well as 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. (See figure 5-8, and appendix table 5-13.) The fourth 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. Fourth grade students also did well on this assessment, scoring above the international average and performing comparatively well in all content areas except measurement (NCES 1997c). (See figure 5-8 and appendix table 5-14.)

As with grade 4 students, the TIMSS science assessment taken by eighth grade students covered earth and life sciences and environmental issues, but also included content in physics and chemistry. With a mean score of 534 in science, grade 8 U.S. students scored above the 41-country international average of 516. (See figure 5-9.) U.S. students performed about at the international average in chemistry and physics, and above average on life sciences, earth sciences, and environmental issues (NCES 1997c). (See appendix table 5-15.)

Figure 5-9 shows that mathematics was the weaker area of eighth grade achievement. The assessment covered fractions and number sense; geometry; algebra; data representation and probability; measurement; and proportionality. Overall, eighth grade U.S. students performed below the 41-country international average and about at the international average in algebra, data representation, and fractions and number sense. Performance on geometry, measurement, and proportionality were below the international average. (See figure 5-9 and appendix table 5-16.)

Achievement of Students in the Final Year of Secondary School

The performance of students 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 to examine performance on the general knowledge of mathematics and science expected of all students, as well as more specialized content taught only in advanced courses.

Achievement on General Knowledge Assessments

The TIMSS general knowledge assessments were taken by all students, including those not taking advanced mathematics and science courses. The 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 other 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. (See figure 5-10.) It is noteworthy, however, that the countries performing similarly to the United States included Germany, Russia, France, the Czech Republic, Italy, and Hungary.

The general mathematics assessment covered topics most comparable to seventh grade material internationally and ninth grade material in the United States. Again, U.S. students scored below the international average, outperformed by 14 countries but scoring similarly to Italy, the Russian Federation, Lithuania, and the Czech Republic. As on the general science assessment, only Cyprus and South Africa performed more poorly. (See figure 5-10.) These results suggest that mathematics and science students in the United States appear to be losing ground to students in many other countries as they progress from elementary to middle to secondary school.

Achievement of Advanced Students

The TIMSS physics assessment was administered to students in countries who were taking advanced science courses and by U.S. students who were taking or had taken physics I and II, advanced physics, or advanced placement (AP) physics. The assessment covered mechanics and electricity/magnetism as well as particle, quantum, and other areas of modern physics.

Compared to their counterparts in other countries, U.S. students performed below the international average of 16 countries on the physics assessment. The mean achievement scores of the U.S. (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 and no country achieved at a lower level. Advanced Placement physics students in the U.S. (not shown) scored 474 on the assessment, while 6 countries scored higher (scores ranging from 518 to 581). Only Austria performed at a significantly lower level, with a score of 435 (NCES 1998a).

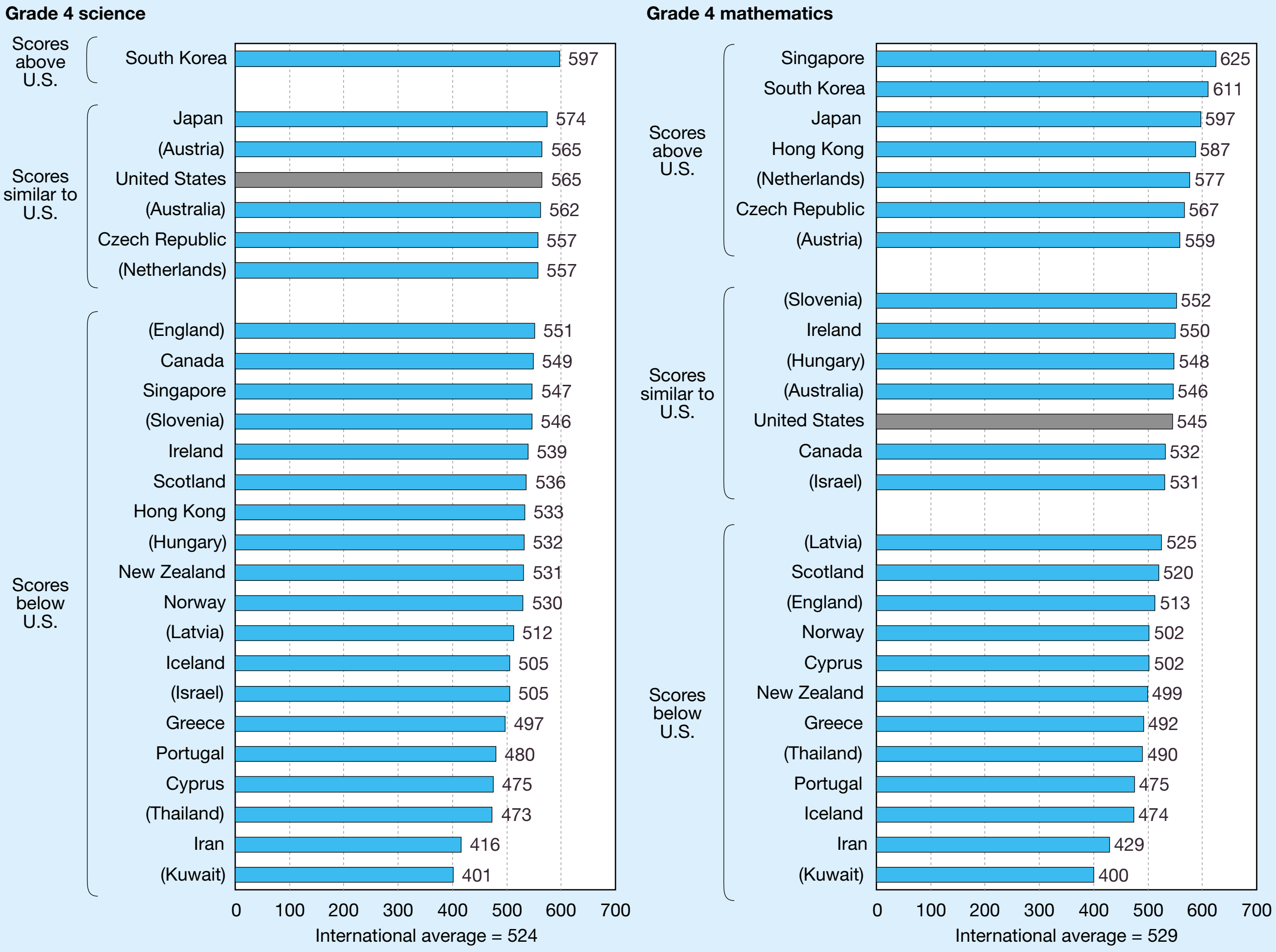
The advanced mathematics assessment was administered to students in other countries who were taking advanced mathematics courses and by U.S. students who were taking or had taken calculus, pre-calculus, or AP calculus. One-quarter of the items tested calculus knowledge. Other topics included numbers,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

The international average on the advanced mathematics assessment was 501. American students, with a score of 442, were outperformed by students in 11 nations, whose average scores ranged from 475 to 557. No nation performed significantly below the United States, while Italy, the Czech Republic, Germany, and Austria performed at about the same level. (See figure 5-11.) U.S. students who had taken AP calculus (not shown) had an average score of 513, exceeded only by students in France. Five nations scored significantly lower than the AP calculus students in the United States.

Performance of the Highest Achievers

Contrasting the performance of the "best and brightest" American students with the best in other nations provides a comparison of the students in each country who are most likely to move through the educational pipeline to careers in science, mathematics, and engineering. One widely comparative index is the percentage of students in each country scoring within the top 10 percent of the students in all participating countries at all grade levels in international distribution. Data on this measure were reported only for grade 4 and grade 8 students.

Figure 5-8.
Average scale score on grade 4 TIMSS science and mathematics assessments relative to U.S. averages, by country: 1994–95



TIMSS = Third International Mathematics and Science Study

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

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

See appendix tables 5-13 and 5-14.

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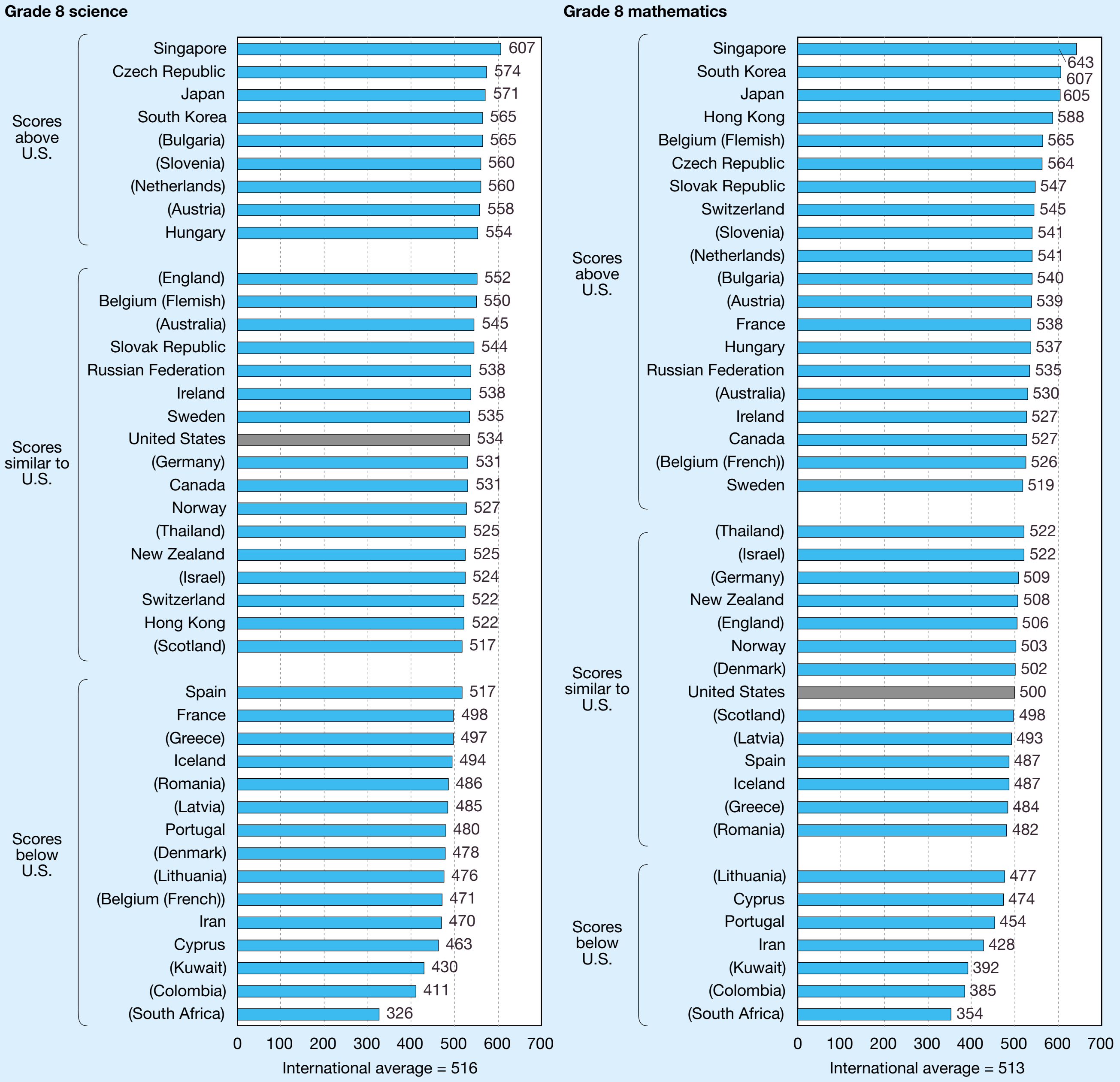
Figure 5-9.
Average scale score on TIMSS science and mathematics assessments for students in grade 8, by country: 1994–95



TIMSS = Third International Mathematics and Science Study

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

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

See appendix tables 5-15 and 5-16.

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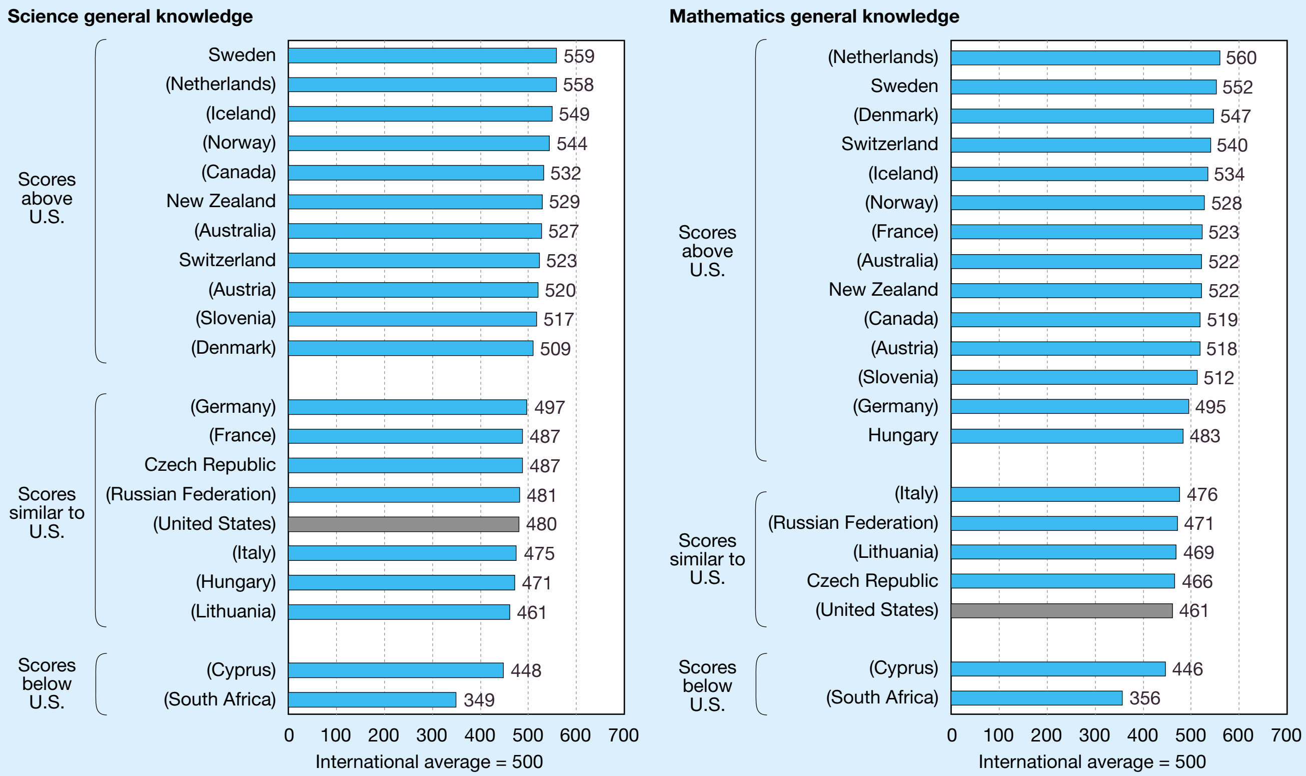
Figure 5-10.
Mean scale score on TIMSS general knowledge assessments in mathematics and science for students in their final year of secondary school: 1994–95



TIMSS = Third International Mathematics and Science Study

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

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

See appendix table 5-17.

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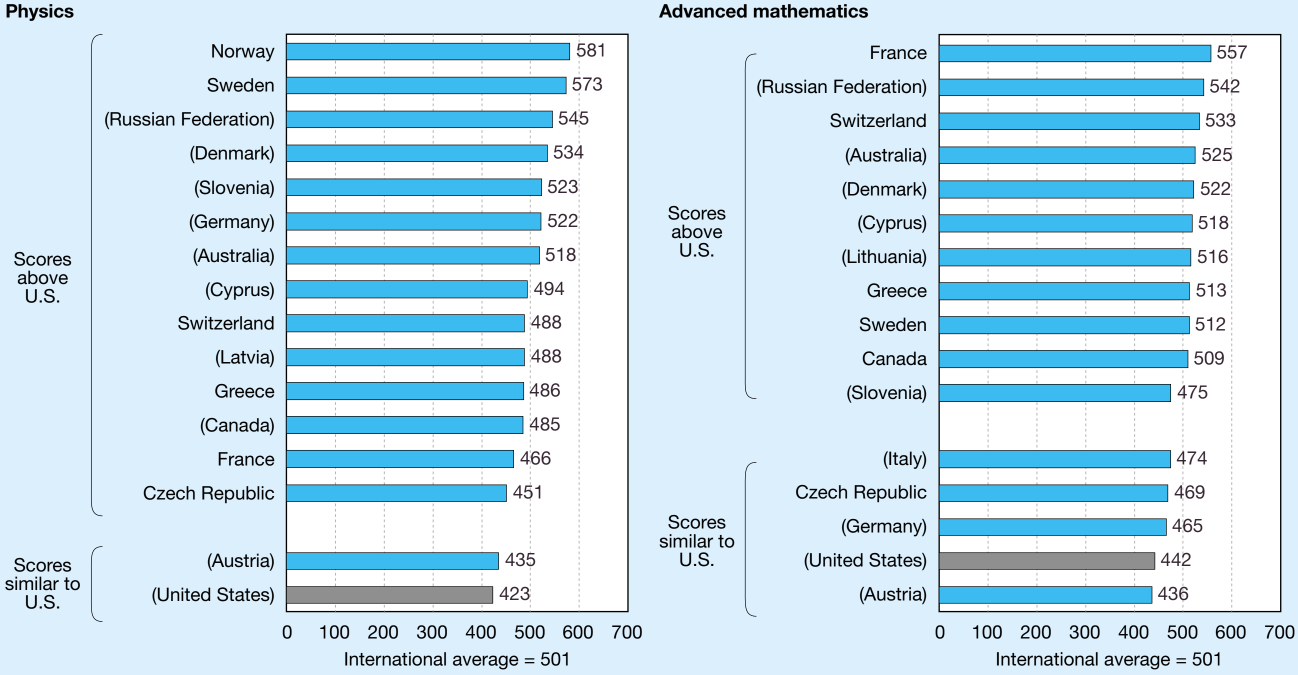
Relatively speaking, grade 4 students were the most internationally competitive of U.S. students. Sixteen percent of fourth grade U.S. students scored in the top 10 percent in science and 9 percent did so in mathematics. Thirteen percent of grade 8 students performed as well as the top 10 percent of TIMSS participants, but only 5 percent reached that benchmark in mathematics. (See appendix table 5-19.) Students in some U.S. schools are performing well above the national average and well above students from many other countries; schools in the First in the World Consortium are in this select group. (See sidebar, "First in the World Consortium Near the Top.")

Performance of Students from the G-7 Nations

Of perhaps particular interest to policymakers is how well the U.S. students performed relative to the country's major trading partners, the six additional members of the "group of 7" (G-7): Canada, France, Germany, Italy, Japan, and the United Kingdom (England, Scotland, Northern Ireland, and Wales). Because not all countries participated in each of the assessments, the potential comparisons are limited. A comparison of mean scale scores of the G-7 countries shows that on the science assessment the scores of fourth graders in the United States did not differ significantly from those in Japan and were higher than those of Canada, England, and Scotland. In 4th grade mathematics, Japanese students achieved a higher level than the United States, while the United States did not differ significantly from Canada and was higher than Scotland and England (NCES 1998b). (See figure 5-8.) On the grade 8 science assessment, only Japan outscored the United States, whose performance was comparable to that of England, Scotland, Canada, and Germany but better than France. In mathematics, the achievement of U.S. students was surpassed by that of students in Japan, France, and Canada, while U.S. students performed similarly to eighth grade students in Germany, England, and Scotland (Beaton et al. 1996a, b). (See figure 5-9.)

Figure 5-11.
Average scale score on TIMSS physics and advanced mathematics assessment for students in their final year of secondary school: 1994–95



TIMSS = Third International Mathematics and Science Study

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

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

See appendix table 5-18.

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Summary of TIMSS Findings

In brief, the findings of the TIMSS assessments showed that U.S. students have higher achievement in science than in mathematics; that students in the primary grades demonstrated the strongest performance, especially in science; that students in grade 8 showed weaker performance; and that those in grade 12 showed weaker performance still, relative to their cohorts in other countries.

Science and Mathematics Coursework

In 1980, before *A Nation at Risk* motivated states to increase graduation requirements, 37 states had minimal graduation requirements on the books. By 1990, 43 states had specified the courses and number of credits needed for graduation. The National Education Commission on Time and Learning reports several studies showing that new requirements did not appreciably change the number of Carnegie units students were required to take. By one estimate, the average number of credits required for graduation in 1980 was 17. In 1990, the average was 20 credits, representing less than 10 percent difference over the 10 years (NECTL 1994).

The NECTL cites research indicating positive effects of strengthened graduation requirements. Schools offered more academic courses, particularly in mathematics and science, and more students, including minority and at-risk students, actually enrolled in the courses. The 1994 High School Transcript Study (HSTS), which examined the records of more than 25,000 graduating seniors, confirms that outcome. Students took more advanced science and mathematics courses in 1996 than did students who graduated in the late 1970s (NCES 1998e). In 1994, almost all graduating seniors (93 percent) had taken biology and more than one-half (56 percent) took chemistry. In comparison, 77 percent of 1982 seniors had completed biology and 31 percent had completed chemistry. In the class of 1994, almost one-quarter of graduates had completed physics, compared to 14 percent of 1982 graduates. (See figure 5-12 and text table 5-5.) Appendix table 5-21 provides participation rates for advanced placement and other science courses.

In 1994, more graduating students had taken advanced mathematics courses than did their counterparts in prior years. In 1994, 58 percent of students took algebra 2, compared to 36 percent in 1982. The 1994 participation rates for geometry and calculus were 70 percent and 9 percent, respectively.

First in the World Consortium Near the Top

The First in the World Consortium was started by a group of North Shore school superintendents in Illinois to work collectively on specific administrative issues. One of their last meetings focused on Goals 2000 (legislation that called for national goals and world-class standards). From this discussion came a commitment to create a regional consortium of districts driven by the need to pursue a world-class education for their students.

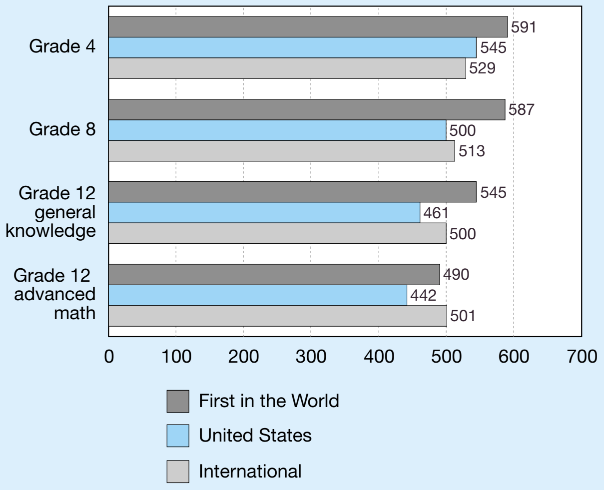
Schools in the First in the World Consortium showed quite strong performance on all TIMSS assessments. They scored well above the general population of U.S. students and above the international mean at all three grades and on both the general knowledge and advanced exams in mathematics and science at the end of secondary school.

Highest scoring country

Grade	Mathematics		Science	
4	Singapore	625	South Korea	597
8	Singapore	643	Singapore	607
12 Literacy	Netherlands	560	Sweden	559
12 Advanced ...	France	557	Norway	581

SOURCE: IEA Third International Mathematics and Science Study, 1994-95.

Mathematics



Science

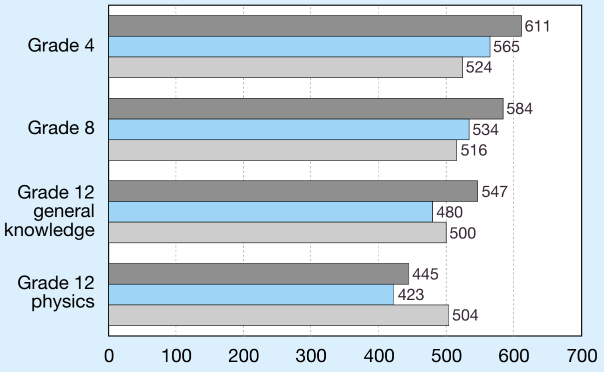
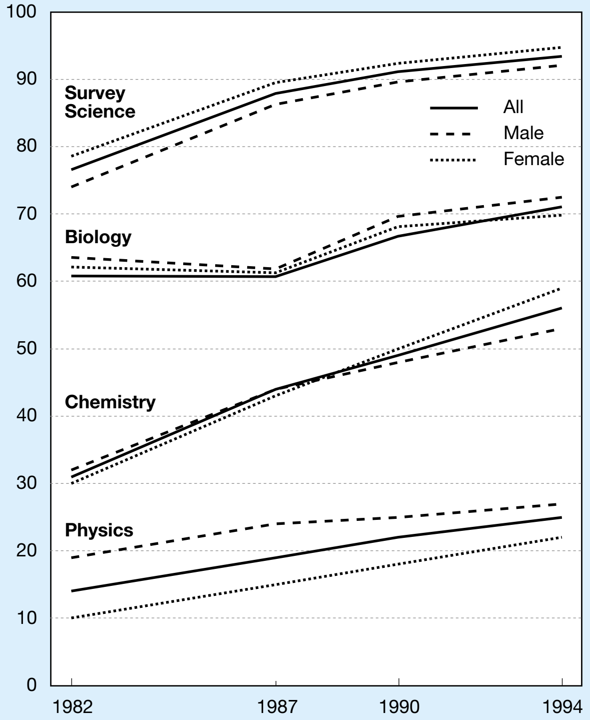


Figure 5-12.
Percentage of high school graduates taking science courses, by gender: 1982–94



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

See appendix tables 5-21 & 22.

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Corresponding figures for 1982 were 46 percent in geometry and 5 percent in calculus. From 1982 to 1994, there was a corresponding decrease in lower-level courses such as general mathematics, which dropped from 30 percent to 16 percent for 1994 over that period. (See figure 5-13 and text table 5-6.) Refer to appendix table 5-22 for information on other mathematics courses, including AP calculus (NCES 1998e).

Gender Differences in Course Participation. The association between courses taken in high school and later educational outcomes has been established for some time (Sells 1978 and Smith 1996). Given the lower representation of women throughout the science, mathematics, and engineering pipeline, there has long been an interest in tracking gender differences in the patterns of advanced science and mathematics courses taken. Data from the recent transcript study show that, in 1982, approximately 79 percent of female graduates completed biology, 30 percent completed chemistry, and 10 percent completed physics (NCES 1998e). The corresponding numbers in 1994 were 95 percent, 59 percent, and 22 percent, respectively. For males, 74 percent completed biology in 1982 and 92 percent in 1994, 32 percent

Text table 5-5.

Percentage of high school graduates earning credits in science courses, by gender and race/ethnicity: 1982 and 1994

Year of graduation and characteristic	Survey science	Biology	Chemistry	Physics
1982				
All	62	77	31	14
Male	64	74	32	19
Female	61	79	30	10
White	62	79	34	17
Asian/Pacific Islander	41	84	53	35
Black	68	73	22	8
Hispanic	63	69	16	6
American Indian/Alaskan Native	58	67	26	8
1994				
All	71	93	56	25
Male	73	92	53	27
Female	70	95	59	22
White	72	94	58	26
Asian/Pacific Islander	62	92	69	44
Black	72	92	44	15
Hispanic	70	94	46	16
American Indian/Alaskan Native	79	92	41	10

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

See appendix tables 5-21 and 5-23.

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completed chemistry in 1982 and 53 percent in 1994, and 19 percent completed physics in 1982 and 27 percent in 1994. For both male and female graduates, the biggest percentage-point increases were in physics. In all three of these advanced science courses, differences between male and female participation decreased from 1982 to 1994. (See figure 5-12, text table 5-5, and appendix table 5-21.)

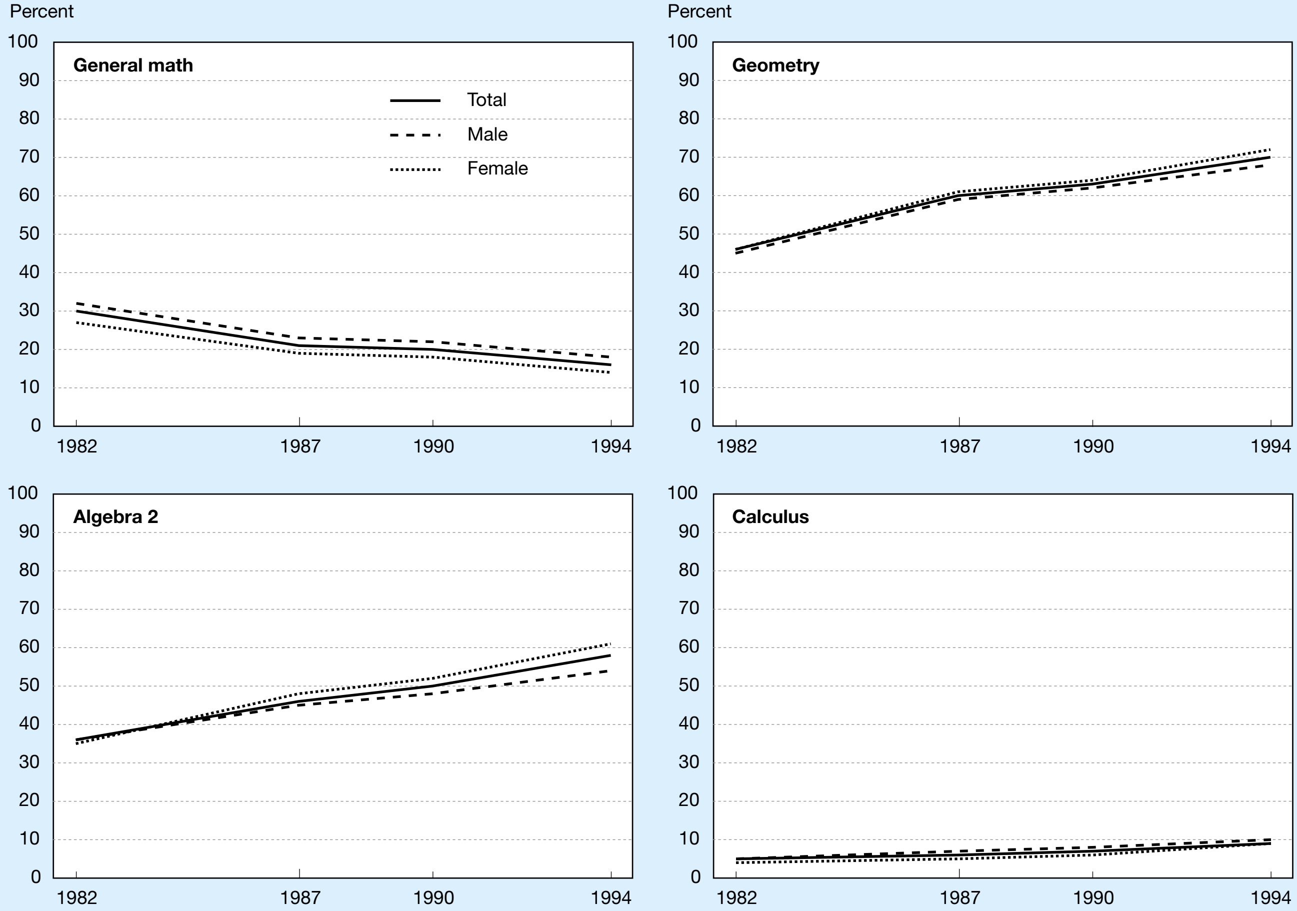
Both male and female students took more advanced mathematics courses in 1994 than in 1982. For both genders, completion rates for algebra 2 and geometry increased 19 to 26 percentage points. The percentages of male and female students completing calculus doubled over that period, reaching almost 10 percent for both genders in 1994. In 1994, approximately 54 percent of male students and 61 percent of female students completed algebra 2 and 68 percent of males and 72 percent of females completed geometry. (See figure 5-13, text table 5-6, and appendix table 5-22.)

Ethnic Differences in Course Participation. Educators have also tracked course taking patterns by ethnic group (NCES 1998e). Students from racial and ethnic groups that are typically underrepresented in science made substantial gains in their proportions taking advanced science courses. More than 90 percent of black, Hispanic, and American Indian/Alaskan Native students now complete biology. In chemistry, the proportion of black students completing chemistry doubled between 1982 and 1994 (from 22 to 44 percent), the completion rate for Hispanic students nearly tripled (from 16 to 46 percent), and for American Indian/Alaskan Natives, the proportion increased by more than one-half (from 26 to 41 percent). All categories made progress in physics course taking between 1982 and 1994, although the proportions of students from black, Hispanic, and American Indian/Alaskan Native groups remained 16 percent or lower in 1994. Corresponding 1994 rates for white and Asian/Pacific Islander students were 26 percent and 44 percent, respectively. (See figure 5-14 and text table 5-5.)

Figure 5-15, which shows the pattern of higher-level mathematics courses completed by ethnic group, indicates that more high school seniors in all ethnic groups completed advanced mathematics courses in 1994 than in 1982. Increases for white and Asian/Pacific Islander students are evident in geometry, algebra 2, and calculus. Increases were also apparent for students in racial/ethnic groups that typically are underrepresented in mathematics and the sciences.

For American Indian/Alaskan Natives, the course completion rate for algebra 2 increased from 19 percent to 42 percent; for geometry the rate moved from 34 to 60 percent. The proportion of black students completing algebra 2 increased from 24 percent to 44 percent; for geometry, the increase was from 29 to 58 percent. The geometry completion rate of Hispanics increased from 26 to 69 percent and in algebra 2 from 20 to 50 percent. In 1994, about one-quarter of Asian/Pacific Islander students completed calculus compared with about 10 percent of whites, 6 percent of Hispanics, and 4 percent each of black

Figure 5-13.
Percentage of high school graduates earning credits in selected mathematics courses, by gender: 1982–94



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

See appendix table 5-22.

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and American Indian/Alaskan Native students. In 1994, the familiar pattern of course completions held. In 1994, as in 1982, more white and Asian/Pacific Islander students completed advanced mathematics courses. (See figure 5-15.)

Research is mixed as to whether the positive effects of stronger requirements were counterbalanced by negative effects. For example, minority and at-risk students failed more courses than before mandates were put into practice (NECTL 1994). Opinions differ on the quality of the added courses, especially those taken by low achieving students. There was particular concern about the quality of new courses designed for low achievers, who, under the traditional pipeline, would have taken general or basic mathematics. Some research suggests that most of the new courses mandated by increased graduation requirements were remedial, low level, or basic rather than advanced (Porter, Smithson, and Osthoff 1994).

Other recent studies have come to a different conclusion. Studying 18 high schools in 12 districts in 6 states, Porter, Smithson, and Osthoff (1994) found no evidence that the newer courses were diluted. Gamoran's (1996) research replicated this finding and also reported that bridging courses achieved some success. Bridging courses helped ease the transition of lower achieving students to college-preparatory courses. The question has great relevance to education policy as schools in Boston require all ninth grade students to take algebra, and schools in New York City require all students to take academic mathematics and science courses during their first two years of high school. Gamoran's research also showed that students who took bridging courses were not as academically successful as students taking college-preparatory mathematics; however, their success was greater than that of students who had taken general mathematics courses (Gamoran 1996).

On balance it appears too early to draw general conclusions about the quality of these new courses. The studies cited here—both confirming and disconfirming that the

Text table 5-6.
Percentage of high school graduates earning credits in mathematics courses, by gender and race/ethnicity: 1982 and 1994

Year of graduation and characteristic	Mathamatics course			
	General Math	Algebra 2	Geometry	Calculus
1982				
All	30	36	46	5
Male	32	36	45	5
Female	27	35	46	4
White	25	40	51	5
Asian/Pacific Islander	17	56	65	13
Black	47	24	29	1
Hispanic	43	20	26	2
American Indian/Alaskan Native	41	19	34	4
1994				
All	16	58	70	9
Male	18	54	68	10
Female	14	61	72	9
White	15	62	72	10
Asian/Pacific Islander	18	66	76	24
Black	27	44	58	4
Hispanic	16	50	69	6
American Indian/Alaskan Native	19	42	60	4

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

See appendix tables 5-22 and 5-24.

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courses were diluted—were conducted in only a handful of states and school districts, and in a handful of courses. Moreover, the earlier studies appear to have been conducted not long after the mandates were enforced. Thus, there may have been little opportunity for revisions and improvement.

Curriculum and Instruction

Challenging instruction is at the core of new educational standards. Both the science and mathematics standards present compelling visions of instruction, although neither provides an exact blueprint. Measuring the extent to which this vision is becoming a reality is difficult because available methodologies 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) and the content of lessons, as well as the use of instructional resources such as textbooks and technology. Lacking, until quite recently, were indicators that better reflect instruction as a process.

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 to 3,170 hours in Japan. The National Educational Commission on Time and Learning 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 8 others provided recommendations regarding academic time. Based on these and other findings, the Commission concluded that "[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).

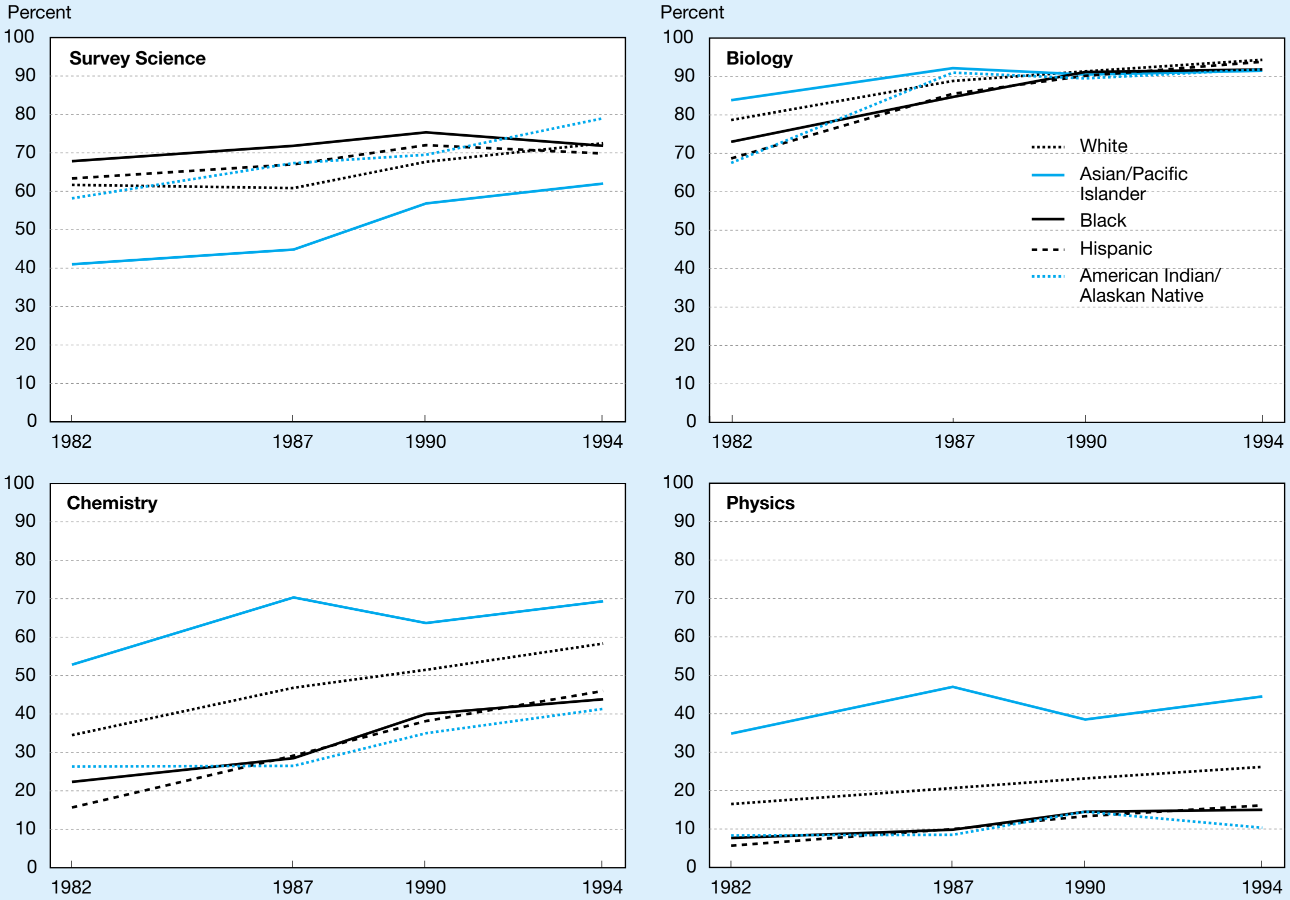
TIMSS data suggested that this may not have been true of mathematics and science in 1995. Students in the United States receive at least as much classroom time in mathematics and science instruction as students in other nations—close to 140 hours per year in mathematics and 140 hours per year in science. Students in Germany, Japan, and the United States spent about the same 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 1996a, 1997b, and 1997c). (See figure 5-16.) 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 after school clubs. Second, disruptions for announcements, special events, and discipline problems in U.S. classrooms considerably reduce the amount of allocated time actually spent on instructional activities (Stigler et al. 1999).

Content: Curriculum and Textbooks

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. U.S. curricula, by contrast, 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. curricula are quite repetitive—the same topic appears and reappears at several different grades. Another result is that topics are not presented in any great depth, giving U.S. curricula the appearance of being unfocused and shallow in appearance.

The Schmidt et al. (1997) study also suggested that U.S. curricula make fewer intellectual demands on students, delaying until later grades topics that are covered much earlier in other countries. U.S. mathematics curricula also were judged to be less advanced, less challenging, and out of step with curricula 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 curricula, by comparison, are closer to international norms in content and in the sequence of topics.

Figure 5-14.
Percentage of high school graduates earning credits in selected science courses, by race/ethnicity: 1982–94



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

See appendix table 5-23.

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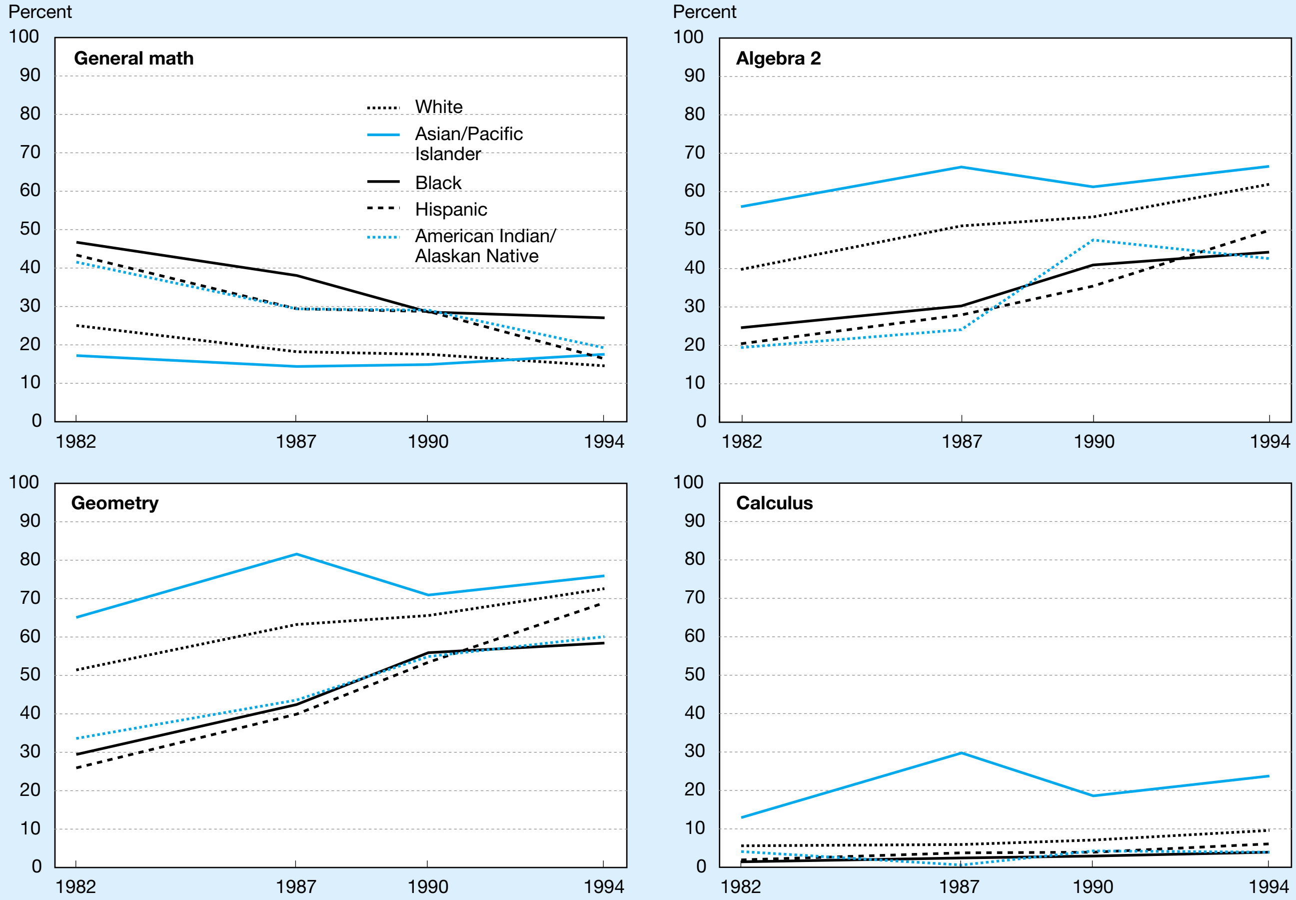
Figure 5-15.
Percentage of high school graduates earning credits in mathematics courses, by race/ethnicity: 1982–94



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

See appendix table 5-24.

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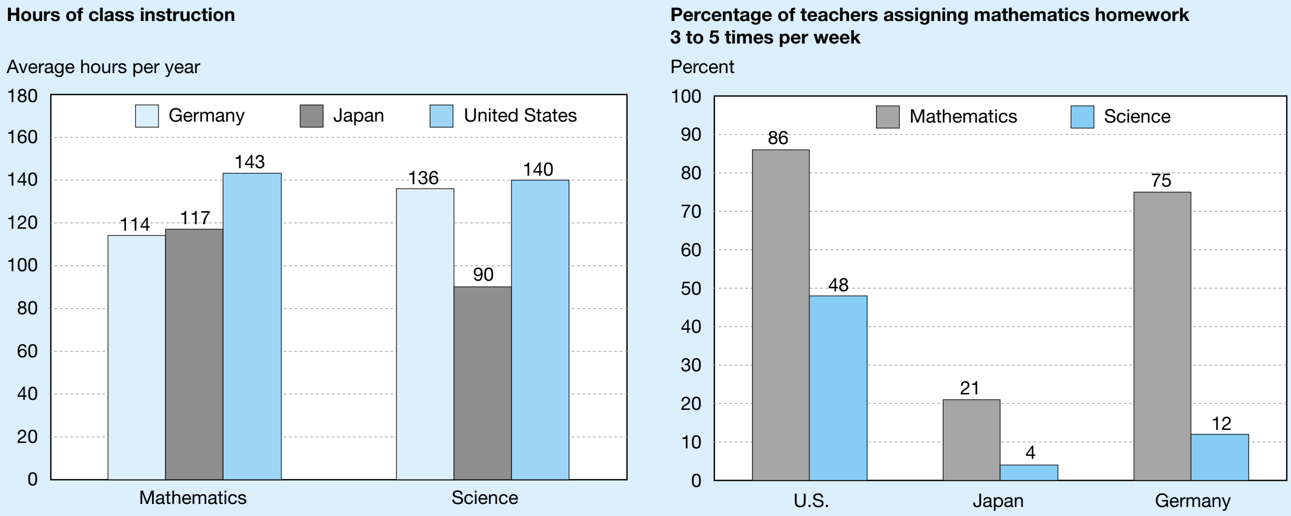
Textbooks reflect the same limitations as documented by curriculum analyses: too many topics with too little coverage and too little development of topics. (See figure 5-17.) Compared to textbooks used in other countries, science and mathematics textbooks in the United States convey less challenging expectations and are repetitive while providing 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) reinforced the findings of TIMSS and other studies about the limitations of mathematics and science textbooks. AAAS conducted a conceptual analysis of content, based on 24 instructional criteria divided into the following seven categories:

- Identifying/providing a sense of purpose;
- Building on/taking into account student ideas;
- Engaging students in mathematics/engaging students with relevant phenomena;
- Developing mathematical ideas/developing and using scientific ideas;
- Promoting student thinking about mathematics/about phenomena, experience, and knowledge;
- Assessing student progress; and
- Enhancing the mathematics/science learning environment.

The "AAAS Project" presents the 24 criteria used in evaluating middle school science textbooks. Middle school mathematics textbooks were evaluated using parallel criteria. (See sidebar, "AAAS Project.")

Figure 5-16.
Selected characteristics of grade 8 mathematics and science instruction in Germany, Japan, and the United States: 1994–95



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

SOURCE: National Center for Education Statistics (NCES). 1996. *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.

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The study examined 9 middle-grade 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/mathematics education professors. With funding from NSF, AAAS developed and tested the evaluation procedure over a three-year period in collaboration with over 100 scientists, mathematicians, educators, and curriculum developers. On a 0-to-3-point scale (where 3 represents "satisfactory"), all 9 science textbooks scored below 1.5. Six mathematics texts scored below 1.5, while only half that number scored above 2.5 points (AAAS 1999a,b).

Instructional Practice

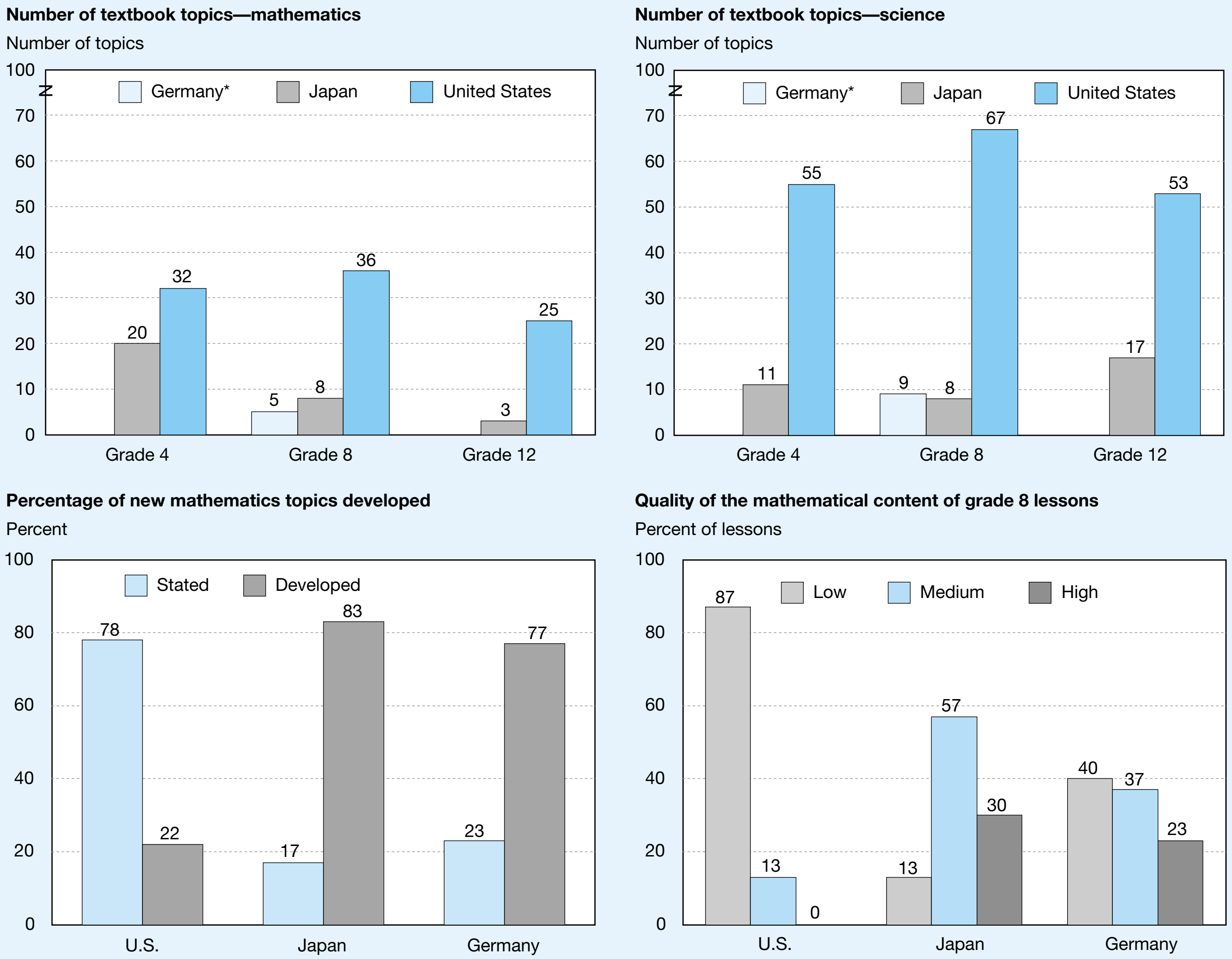
Most information about instructional practice has come from surveys in which teachers were asked about their use of specific aspects of their teaching. In a recent survey, 82 percent of full-time U.S. mathematics teachers and 74 percent of full-time science teachers gave themselves good grades on using practices consistent with educational standards in their fields (NCES 1999a). But classroom observational studies, which have added depth and dimension to depictions of practice, often painted quite a different picture. These studies demonstrated 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 (Cohen 1991, Spillane and Zeuli 1999, and Stigler et al. 1999).

The TIMSS video study of grade 8 mathematics instruction is a case in point. Lessons in U.S., German, and Japanese classrooms were fully documented, including descriptions of the teacher's actions, the students' actions, the amount of time spent in each activity, the content presented, and the intellectual level of the tasks 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;
- U.S. mathematics teachers' typical goal is to teach students how to do something, while Japanese teachers' goal is to help them understand mathematical concepts;
- Japanese classes share many features called for by U.S. mathematics reforms while U.S. classes are less likely to exhibit these features; and
- Although most U.S. mathematics teachers report familiarity with reform recommendations, relatively few apply the key points in their classrooms.

Ratings of instructional quality of mathematics instruction in eighth grade classrooms provided by mathematicians indicated approximately 30 percent of lessons in Japanese classrooms as "high quality" and 13 percent as "low quality." In German classrooms, 23 percent of lessons received high ratings and 40 percent low ratings. In comparison, approximately 87 percent of U.S. lessons were considered low qual-

Figure 5-17.
Selected characteristics of grade 4, 8, and 12 mathematics and science instruction in Germany, Japan, and the United States: 1994–95



Number of textbook topics—mathematics

Number of textbook topics—science

Percentage of new mathematics topics developed

Quality of the mathematical content of grade 8 lessons

*Grade 4 and grade 12 data for Germany not available for this comparison.

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

SOURCES: Stigler, J.W., P. Gonzales, T. Kanaka, S. Knoll, and A. Serrano. 1999. *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, Office of Educational Research and Improvement; Schmidt, W.H., C.C. McKnight, and S.A. Raizen. 1997. *A Splintered Vision: An Investigation of U.S. Science and Mathematics Education.* Boston, MA: Kluwer Academic Publishers.

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ity and none was considered high quality. (See figure 5-17.) However, due to 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.

Technology

Throughout the United States, school districts have dramatically increased the access of students and teachers to new forms of technology such as hand-held calculators, desktop computers, and the Internet. Hand-held 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 National Council of Teachers of Mathematics (NCTM) Curriculum and Evaluation Standards (NCTM 1989) urges 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 problems that foster development of conceptual power. The NCTM suggests that by using this approach, stu-

AAAS Project

Evaluating the Quality of Middle Grade Science Textbooks

Category I. Providing a Sense of Purpose
- Conveying unit purpose
- Conveying lesson purpose
- Justifying activity sequence

Category II. Taking Account of Student Ideas
- Attending to prerequisite knowledge and skills
- Alerting teacher to commonly held student ideas
- Assisting teacher in identifying own students' ideas
- Addressing commonly held ideas

Category III. Engaging Students with Relevant Phenomena
- Providing variety of phenomena
- Providing vivid experiences

Category IV. Developing and Using Scientific Ideas
- Introducing terms meaningfully
- Representing ideas effectively
- Demonstrating use of knowledge
- Providing practice

Category V. Promoting Student Thinking about Phenomena, Experiences, and Knowledge
- Encouraging students to examine their ideas
- Guiding student interpretation and reasoning
- Encouraging student to think about what they've learned

Category VI. Assessing Progress
- Aligning assessment to goals
- Testing for understanding
- Using assessment to inform instruction

Category VII. Enhancing the Science Learning Environment
- Providing teacher content support
- Encouraging curiosity and questioning
- Supporting all students

SOURCE: American Association for the Advancement of Science (AAAS). 1999a. Project 2061. "Heavy Books Light on Learning: Not One Middle Grades Science Text Rated Satisfactory." Available from <<http://www.project2061.org/newsinfo/press/rlo92899.htm>>.

dents 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 the basic arithmetic operations.

Both the NAEP and the TIMSS surveys included questions for teachers and students on their level of calculator use in schools. The TIMSS surveys show that 99 percent of eighth grade students and 95 percent of fourth grade students in the United States own calculators. The range was from 76 percent in Norway to 95 percent in the United States and the Czech Republic. (See text table 5-7.) In the United States, many schools provide calculators for use by students who do not own them. School-owned calculators used in fourth 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 less common among U.S. elementary school students than it is among middle school students in most countries. Although U.S. teachers are more likely than teachers in most other countries to use calculators in the lower grades, about 30 percent still report that they never use calculators. (See text table 5-7.) On the other hand, about the same percentage of these teachers report using calculators to solve complex problems in fourth grade classrooms, about the same proportion of teachers as in Canada and England.

By grade 8, classrooms in nearly all countries use calculators for mathematics instruction. The extent of calculator use is comparable in most countries, except in South Korea and Ireland, where calculators are seldom used in middle school classrooms. A large percentage of U.S. teachers (about three-fourths) report that they use calculators to help students solve complex problems.

Computers also are becoming ubiquitous in U.S. schools. In the 1997/98 school year, 71 percent of teachers in grades 4 to 12 had students use computers during class time at some point during the school year. (See appendix table 5-26.) Teachers of secondary academic subjects are less likely to have their students use computers than are elementary teachers of self-contained classes or teachers of business and vocational subjects. Overall, about one-half of mathematics teachers (49 percent) reported some use of computers by students during at least one of the classes they taught that year, compared to 75 percent of English teachers. Although computers were introduced to classrooms almost two decades ago, computers are a form of technology that still may be unfamiliar to many teachers. The results of a 1998 survey reported that only one teacher in five felt "very well prepared" to integrate education technology in the subject they taught (NCES 1999b).

In addition to issues of professional development related to computer use, equity issues also have been a concern. A study by the Educational Testing Service (ETS) examined the relationship of achievement on the 1996 NAEP mathematics assessment to computer access, frequency of use, and level of teachers' professional development in technology (ETS 1999). Students who scored the highest among eighth graders were more likely to use computers at home, more likely to have teachers with recent professional development in technology, and more likely to have teachers who used computers to teach higher order thinking skills. In general, the study concluded that the use of computers can be positively associated with student achievement when it is used in productive ways such as increasing use of higher order concepts and when teachers are informed of their use (ETS 1999).

Studies have also found that socioeconomic variables influence computer access (Becker 1997 and ETS 1999). There were few differences in computer use at school among fourth or eighth graders, except that black children in the fourth grade used the computer somewhat more often. Black, poor,

Text table 5-7.
Mean students mathematics scores and percent of students and teachers reporting hand-held calculator use in 4th and 8th grade, by country: 1995

	Mathematics scores		Fourth grade				Eighth grade teachers		
			Student		Teacher				
Country	4th grade	8th grade	Percent having calculators in home	Never use calculator in math class	Never use in class	Use to solve complex problems	Never use	Use every day	Use to solve complex problems
Singapore	625	643	93	96	97	1	1	82	82
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	91	96	98	0	2	87	70
Ireland	550	527	86	91	88	3	68	11	7
United States	545	500	95	34	29	26	8	62	76
Hungary	548	537	88	90	78	5	29	60	53
Canada	532	527	87	51	37	23	5	80	86
England	513	506	93	15	8	28	0	83	73
Norway	502	503	76	89	93	1	2	82	72
New Zealand	499	508	90	18	5	50	7	66	70

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

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urban, and rural students in eighth grade were less likely to have access to a computer at home, less likely to have teachers who use computers for learning higher order skills, and less likely to have mathematics teachers who had participated in professional development related to technology in the five prior years (ETS 1999).

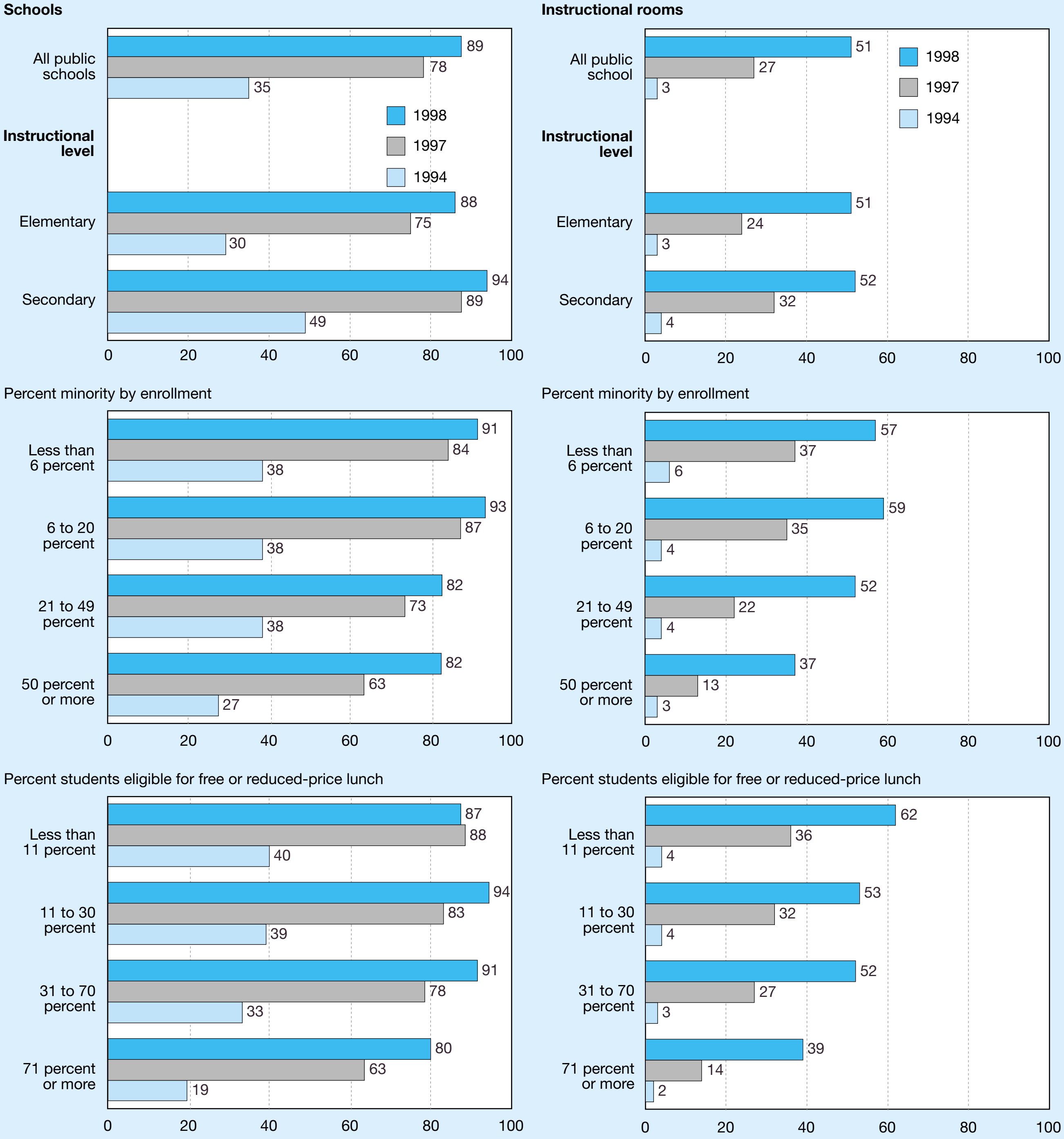
Until recently, "technology in schools" meant computers. Presently the newest technology being explored in schools is the Internet. By 1998, about 90 percent of all schools reported they had access to the Internet, an increase of about 15 percentage points each year since 1994, when 35 percent of schools reported Internet connectivity. (See figure 5-17.) However, for some of these schools only one computer was linked to a single phone line. It is remarkable, therefore, that about half of classrooms had access to the Internet in 1998 (NCES 1998d, Becker 1999a,b). (See also chapter 9, "Significance of Information Technologies.")

Another recent study showed that teachers with several computers in the classroom are much more likely to perceive the value of the Internet and to use the Internet for student research projects (Becker 1999a). However, results also showed that mathematics teachers are the least likely of all teachers to perceive Internet use as having value for classroom instruction. Only about 12 percent of mathematics teachers used the Internet themselves compared with 20 percent of other teachers (Becker 1999a,b). Even as access to computers and other forms of technology in the classroom has increased rapidly, newspaper reports suggest that many teachers (75 percent of those responding to an *Education Week* survey) believe that there were still not enough Internet-connected computers in the classroom to make good use of them for instruction (*Education Week* 1999).

Figure 5-18 suggests that although there has been rapid growth in Internet access and use in all types of schools, there also are equity issues to be resolved. In Fall 1998, about 90 percent of schools at the lowest poverty levels had Internet access, compared to 80 percent at the highest poverty levels (based on the percentage of students receiving reduced-price lunches). Although the percentage of classrooms with Internet connections also increased greatly in one year for all categories of schools, inequities were apparent at this level as well. In Fall 1998, 40 percent of classrooms in high poverty schools had Internet access, compared to 62 percent of classrooms in low poverty schools. Unequal access to the Internet in schools has led many educators and policymakers to be concerned about developing a "digital divide" that separates poor and minority children from more affluent and white children.

In summary, at the beginning of a new century, classrooms are clearly undergoing a transformation. The rapid changes make descriptions of a "typical" classroom based on survey results a few years old already out of date. More detailed discussion of the growth of information technologies in schools and a review of their effectiveness in education are included in the chapter on information technology.

Figure 5-18.
Percentage of public schools and percentage of instructional rooms having access to the Internet, by school characteristics: 1994, 1997, and 1998



SOURCES: National Center for Education Statistics (NCES). 1995. *Advanced Telecommunications in U.S. Public Schools, K-12.* NCES 95-731; 1996. *Advanced Telecommunications in U.S. Public Elementary and Secondary Schools, 1995.* NCES 96-854; 1997. *Advanced Telecommunications in U.S. Public Elementary and Secondary Schools, Fall 1996.* NCES 97-944; 1998. *Internet Access in Public Schools.* NCES 98-031. Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement; and data from the Fast Response Survey System, “Survey on Internet Access in U.S. Public Schools, Fall 1998,” FRSS 69, 1998.

See appendix table 5-25.

Science & Engineering Indicators – 2000

Teachers and Teaching

Currently, there are approximately 2.7 million teachers in U.S. public schools: 1.6 million in primary schools and 1.1 million in secondary schools. (See text table 5-8.) By the year 2009, the number of public elementary and secondary teachers is projected to increase by 2.4 percent. (See text table 5-9.) One question facing the education community is whether supply will be sufficient to meet demands in the next ten years. The U.S. Department of Education projects that 2 million teachers will need to be hired in the next 10 years (NCES 1999f). Some analysts maintain that teacher preparation programs will not graduate enough teacher candidates to meet this demand. Others disagree and point out that the critical question is not whether there will be enough teachers to satisfy demand, but enough to assure that every child and every classroom has a competent teacher (Darling-Hammond 1996).

Another aspect of the supply and demand problem for the teaching profession is related to societal changes that have taken place in recent years. As noted earlier, the school population has increased in diversity. From this perspective, the composition of the current teaching force has not kept pace. In 1976, nearly 88 percent of public school teachers were white; in 1996, the estimate was 91 percent (NCES 1997a). Consistent with these numbers, a 1996 survey of state departments of education reported that few students have the opportunity to study science and mathematics with minority teachers: only 14 percent of students taking mathematics and biology, 10 percent taking chemistry, and 7 percent taking physics (Blank and Langeson 1997).

The gender balance in the teaching force has been a matter of interest for some time as well because of the lower representation of women in some areas of science noted earlier in this chapter (NSF 1997a,b). There has been some change in the last two decades, but not always in the desired direction. From 1976 to 1996, the percentage of male teachers increased from 33 percent to 42 percent. In 1985, two-thirds of mathematics and science teachers were male. More recent surveys suggest that the balance is shifting toward equality in the numbers, except in physics, where currently 72 percent of teachers are male (NCES 1998b).

Text table 5-8.
Classroom teachers in public elementary and secondary schools: 1985–2009
(Thousands)

Year	K–12	Elementary	Secondary
1985	2,206	1,237	969
1990	2,398	1,429	969
1995	2,598	1,525	1,073
1999[a]	2,700	1,580	1,120
2000[a]	2,712	1,583	1,129
2005[a]	2,765	1,581	1,184
2008[a]	2,768	1,578	1,190
2009[a]	2,766	1,578	1,188

[a]Projected.

SOURCE: National Center for Education Statistics (NCES). 1999. *Projections of Education Statistics to 2009.* NCES 1999-038. Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement.

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Teacher Qualifications

As new standards for mathematics and science education create higher expectations for student achievement, more is expected of teachers as well. These higher expectations raise the question of what high quality teaching entails. In the absence of completely satisfactory measures of quality, indicators of teacher preparation and qualifications have been used as proxies. Studies show that teacher qualifications make a real difference to achievement.

Results from the 1996 NAEP survey of teachers showed that students with higher mathematics scores were more likely to have teachers who were certified, had more than five years of teaching experience, and, in the case of eighth grade students, had majored in mathematics rather than in any field of education (Hawkins, Stancavage, and Dossey 1998). In science, the results were similar. Students with better achievement had teachers who had college majors in science, were certified in science (eighth grade only), and had more years of teaching experience (O'Sullivan, Weiss, and Askew 1998). Earlier studies also reported a positive relationship between achievement and teacher qualifications (Chaney 1995).

Other studies have confirmed the strength of the relationship between achievement and teacher characteristics. One of those studies demonstrated that, with socioeconomic status controlled, performance differences between white and black students could be explained largely by differences in their teachers' qualifications (Ferguson 1991). Analyses of other data further suggest that better achievement results are obtained when resources are spent to improve the quality of teaching than when the same resources are applied to options such as reducing class size or raising teachers' salaries (Ferguson 1991; Greenwald, Hedges, and Laine 1996).

Degrees Earned

TIMSS survey data indicated that mathematics and science teachers in U.S. schools completed more years of college than their counterparts in most other countries (NCES 1996a, 1997b). A 1998 survey of full-time teachers showed that, in fact, almost all had undergraduate degrees and many had master's or other advanced degrees as well. Overall, approximately 55 percent of high school teachers, 46 percent of middle school teachers, and 40 percent of elementary school teachers held master's degrees (NCES 1998b). Among secondary mathematics and science teachers, approximately 45 percent had advanced degrees, as was true for teachers of other core subjects including English and social studies (NCES 1998b).

Text table 5-9.
Percentage of public secondary school (grades 7–12) teachers in each field without a major or a minor in that field and students taught by those teachers

	English	Math	Science	Life sciences	Physical sciences	Social studies	History
Teachers							
Total	24.1	31.4	19.9	32.9	56.9	19.3	53.1
School poverty level							
Low poverty	20.1	26.8	17.5	29.2	51.3	15.8	46.4
High poverty	25.7	42.8	27.8	40.1	65.1	25.1	60.0
School size							
Small	30.4	41.2	25.5	38.1	64.5	25.5	62.8
Large	22.4	27.5	17.6	30.1	53.7	17.2	48.1
Students taught by teachers							
Total	20.8	26.6	16.5	38.5	56.2	13.4	53.9
Track of class							
Low track	24.7	33.5	20.4	42.3	66.8	14.3	55.1
Medium track	11.8	15.7	9.2	31.4	42.8	8.9	44.9
High track	11.2	20.4	7.2	20.7	43.0	11.2	51.1
Grade level of class							
7th grade	32.2	48.8	31.8	60.4	73.8	23.9	56.3
8th grade	32.9	37.1	23.8	32.9	75.7	19.7	60.5
9th grade	15.7	18.1	10.7	27.9	61.7	8.7	48.7
10th grade	11.1	16.8	8.9	29.3	45.7	8.8	51.1
11th grade	11.2	15.9	6.4	23.5	36.8	6.8	47.0
12th grade	13.9	24.2	13.1	25.3	41.0	11.3	62.4

SOURCE: Ingersoll, R. 1999. "The Problem of Underqualified Teachers in American Secondary Schools." *Educational Researcher* 28, No. 2 (March): 26–37.

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Undergraduate Major

The importance of teachers' academic preparation in undergraduate years has increased as educational standards are more widely adopted. To help students meet high standards, teachers must have a thorough knowledge of their subject matter and a solid understanding of concepts in their fields. Until recently, most states did not require teachers to have academic majors in the fields in which they most often taught.

A 1996 NAEP survey found that the majority of mathematics and science teachers do not have academic degrees in their fields. The data showed that 83 percent of fourth grade students and 32 percent of eighth grade students had mathematics teachers who had college majors in education. Nine percent of fourth graders and 49 percent of eighth graders have teachers who majored in mathematics. Four and 13 percent of these students, respectively, had teachers with a major in mathematics education. NAEP survey data showed that 74 percent of fourth grade students and 20 percent of eighth grade students had science teachers who majored in education (excluding science education). Five percent of fourth grade students and 45 percent of eighth grade students had science teachers who majored in science. Five and 11 percent of these students, respectively, had teachers who majored in science education.

Examining data from another perspective, 1996 NAEP survey findings indicated that only 9 percent of fourth grade students had teachers who majored in mathematics and an additional 4 percent had teachers who majored in mathematics education. Approximately 49 percent of eighth grade students were taught by teachers with degrees in science and 13 percent by teachers with degrees in science education (NCES 1998c).

Experience

Teaching experience is another widely used quality indicator. The 1998 NCES teacher survey showed that the majority of full-time teachers had 10 or more years of experience in their profession (NCES 1999b). Results of the 1996 NAEP survey showed that one-half of the students taking mathematics and science in grades four and eight had teachers who had been in the profession 11 years or longer. An important concern raised by the National Commission on Teaching and America's Future is that teachers with the least experience often are placed in central city schools, where the need for experienced teachers may be greatest (NCTAF 1996).

Certification

Certification is also a factor in determining a teacher's qualifications to teach in a particular field. The 1996 NAEP surveys reported that approximately 32 percent of fourth grade and 81 percent of eighth grade students study mathematics with a teacher certified in mathematics. Close to 25 percent of fourth grade students and 75 percent of eighth grade students study science with teachers certified in some area of science or in science education. Certification and licensing have been contentious issues in the profession for some time now. The National Commission on Teaching and America's Future estimated that, in recent years, approximately 50,000 people have entered classrooms with emergency or substandard licenses (NCTAF 1996).

In- and Out-of-Field Teaching Assignments

Often, secondary school teachers are assigned to courses for which they lack certification or other appropriate preparation. "Out-of-field" teaching is the term applied to this practice. Estimates of the extent of out-of-field teaching vary depending on the criteria used. For example, when the criterion for teaching is a graduate degree in the subject taught, the incidence of out-of-field teaching in mathematics and science is quite high. When the criterion is certification alone, estimates drop to less than 15 percent for both subjects (NCES 1997a). Ingersoll, who has done the most extensive examinations of this phenomenon, defines out-of-field teaching in terms of undergraduate major and minor (Ingersoll 1996, 1999).

Using Ingersoll's definition, out-of-field teaching is most common in physical science (57 percent) and history (53 percent), followed by life sciences and mathematics (33 percent and 31 percent, respectively). (See text table 5-9.) Out-of-field teaching is more common in small schools and in schools with larger numbers of low income or minority students. (See figure 5-19.) Students in lower secondary grades (7 through 9) and students in lower academic tracks experience more out-of-field teaching than students in higher grades and higher ability tracks. Out-of-field teaching is also more widespread in some states than in others (Ingersoll 1996).

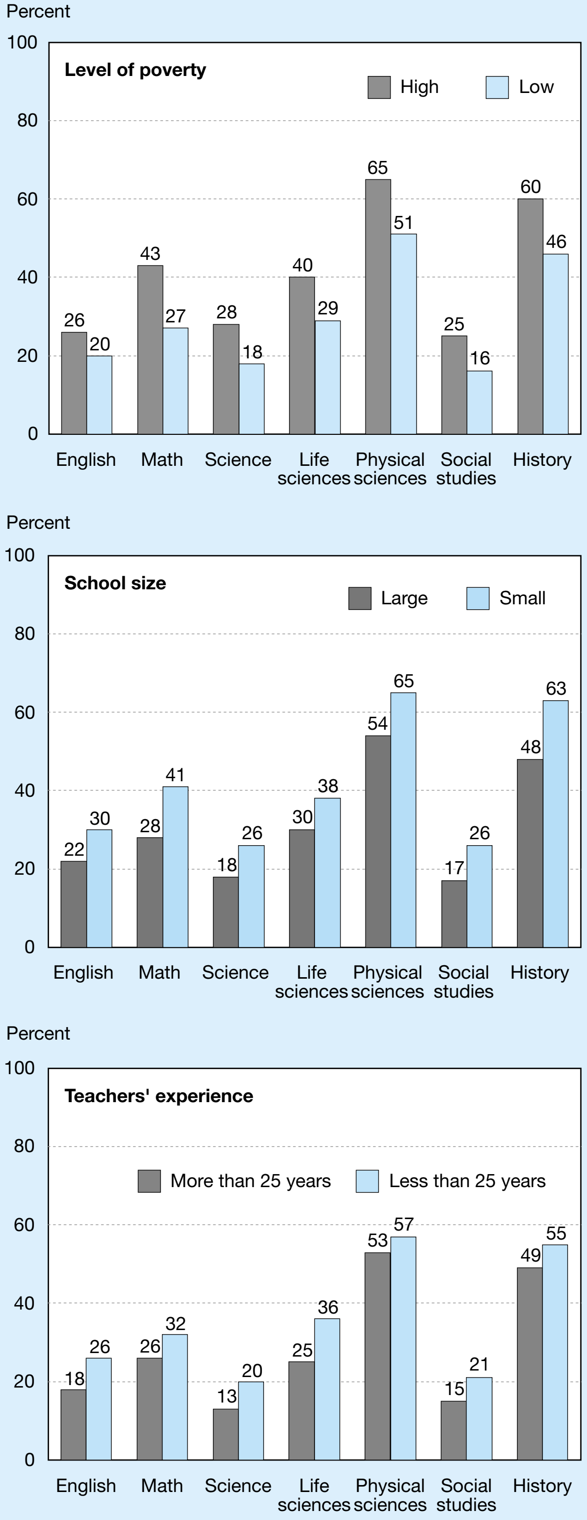
Out-of-field teaching is a major concern to the profession because it is a factor contributing to the number of teachers who are not appropriately prepared for the subjects they teach. Equity issues also fuel these concerns because poor and minority children are more often faced with teachers who are working outside their areas of preparation and expertise (Ingersoll 1996, NCTAF 1996, and Ingersoll 1997).

These findings are consistent with those of a recent study on teachers' perceived preparedness to function in various areas. While 71 percent of teachers feel well prepared to maintain order and discipline in their classrooms, over 36 percent feel well prepared to implement state or district curriculum and performance standards and only 20 percent were prepared to address the needs of limited English proficiency students or students from diverse cultural backgrounds (NCES 1999b).

The Teaching Profession in the 21st Century

Teachers, teacher educators, and state departments of education have been working for at least two decades to upgrade the quality of teaching. Some states and teacher preparation

Figure 5-19.
Percentage of secondary school (grades 7–12) teachers in each field without a major or a minor in that field



SOURCE: Ingersoll, R. 1999. "The Problem of Underqualified Teachers in American Secondary Schools." *Educational Researcher* 28, No. 2 (March): 26–37.

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programs now require teacher candidates to major in an academic subject. Teacher preparation programs are working with school districts to provide candidates with an additional one or two years of study, focused primarily on classroom experience. Induction programs are being developed to provide new teachers with mentors and support during their early years, when the recruits are most likely to leave the profession.

A new teacher education infrastructure is being developed. Standards for accrediting teacher preparation programs have been developed by the National Commission on Accreditation in Teacher Education (NCATE). Standards for licensing beginning teachers and guiding professional development have been formulated by the Interstate New Teachers Assessment and Support Consortium (INTASC), a collaboration of state-level staff and professional organizations concerned with teacher preparation and licensing. Standards for certifying accomplished teaching are being developed by the National Board for Professional Teaching Standards. As envisioned, these standards, aligned closely with each other and with standards for student learning, will form an integrated system that carries the prospective teacher from entry into a teaching program, through licensing and certification, through becoming an accomplished teacher, and on to lifelong professional development (Wise 1989, INTASC 1991, NBPTS 1991, INTASC 1994, Wise and Leibrand 1996, and Darling-Hammond and Ball 1997).

In addition to resolving questions about teacher qualifications, the profession also must resolve equity issues related to the quality of instruction for students in different circumstances. Poorer schools and schools with more minority students are less likely to have qualified teachers when judged by major, certification status, or years of teaching experience. Minority students are less likely to have teachers who are judged as very effective when evaluated using value-added criteria that reflect student growth in achievement (Education Trust 1998). This fact has important policy consequences. Students with the greatest need often are placed in the care of teachers who are least prepared to provide the kind of support they require (Holmes Group 1986; Oakes, Gamoran, and Page 1992; Chaney 1995; Ingersoll 1995, 1996, 1997, 1999).

Conclusion

This chapter presented indicators of changes in U.S. elementary and secondary schools in student achievement, curriculum, instructional practices, and the teaching profession. 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. 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 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. In the 1990s, NSF carried out a program of systemic reform to seek improved methods of education. 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 having taken advanced courses in mathematics and science than did their counterparts three decades ago. As measured by the National Assessment of Educational Progress, student achievement in mathematics and science has increased since the mid-1970s, but little change has occurred since 1990. The achievement of students in most demographic groups has improved significantly since the late 1970s. Much of that improvement, however, has been in lower skill areas. There have been small increments in the proportion of students achieving at higher levels of performance, but not nearly enough to conclude that National Education Goal 3 has been well met. Many students leave elementary and middle school without strong foundations in mathematics and science. This is a particular concern when regarding black and Hispanic students who continue to perform far below their white counterparts.

The performance of females compared with males on tests of mathematics and science has changed somewhat during the past two decades. At elementary school, few significant differences in performance levels for either mathematics or science were observed in 1996, the last year NAEP was available. At middle school, no differences are detectable for mathematics, but some difference between genders exists in science. At high school, the tendency of males to outperform females is still detectable in mathematics and clearly evident in science, although the differences have been narrowing since 1977.

Among the National Education Goals is the assertion that the mathematics and science achievement of U.S. students will be first in the world by the year 2000. Fourth grade students come close to meeting this expectation in both subjects, but grade 8 and grade 12 U.S. students perform below their peers in other countries according to results collected in 1995 for the Third International Mathematics and Science Study (TIMSS).

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 in NAEP assessments. Asian/Pacific Islander and white students are better represented in advanced courses than are black and Hispanic students. Asian/Pacific Islander and white students continue to outperform black and Hispanic students. Students of color and less-affluent students still have less access to high-end technology and less access to teachers with the proper education and certification in the subjects they teach. Although differences among ethnic groups continue, there have been important improvements: black and Hispanic students are now taking more advanced courses in high school, their performance on mathematics and science achievement tests has improved substantially, and discrepancies among racial/ethnic groups have narrowed in some cases in the last two decades.

The role of education technology in U.S. schools has been changing rapidly. Hand-held calculators are commonly used in both U.S. homes and classrooms. About one-fourth of fourth grade teachers and three-fourths of eighth grade teachers report that they use calculators for solving complex problems. By 1998, nearly all schools reported that at least one computer was linked to the Internet and half of the classrooms had access to the Internet. Computers are less often used in mathematics classes than in other subjects. Teachers who had several computers in their classroom were the most likely to report that the Internet was of use to them for student research projects, but at the same time, only about 20 percent of teachers feel "very well prepared" to integrate technology into the subjects they teach.

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Chapter 6
Academic Research and Development: Financial and Personnel Resources, Support for Graduate Education, and Outputs

Contents

Highlights

Financial Resources for Academic R&D

- **In 1998, an estimated $26.3 billion (in current dollars) was spent for research and development (R&D) at U.S. academic institutions (equivalent to $23.4 billion in constant 1992 dollars).** The Federal Government provided $15.6 billion, the academic institutions $5.0 billion, state and local governments $2.1 billion, industry $1.9 billion, and other sources $1.8 billion.
- **Over the past 45 years (between 1953 and 1998), average annual R&D growth 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 0.31 percent of gross domestic product (GDP), a more than fourfold increase.
- **The academic sector performs just under 50 percent of basic research, continuing 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. Of estimated 1998 academic R&D expenditures, an estimated 69 percent 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.** It provided an estimated 59 percent of the funding for R&D performed in academic institutions in 1998, down from its peak of 73 percent in the mid-1960s. Since 1994, non-Federal support has increased more rapidly than Federal support.
- **Three agencies are responsible for over four-fifths of Federal obligations for academic R&D: the National Institutes of Health (NIH—58 percent), the National Science Foundation (NSF—15 percent), and the Department of Defense (DOD—10 percent).** The National Aeronautics and Space Administration (5 percent), the Department of Energy (4 percent), and the Department of Agriculture (3 percent) provide an additional 12 percent of obligations for academic R&D. 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.
- **There has been a sizable increase in the number and types of universities and colleges receiving Federal R&D support during the past three decades.** Almost the entire increase occurred among other than research and doctorate-granting institutions, with 604 of these institutions receiving Federal R&D support in 1997, compared to 520 in 1990, 461 in 1980, and 341 in 1971. Although the share of Federal R&D support received by these institutions has increased over this period from 8 to 13 percent (rising from $0.4 billion to $1.5 billion in real terms), the research and doctorate-granting institutions continue to receive close to 90 percent of these funds.
- **After the Federal Government, academic institutions performing R&D provided the second largest share of academic R&D support.** After declining slightly in the early 1990s, the institutional share has been increasing since 1994, reaching an estimated 19 percent in 1998. Some of these funds directed by the institutions to research activities derive originally from Federal and state and local government sources, but—since the funds are not restricted to research, and the universities decide how to use them—they are classified as institutional funds.
- **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 three decades.** Industry's share was an estimated 7 percent in 1998, its highest level since 1958. However, industrial support still accounts for one of the smallest shares of academic R&D funding.
- **Over half of academic R&D expenditures have gone to the life sciences during the past three decades.** In 1997, the life sciences accounted for 56 percent of total academic R&D expenditures, 54 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 1997, the Federal Government supported close to 80 percent of academic R&D expenditures in both physics and atmospheric sciences, but only about 30 percent in political science and the agricultural sciences.
- **Total academic science and engineering research space increased by almost 28 percent between 1988 and 1998, up from about 112 million to 143 million net assignable square feet.** When completed, construction projects initiated between 1986 and 1997 are expected to produce over 63 million square feet of new research space, equivalent to about 45 percent of 1998 research 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 decade.** After reaching a high of 7 percent in 1986, it declined to 5 percent in 1997.

The Academic Doctoral Science and Engineering Workforce

- **Employment of doctoral scientists and engineers in academia reached a record 232,500 in 1997. Those with full-time faculty appointments were also at an all-time high of 178,400.** But faster growth outside the faculty ranks pushed the full-time faculty share of academic S&E employment to a low of 77 percent.
- **Doctoral employment at major research universities was stable over the decade; robust growth at other universities and colleges accelerated after 1995.**
- **Women accounted for the bulk of net growth in doctoral academic employment.** In 1997, 59,200 women represented one-quarter of employment and 22 percent of those in full-time faculty positions.
- **Doctoral academic minority employment reached 39,100 in 1997, with long-term increases generally in line with rising numbers of Ph.D. degrees earned.** American Indian, Alaskan Native, black, and Hispanic S&E doctorates comprised 6 percent of total employment and of faculty; Asians and Pacific Islanders were 11 percent of total employment.
- **The average age of the doctoral academic science and engineering faculty continues to rise.** Those 55 years or older constituted 13 percent of the total in 1973, 26 percent in 1997.
- **About 29,000 doctorates in the 1994–96 Ph.D. cohorts held academic positions in 1997. Forty-one percent each were in full-time faculty and postdoctoral positions.** In the early 1970s, 76 percent held faculty appointments, while 13 percent held postdoctorates.
- **Fewer than one-third of new science and engineering Ph.D.s hired by the research universities obtained full-time faculty appointments—less than half the percentage of the early 1970s.** In the other institutions, about 60 percent were hired into faculty positions.
- **The tenure-track fraction among young Ph.D.s with faculty appointments—about 75 percent—has remained roughly stable since the early 1970s.**
- **The physical sciences' shares of doctoral academic employment and full-time faculty have declined; the life sciences' shares have increased.** The bulk of the life sciences' growth took place in the nonfaculty segment, especially among postdoctorates.
- **The academic doctoral S&E research workforce—defined as those with research or development as their primary or secondary work responsibility—numbered an estimated 164,700 in 1997.** This represented a very robust 7 percent growth over 1995.
- **In 1997, 39 percent of the doctoral scientists and engineers in academia reported receiving support from the Federal Government.** This percentage has been stable in the 1990s.
- **The balance among S&E Ph.D.s reporting teaching or research as their *primary* activity has shifted toward research, for faculty and nonfaculty alike. But among *recent* Ph.D.s in faculty positions, trends in *primary* activity have reversed direction since the late 1980s:** Teaching rose from 56 percent to 68 percent; research declined from 38 percent to 23 percent.

Financial Support for S&E Graduate Education

- **In 1997, enrollment of full-time S&E graduate students registered a decline for the third consecutive year.** This period of decline followed steady increases in the enrollment of full-time S&E graduate students in every year since 1978.
- **The proportion of full-time graduate students in science and engineering with a research assistantship as their primary mechanism of support increased between 1980 and 1997.** Research assistantships were the primary support mechanism for 67 percent of the students whose primary source of support was from the Federal Government in 1997, compared to 55 percent in 1980. For students whose primary source was non-Federal, research assistantships rose from 20 percent to 29 percent of the total during this period. These shifts occurred primarily in the 1980s, and the relative usage of different types of primary support mechanisms has been fairly stable during the 1990s.
- **The Federal Government plays a larger role as the primary source of support for some support mechanisms than for others.** A majority of traineeships in both private and public institutions (54 percent and 73 percent, respectively) are financed primarily by the Federal Government, as are 60 percent of the research assistantships in private and 46 percent in public institutions.
- **The National Institutes of Health and National Science Foundation are the two Federal agencies that have been the primary source of support for full-time S&E graduate students relying on research assistantships as their primary support mechanism.** Each of these agencies supports about one-quarter of Federal graduate research assistantships. The Department of Defense supports about 15 percent.
- **Research assistantships are more frequently identified as a primary mechanism of support in the physical sciences, the environmental sciences, and engineering than in other disciplines.** Research assistantships comprise more than 50 percent of the primary support mechanisms for graduate students in atmospheric sciences, oceanogra-

phy, agricultural sciences, chemical engineering, and materials engineering. They account for less than 20 percent in the social sciences, mathematics, and psychology.

Outputs of Scientific and Engineering Research

- **In the mid-1990s, approximately 173,200 scientific and technical articles per year were published by U.S. authors in a set of refereed U.S. journals included in the Science Citation Index (SCI) since 1985.** Seventy-three percent had academic authors; industrial, government, and nonprofit sector authors each contributed 7–8 percent.
- **The number of industrial articles declined by 12 percent, from an annual average of 15,050 in 1988–91 to 13,220 in 1995–97. Industrial article volume in physics fell by 40 percent over the period, but output rose strongly in clinical medicine (19 percent) and biomedical research (12 percent).** This trend signals a shift in publishing activity toward pharmaceutical and other life-sciences-oriented industry segments.
- **Increasingly, scientific collaboration within the United States involves scientists and engineers from different employment sectors. In 1997, 30 percent of all academic papers involved such cross-sectoral collaboration.** Other sectors' collaboration rates were higher: 65 percent for industrial papers and 68 percent for those from the government and nonprofit sectors.
- **Much of the growth in U.S. coauthorship reflects increases in international collaboration.** By the mid-1990s, nearly one of every five U.S. articles had one or more international coauthors, up from 12 percent earlier in the decade.
- **Globally, five nations produced more than 60 percent of the articles in the SCI set of journals:** the United States (34 percent), Japan (9 percent), the United Kingdom (8 percent), Germany (7 percent), and France (5 percent). No other country's output reached 5 percent of the total.
- **The development or strengthening of national scientific capabilities in several world regions resulted in a continuation of a long-term decline in the U.S. share of total article output.** Shares of Western European countries as a group and Asia increased. The number of U.S. articles declined by 4 percent from its high earlier in the decade, while those of Western Europe and Asia rose by 18 and 31 percent, respectively.
- **Countries' science portfolios, as reflected in their published output, show some striking differences.** In some, like the United States, United Kingdom, and many smaller European states, the bulk of the articles falls in the life sciences. In others, notably many Central and Eastern European and Asian countries, the share of articles in the physical sciences and engineering is higher.
- **The increasingly global nature of science is reflected in growing scientific collaboration. In 1997, half of the articles in a set of key world journals covered by the SCI had multiple authors; 30 percent of these coauthored articles involved international collaboration, compared to 23 percent a decade earlier.** This trend affected most nations and fields.
- **The international nature of science is further underscored by patterns of citation. Averaged across all nations, about 59 percent of all citations were to nondomestic articles, up from 53 percent early in the decade.** Citations to U.S. articles nearly always exceeded the volume of citations to the domestic literature.
- **Two trends characterize the position of the United States in international collaboration. For most nations with strong international coauthorships, the number of articles with U.S. coauthors rose.** But many nations broadened the reach of their international collaborations, causing a diminution of the U.S. share of the world's internationally coauthored articles.
- **The linkage between research and perceived economic utility is getting tighter. The percentage of U.S. patents citing scientific and technical articles as "prior art" increased strongly, from 11 percent of all patents in 1985 to 23 percent in 1995. The number of articles cited on these patents grew explosively from 8,600 in 1987 to 108,300 in 1998.** This trend was rooted in the extremely rapid rise of citations to biomedical research and clinical medicine, reflecting perceptions of the life sciences' economic potential and related patenting trends. However, it was not limited to these fields.
- **Academic institutions are seeking to realize financial benefits from their research results. The number of academic patents has risen thirteenfold since the early 1970s.** The 3,151 patents awarded in 1998 represented about 5 percent of U.S.-owned patents, up from 0.5 percent in the earlier period.
- **University patents in the three largest academic technology classes—all with presumed biomedical applicability—constituted 41 percent of all academic patents in 1998.** Overall, academic patents are concentrated in far fewer technology areas than are industrial patents, and are growing more so.
- **University gross income from patenting and licenses reached $483 million in 1997.** Half or more of total royalties were directly related to the life sciences.
- **The number of startups and of licenses and options granted increased strongly.** Forty-one percent of new licenses and options went to large firms, 48 percent to small existing companies, and 11 percent to startups.

Introduction

Chapter Background

This chapter addresses key aspects of the academic research and development (R&D) enterprise: financial resources, physical infrastructure, science and engineering (S&E) doctoral employment, financial support for S&E graduate education, and research outputs. Half a century ago, these same aspects were of sufficient concern to merit discussion in the two seminal reports focusing on the U.S. R&D system, *Science—The Endless Frontier* (Bush 1945) and *Science and Public Policy* (Steelman 1947).

Both the Bush and the Steelman reports stressed the critical importance of a Federal role in supporting academic research, recommending a major expansion of that role. Today, that vision has materialized. A strong national consensus supports the public funding of academic research, and the Federal Government provides roughly 60 percent of the financial resources for academic R&D. A number of contemporary issues have arisen relating to this support; the appropriate balance of funding across S&E disciplines and accountability requirements—including measuring outputs and larger social outcomes—are examples.

The Steelman report focused on an aspect of the academic R&D enterprise that has become an enduring concern: broadening and strengthening the academic base of the Nation's science and engineering and R&D enterprise. Talent was sure to be found everywhere, and the Steelman report recommended using a portion of National Science Foundation (NSF) funds to strengthen weaker but promising colleges and universities in order to increase U.S. scientific potential. In point of fact, the number of academic institutions receiving Federal support for R&D activities has increased dramatically since the issuance of the report.

The Steelman report also noted that research facilities were less adequate at universities and colleges than elsewhere and called for additional libraries, laboratory space, and equipment and for Federal aid to academic institutions for the construction of facilities and purchase of equipment. Except for a decade during the 1960s and early 1970s, when a number of agencies conducted broad institutional support programs, the Federal Government has not taken a major role in providing direct support to universities and colleges for the construction of their research facilities. In recent years, it has accounted for about 8 to 9 percent of the funds for laboratory construction and renovation, with the institutions providing over 60 percent. In contrast, the Federal Government has accounted for almost 60 percent of direct current funds expenditures for academic research equipment during the past two decades. The Federal Government also indirectly supports both facilities and equipment through reimbursement on Federal grants and contracts.

The Steelman report placed strong emphasis on human resources development. An early chapter bears the title "Manpower: The Limiting Resource" and noted a broad disparity in the growth paths of the Nation's R&D budget and highly trained personnel. While recommending strong increases in R&D funding, the report recognized the need to alleviate inadequate personnel resources. It pointed to the critical role of doctoral science and engineering faculty in the universities and colleges, noting both their teaching and their research responsibilities. The report estimated that it would take an additional 15,000 such faculty to restore the prewar student-teacher ratio, while also expanding the sector's capacity for research. The discussion of these issues in recent years has been quite different, focusing on a burgeoning supply of new science and engineering Ph.D.s and a sometimes-variable labor market for other degree-holders, punctuated by debates about shortages and oversupply.

Both the Bush and the Steelman reports focused on an issue that has drawn increasing attention over the past decade—the importance of integrating education and research in higher education. They stressed that research is required for the teaching of science, and that fully trained scientists can only be produced through involvement in research. The Steelman report noted that the recommended expansion of academic research grants would result in the employment of graduate students as research assistants, which in turn would result in better scientific training. Research assistantships now comprise the largest primary graduate student support mechanism; two-thirds of federally supported students receive their support in the form of a research assistantship. A number of Federal graduate traineeship programs, and even more recently some Federal graduate fellowship programs, have emphasized the integration of education and research.

Half a century ago, the Steelman and Bush reports largely took for granted the positive outcomes and impacts of research and development. Today's mature and established publicly funded R&D system faces new demands, not envisioned then, of devising means and measures to account for the proximate outputs of specific Federal R&D investments, including those for academic R&D, and their longer-term consequences for valued social ends.

Even though the academic R&D enterprise has enjoyed strong growth for the past several decades, the Nation's universities and colleges face challenges in their finances, enrollment, faculty, and competitive environment. Many of these factors will have some form of impact on the academic R&D enterprise. This chapter seeks to provide data on some pertinent trends and analysis bearing on these issues.

Chapter Organization

The chapter opens with a discussion of 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 over half a century, the importance of selected agencies in supporting individual fields is explored in some detail. Data are also presented on changes in the number of academic institutions receiving Federal R&D support. The section then examines the status of two key elements of university research activities—facilities and instrumentation.

Basic Research

Science and Public Policy (Steelman report)

Part One—Science for the Nation, IV. A National Science Program

Basic research traditionally has been conducted in the colleges and universities. While industry engages in some basic research and the Government laboratories conduct a somewhat greater amount, the proportions in both instances are small. The principal function of the colleges and universities is to promote the progress of learning and they must be the primary means through which any expanded program of basic research is carried out. There are several reasons for this.

First, the scientific method, being based upon experiment, requires research for the teaching of science. Fully trained scientists can be produced only through practicing research.

Second, basic research is so broad in its application and so indirectly related to any industrial process, or in fact to any particular industry, that it is not profitable for private enterprise to engage in extensive basic research. Industries do sometimes support it through fellowships and other grants to universities, but the sums involved are not large.

Third, research, while carried out by individuals, has always been a cooperative venture. Scientists have exchanged information and collaborated with each other in the performance of research; and science progresses characteristically through a combination of knowledge from many different sources. Research thrives in situations where scientists with many diverse interests and fields of knowledge can be brought together in an exchange of both knowledge and ideas. Thus the universities, which foster all branches of knowledge, are ideal breeding grounds for basic research. (Steelman 1947, 29.)

The next section discusses trends in the employment, demographic characteristics, and activities of academic doctoral scientists and engineers. The discussion of employment trends focuses on full-time faculty, postdoctorates, and other positions. Differences are examined between the Nation's largest research universities and other academic institutions, as are shifts in the faculty age structure. The involvement of women, underrepresented minorities, and Asians and 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 the Federal support they report for their research. Selected demographic characteristics of recent doctorate-holders entering academic employment are examined.

The third section looks at the relationships between research and graduate education. It covers overall trends in graduate support and patterns of support in different types of institutions, and compares support patterns for those who complete an S&E doctorate with the full population of graduate students. The role of graduate research assistantships is examined in some detail, including the sources of support for research assistants and the spreading incidence of research assistantship (RA) support to a growing number of academic institutions.

The chapter's final section deals with two research outputs: scientific and technical articles in a set of journals covered by the Science Citation Index (SCI), 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 4.) The section specifically looks at the output volume of research (article counts), collaboration in the conduct of research (joint authorship), use in subsequent scientific activity (citation patterns), and use beyond science (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[1]

Academic R&D is a significant part of the national R&D enterprise. 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 relating to a number of important issues that relate to the financing of academic R&D. Among these issues are 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 science and engineering fields and subfields or fine fields; the distribution of funding among and the extent of participation of various types of academic R&D performers; 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. This section focuses on providing data on these aspects of the academic R&D enterprise which individually and in combination influence its evolution.

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[1] Data in this section come from several different National Science Foundation (NSF) surveys that do not always use comparable definitions or methodologies. NSF's three main surveys involving academic R&D are the (1) Survey of Federal Funds for Research and Development; (2) Survey of Federal Science and Engineering Support to Universities, Colleges, and Nonprofit Institutions; and (3) Survey of Research and Development Expenditures at Universities and Colleges. The results from this last survey are based on data obtained directly from universities and colleges; the former two surveys collect data from Federal agencies. For descriptions of the methodologies of these and other NSF surveys, see NSF (1995b and 1995c).Federally Funded Research and Development Centers associated with universities are tallied separately and are examined in greater detail in chapter 2.

Academic R&D in the National R&D Enterprise[2]

The continuing importance of academe to the Nation's overall R&D effort is still recognized today, especially its contribution to the generation of new knowledge through basic research.

In 1998, an estimated $26.3 billion, or $23.4 billion in constant 1992 dollars, was spent on R&D at U.S. academic institutions.[3] This was the 24th consecutive year in which constant dollar spending increased from the previous year. Academia's role as an R&D performer has increased fairly steadily during the past half-century, rising from about 5 percent of all R&D performed in the country in 1953 to almost 12 percent in 1998. (See figure 6-1.) However, since 1994, the sector's performance share has dipped slightly from its high of almost 13 percent (see "Growth" section below). For a description of the role of universities in national R&D expenditures in the first part of the 20th century, see chapter 1, "Science and Technology in Times of Transition: the 1940s and 1990s."

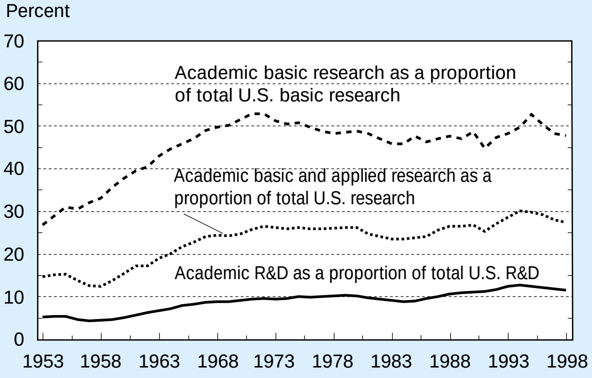
Character of Work

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] Of 1998 academic R&D expenditures, an estimated 93 percent went for research (69 percent for basic and 24 percent for applied) and 7 percent for development. (See figure 6-2.) From a national research—as opposed to national R&D—perspective, academic institutions accounted for an estimated 27 percent of the U.S. total in 1998. 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. It has since fluctuated between 23 and 30 percent. And, in terms of basic research alone, the academic sector is the country's largest performer, currently accounting for an estimated 48 percent of the national total. Between 1953 and 1972, the academic sector's basic research performance grew steadily, increasing from about one-quarter to just over one-half of the national total. It has since fluctuated between 45 and 51 percent of the national total. (See figure 6-1.)

Growth

Over the long term (between 1953 and 1998), average annual R&D growth (in constant 1992 dollars) has been stronger for the academic sector than for any other R&D-performing sector—6.5 percent, compared to about 5.7 per-

Figure 6-1.
Academic R&D, research, and basic research as a proportion of U.S. totals: 1953–98

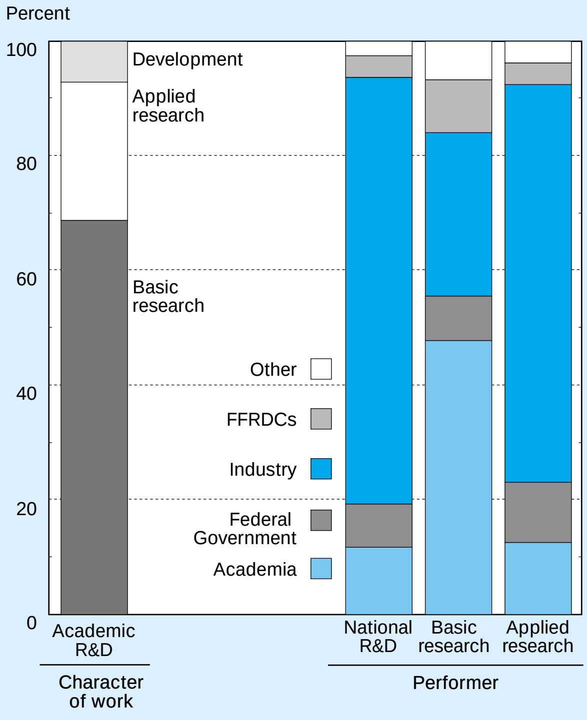


NOTE: Data for 1998 are preliminary.

See appendix tables 2-3, 2-7, and 2-11.

Science & Engineering Indicators – 2000

Figure 6-2.
Academic R&D expenditures by character of work and national R&D expenditures by performer and character of work: 1998



FFRDC = Federally Funded Research and Development Center

NOTE: Data are preliminary.

See appendix tables 2-3, 2-7, 2-11, and 6-1.

Science & Engineering Indicators – 2000

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[2] For more information on national R&D expenditures, see "Economic Measures of R&D" in chapter 2.

[3] For the purposes of this discussion, academic institutions generally comprise institutions of higher education that grant doctorates in science or engineering and/or spend at least $50,000 for separately budgeted R&D. In addition, all Historically Black Colleges and Universities (HBCUs) with R&D programs are included, regardless of the level of R&D.

[4] Notwithstanding this delineation, the term "R&D"—rather than just "research"—is used throughout this discussion unless otherwise indicated, since much of the data collected on academic R&D does not differentiate between "R" and "D." Moreover, it is often difficult to make clear distinctions among basic research, applied research, and development. For the definitions used in NSF resource surveys, see chapter 2.

cent for federally funded research and development centers (FFRDCs), 5.2 percent for other nonprofit laboratories, 4.8 percent for industrial laboratories, and 2.5 percent growth for Federal laboratories. (See appendix table 2-4 for time series data by R&D-performing sector.) This long-term trend has held for more recent times as well—through the 1980s and the early part of the 1990s—although average annual growth was higher for all R&D-performing sectors between 1953 and 1980 than it has been since 1980. However, beginning in 1994 growth of R&D performed in industry (an estimated 7.6 percent annually) started to outpace growth of academically performed R&D (an estimated 3.2 percent annually). As a proportion of gross domestic product (GDP), academic R&D rose from 0.07 to 0.31 percent between 1953 and 1998, a more than fourfold increase. (See appendix table 2-1 for GDP time series.)

University R&D Expenditures

Science and Public Policy (Steelman report)
Part One—Science for the Nation, IV.
A National Science Program

There is every reason to anticipate a doubling of research and development expenditures by industry in the next decade, in view of the long term trends and the increasing dependence of industry upon research and development. But there is little likelihood of any considerable expansion of university expenditures out of their present income sources. Endowment income has sharply declined over the last 15 years and there is little likelihood of any considerable rise in interest rates in the future. Moreover, the large fortunes which were the source of new endowment funds are now considerably limited by taxation. So far as State-supported institutions are concerned, the long-run financial position of many states makes large increases in university support unlikely. A similar situation confronts the private foundations, which are not, in any event, of great significance in the over-all financial picture. The foundations have contributed enormously to the extension of knowledge and to the support of basic research, but their expenditures have been small in terms of the total budget. It is not likely that their share will expand in the future. (Steelman 1947, 26-7.)

Major Funding Sources

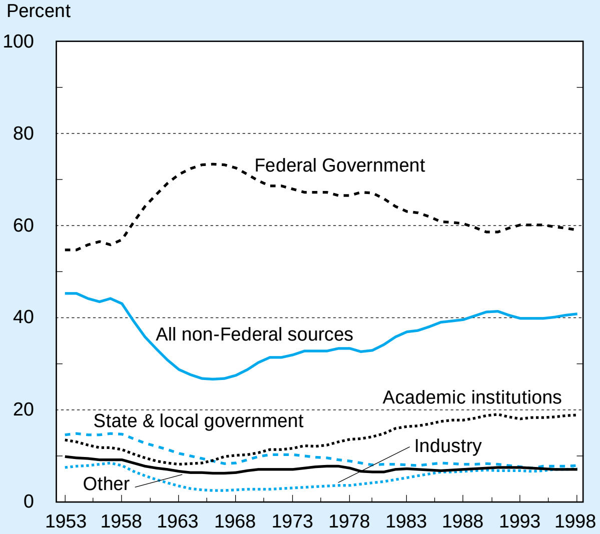
The continued reliance of the academic sector on a variety of funding sources for support of its R&D activities requires continuous monitoring of the contributions of those sources.

The Federal Government continues to provide the majority of funds for academic R&D. In 1998, it accounted for an estimated 59 percent of the funding for R&D performed in academic institutions. After increasing from 55 percent in 1953 to its peak of just over 73 percent in 1966, the Federal support share declined fairly steadily until the early 1990s. (See figure 6-3.) Since 1992, it has fluctuated between 59 and 60 percent. The Federal sector primarily supports basic research—72 percent of its 1998 funding went to basic research versus 20 percent to applied. Non-Federal sources also concentrate on basic research, but provide a larger share of their support than the Federal sector for applied research (64 percent for basic and 30 percent for applied research). (See appendix table 6-1.) As a consequence of this differential emphasis, 62 percent of the basic research performed at universities and colleges is supported by the Federal Government, while only 49 percent of the applied research is so supported.

Federal support of academic R&D is discussed in detail later in this section; the following summarizes the contributions of other sectors to academic R&D.[5]

- **Institutional funds.**[6] In 1998, institutional funds from universities and colleges constituted the second largest source of academic R&D funding, accounting for an estimated 19 percent. The share of support represented by this source has been increasing fairly steadily since the early 1960s, save for a brief downturn in the early 1990s. Institutional

Figure 6-3.
Sources of academic R&D funding: 1953–98



NOTE: Data for 1998 are preliminary.

See appendix table 6-2. *Science & Engineering Indicators – 2000*

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[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.

[6] Institutional funds are separately budgeted funds that an academic institution spends on R&D from unrestricted sources, unreimbursed indirect costs associated with externally funded R&D projects, and mandatory and voluntary cost sharing on Federal and other grants. As indicated above, departmental research that is not separately budgeted is not included.

R&D funds may be derived from (1) general-purpose state or local government appropriations, particularly for public institutions; (2) general-purpose grants from industry, foundations, or other outside sources; (3) tuition and fees; (4) endowment income; and (5) gifts that are not restricted by the donor to conduct research. Other potential sources of institutional funds are income from patents or licenses and income from patient care revenues. (See "Academic Patenting: Patent Awards, Licenses, Startups, and Revenue" later in this chapter for a discussion of patent and licensing income.)

- **State and local government funds.** In 1998, the share of academic R&D funding provided by state and local governments was an estimated 8 percent. State and local governments played a larger role during the early 1950s, when they provided about 15 percent of the funding. Their relative role began to decline thereafter except for a brief upturn between 1968 and 1973. Their share of academic R&D funding has fluctuated between 7 and 8 percent since 1980. This share, however, reflects only funds directly targeted to academic R&D activities by the state and local governments and 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.[7] Consequently, the actual contribution of state and local governments to academic R&D is understated, particularly for public institutions.

- **Industry funds.** In 1998, industry provided an estimated 7 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. During the 1950s, industry's share was actually larger than it is currently, peaking at 8.4 percent in 1957. After reaching this peak, the industrial share steadily declined, reaching its low of 2.5 percent in 1966. Industry then began to increase its share from slightly below 3 percent in 1970, to about 4 percent in 1980 and about 7 percent in 1990, where it has since remained. Industry's contribution to academia represented an estimated 1.3 percent of all industry-funded R&D in 1998, compared to 0.9 percent in 1980, 0.6 percent in 1970, and 1.1 percent in 1958. (See appendix tables 2-4 and 2-5 for time series data on industry-funded R&D.) Thus, although increasing recently, industrial funding of academic R&D has never been a major component of industry-funded R&D.

- **Other sources of funds.** In 1998, other sources of support accounted for 7 percent of academic R&D funding. This share has stayed fairly constant at about this level during the past three decades after declining from its peak of 10 percent in 1953. These sources include grants for R&D from nonprofit organizations and voluntary health agencies and gifts from private individuals that are restricted by the donor to conduct 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 appendix table 6-3.) For all *public* academic institutions combined, just over 10 percent of R&D funding in 1997—the most recent year for which data are available—came from state and local funds, about 23 percent from institutional funds, and about 53 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 from institutional sources (10 percent), and a much larger share from the Federal Government (72 percent). The large difference in the role of institutional funds between public and private institutions is most likely due to a substantial amount of general-purpose state and local government funds received by the former that these institutions decide to use for R&D (although data on such breakdowns are not collected). Both public and private institutions received approximately 7 percent of their respective R&D support from industry in 1997. 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.

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 higher education institutions in the United States.[8] In fact, if all such institutions were ranked by their 1997 R&D expenditures, the top 200 institutions would account for about 95 percent of R&D expenditures. In 1997 (see appendix table 6-4[9]):

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[7] This follows international standards of reporting where funds are assigned to the entity determining how they are to be used rather than to the one necessarily providing the funds.

[8] The Carnegie Foundation for the Advancement of Teaching classified about 3,600 degree-granting institutions as higher education institutions in 1994. (See chapter 4 sidebar, "Carnegie Classification of 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, and so forth.).

[9] The Johns Hopkins University and the Applied Physics Laboratory (APL) at the Johns Hopkins University are reported separately in appendix table 6-4. Although not officially classified as an FFRDC, APL essentially functions as one. Separate reporting therefore provides a better measure of the distribution of academic R&D dollars and the ranking of individual institutions.

Other Assistance

Science and Public Policy (Steelman report)
Part One—Science for the Nation, IV.
A National Science Program

While the support of basic research through the National Science Foundation is of the utmost importance, it is only one of several elements in our total national science program. Moreover, it is only one element in our developing program of Federal support for higher education...Few persons would doubt today that we must soon develop a permanent, long-range program of Federal assistance to students and of Federal aid to education in general. Viewed in perspective, the support of basic research in the colleges and universities is part of such a program. It can achieve results only as the colleges and universities themselves are strong and only as means are found to permit able students to pursue their studies.

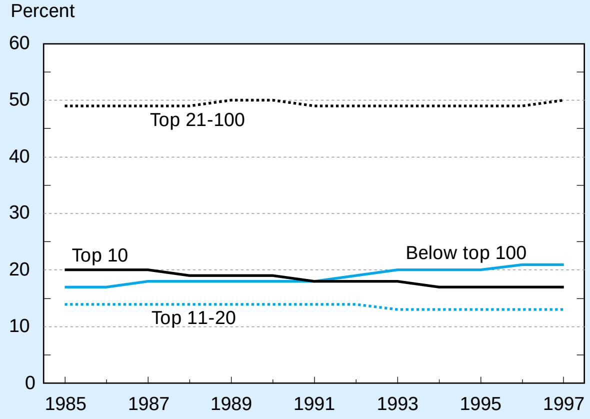
In such terms, it is clear that a portion of the funds expended by the National Science Foundation should be used to strengthen the weaker, but promising, colleges and universities, and thus to increase our total scientific potential. (Steelman 1947, 34.)

[For a discussion of a Federal program created to strengthen research and education in the sciences and engineering and to avoid undue concentration of such research and education, see sidebar, “EPSCoR—the Experimental Program to Stimulate Competitive Research.”]

- the top 10 institutions spent 17 percent of total academic R&D funds ($4.1 billion),
- the top 20 institutions spent 30 percent ($7.3 billion),
- the top 50 spent 56 percent ($13.6 billion), and
- the top 100 spent 79 percent ($19.3 billion).

This historic concentration of academic R&D funds, however, has been diminishing somewhat over the past dozen years. (See figure 6-4.) In 1985, the top 10 institutions received about 20 percent and the top 11–20 institutions 14 percent of the funds, compared to 17 and 13 percent, respectively, in 1997. The composition of the universities in the top 20 has also fluctuated slightly over the period. 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 21 percent of total academic R&D funds. This increased share of the Nation's total academic R&D expenditures by those institutions ranked below the top 100 signifies a broadening of the base. See “The Spreading Institutional Base of federally Funded Academic R&D” in the “Federal Support of Academic R&D” section below for a discussion of the increase in the number of academic institutions receiving Federal support for their R&D activities over the past three decades.

Figure 6-4.
Share of academic R&D of top R&D universities and colleges: 1985–97



See appendix table 6-4. *Science & Engineering Indicators – 2000*

Expenditures by Field and Funding Source[10]

The distribution of academic R&D funds across S&E disciplines is often 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 1997 went to the life sciences, which accounted for 56 percent of total academic R&D expenditures, 54 percent of Federal academic R&D expenditures, and 58 percent of non-Federal academic R&D expenditures. Within the life sciences, medical sciences accounted for 28 percent of total academic R&D expenditures and biological sciences for 17 percent.[11] The next largest block of total academic R&D expenditures was for engineering—16 percent in 1997. (See appendix table 6-5.)

The distribution of Federal and non-Federal funding of academic R&D in 1997 varied by field. (See appendix table 6-5.) For example, the Federal Government supported close to 80 percent of academic R&D expenditures in both physics and atmospheric sciences, but only 30 percent of academic R&D in political science and 29 percent in the agricultural sciences.

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[10] The data in this section are drawn from NSF's 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.

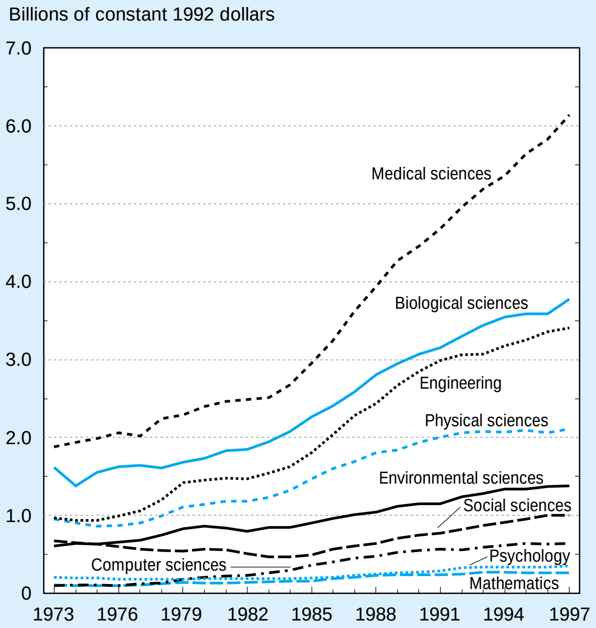
[11] Medical sciences includes research in fields such as pharmacy, veterinary medicine, anesthesiology, and pediatrics. Biological sciences includes research in fields such as microbiology, genetics, biometrics, and ecology. These distinctions may be blurred at times, as the boundaries between fields are often not well defined.

The declining Federal share in support of academic R&D is not limited to particular S&E disciplines. Rather, the federally financed fraction of support for each of the broad S&E fields was lower in 1997 than in 1973, except for the computer sciences (which was slightly higher). (See appendix table 6-6.) The most dramatic decline occurred in the social sciences—down from 57 percent in 1973 to 37 percent in 1997. 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 have not experienced declining Federal shares during the 1990s.

Although academic R&D expenditures in constant dollars for every field have increased between 1973 and 1997 (see figure 6-5 and appendix table 6-7), the R&D emphasis of the academic sector, as measured by its S&E field shares, has changed during this period.[12] (See figure 6-6.) Absolute shares of academic R&D have:

- increased for the life sciences, engineering, and computer sciences;
- remained roughly constant for mathematics; and
- declined for the social sciences, psychology, the environmental (earth, atmospheric, and oceanographic) sciences, and the physical sciences.

Figure 6-5.
Academic R&D expenditures, by field: 1973–97



NOTE: See appendix table 2-1 for GDP implicit price deflators used to convert current dollars to constant 1992 dollars.

See appendix table 6-7. *Science & Engineering Indicators – 2000*

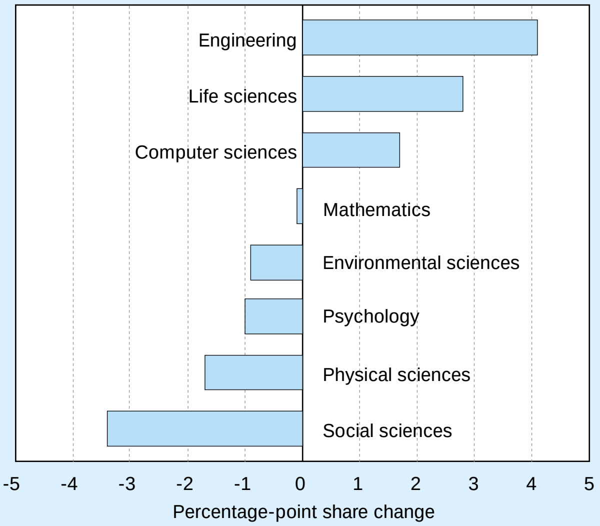
Although the proportion of the total academic R&D funds going to the life sciences' share increased by only 3 percentage points, rising from 53 to 56 percent of academic R&D between 1973 and 1997, the medical sciences' share increased by almost 6 percentage points—from 22 to 28 percent of academic R&D—during this period. The other two major components of the life sciences—agricultural sciences and biological sciences—both lost shares during the period. The engineering share increased by 4 percentage points over this period—from 12 to 16 percent of academic R&D; while the computer sciences' share increased from 1 to 3 percent of academic R&D.

The social sciences' proportion declined by more than 3 percentage points (from 8 to below 5 percent of academic R&D) between 1973 and 1997. Within the social sciences, the 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 sciences, earth sciences, and oceanography—each experienced a decline in share. The physical sciences' share also declined during this period, from 11 to 10 percent. However, within the physical sciences, astronomy's share increased while the shares of both physics and chemistry declined.

Federal Support of Academic R&D

Although the Federal Government continues to provide the majority of the funding for academic R&D, its overall contribution is the combined result of decisions by a number of key

Figure 6-6.
Changes in the share of academic R&D in selected S&E fields: 1973–97



See appendix table 6-7. *Science & Engineering Indicators – 2000*

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[12] For a more detailed discussion of these changes, see *How Has the Field Mix of Academic R&D Changed?* (NSF 1999g).

From Vannevar Bush in Science—The Endless Frontier:

> One of our hopes is that after the war there will be full employment. To reach that goal the full creative and productive energies of the American people must be released. To create more jobs, we must make new and better and cheaper products. We want plenty of new, vigorous enterprises. But new products and processes are not born full-grown. They are founded on principles and new conceptions which in turn result from basic scientific research. Basic scientific research is scientific capital. Clearly, more and better scientific research is one essential to the achievement of our goal of full employment.
>
> How do we increase this scientific capital? First, we must have plenty of men and women trained in science, for upon them depends both the creation of new knowledge and its application to practical purposes. Second, we must strengthen the centers of basic research which are principally the colleges, universities, and research institutes. These institutions provide the environment which is most conducive to the creation of new scientific knowledge and least under pressure for immediate, tangible results. With some notable exceptions, most research in industry and in Government involves application of existing scientific knowledge to practical problems. It is only the colleges, universities, and a few research institutes that devote most of their research efforts to expanding the frontiers of knowledge. (Bush 1945.)

funding agencies with differing missions.[13] Examining and documenting the funding patterns of these agencies are key to understanding both their roles and the overall government role.

Top Agency Supporters

Three agencies are responsible for most of the Federal obligations for academic R&D: the National Institutes of Health (NIH), the National Science Foundation (NSF), and the Department of Defense (DOD). (See appendix table 6-8.) Together, these agencies are estimated to have provided approximately 83 percent of total Federal financing of academic R&D in 1999, as follows:

- NIH—58 percent,
- NSF—15 percent, and
- DOD—10 percent.

An additional 12 percent of the 1999 obligations for academic R&D are estimated to be provided by the National Aeronautics and Space Administration (NASA, 5 percent); the Department of Energy (DOE, 4 percent); and the Department of Agriculture (USDA, 3 percent). Federal obligations for academic research are concentrated similarly to those for R&D. (See appendix table 6-9.) There are some differences, however, since agencies such as DOD place greater emphasis on development, while others such as NSF place greater emphasis on research.

During the 1990s, NIH's funding of academic R&D increased most rapidly, with an estimated average annual growth rate of 3.7 percent per year in constant 1992 dollars. NSF (3.2 percent) and NASA (2.4 percent) experienced the next highest rates of growth. Average annual rates of growth were negative for DOD, DOE, and USDA during this period. Between 1998 and 1999, total Federal obligations for academic R&D are estimated to increase by 5.4 percent in constant dollars. NSF (by 11 percent) and NIH (by 8 percent) are expected to have the largest increases in their academic R&D obligations in 1999.

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 the life sciences, while DOE concentrates on the physical sciences. Other agencies—NSF, NASA, and DOD—have more diversified funding patterns. (See figure 6-7.) 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 6-8.) NSF is the lead funding agency in the physical sciences (34 percent of total funding), mathematics (66 percent), the environmental sciences (46 percent), and the social sciences (38 percent). DOD is the lead funding agency in the computer sciences (48 percent) and in engineering (39 percent). HHS is the lead funding agency in the life sciences (87 percent) and psychology (89 percent). Within fine S&E fields, other agencies take the leading role—DOE in physics (53 percent), USDA in agricultural sciences (99 percent), and NASA in astronomy (77 percent) and in both aeronautical (70 percent) and astronautical (65 percent) engineering. (See appendix table 6-11.)

The Spreading Institutional Base of Federally Funded Academic R&D

The number of academic institutions receiving Federal support for their R&D activities has increased over the past three decades.[14] Although that number has fluctuated during this time period,[15] there was an increase of almost 50 percent in the number of institutions receiving support in 1997, com-

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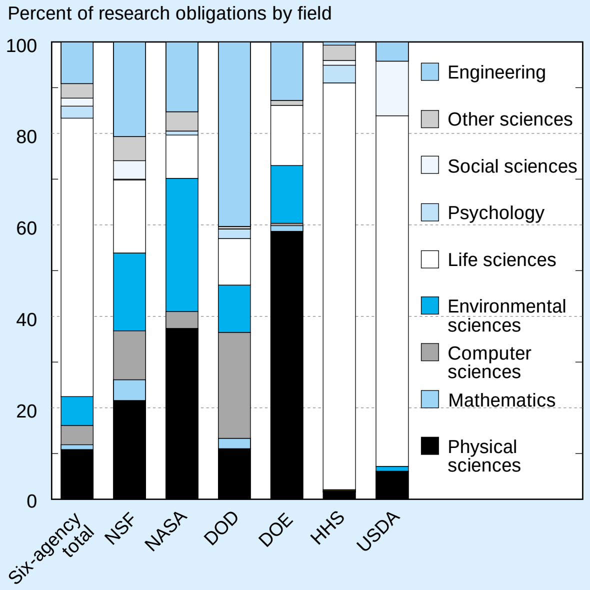
[13] Some of the Federal R&D funds obligated to universities and colleges are the result of appropriations that Congress directs Federal agencies to award to projects that involve specific institutions. These funds are known as congressional earmarks. See Brainard and Cordes (1999) for a discussion of this subject.

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

[15] The rather large decline in the number of institutions receiving Federal R&D support in the early 1980s was most likely due to the fall in Federal R&D funding for the social sciences during that period.

Figure 6-7.
Distribution of Federal agency academic research obligations, by field: FY 1997

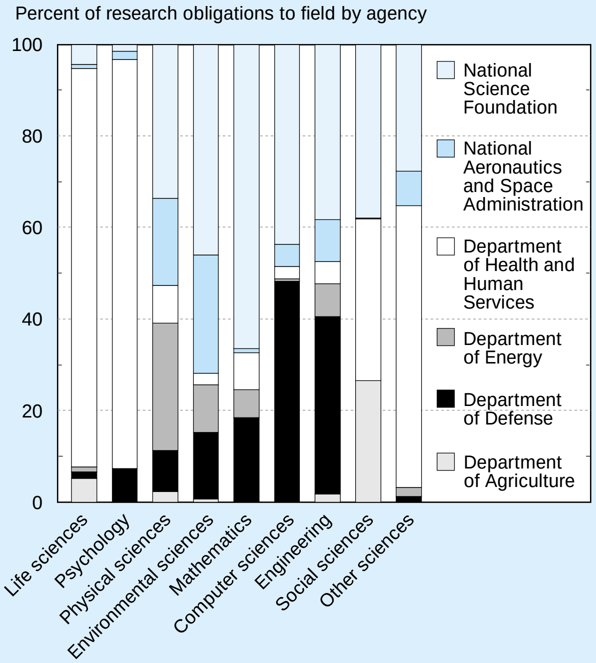


NSF = National Science Foundation; NASA = National Aeronautics and Space Administration; DOD = Department of Defense; DOE = Department of Energy; HHS = Department of Health and Human Services; USDA = Department of Agriculture

NOTE: The six agencies reported represent approximately 96 percent of Federal academic research obligations.

See appendix table 6-10. *Science & Engineering Indicators – 2000*

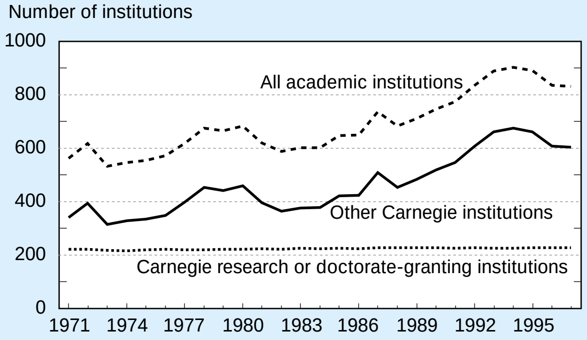
Figure 6-8.
Major agency field shares of Federal academic research obligations: FY 1997



NOTE: The six agencies reported represent approximately 96 percent of Federal academic research obligations.

See appendix table 6-11. *Science & Engineering Indicators – 2000*

Figure 6-9.
Number of academic institutions receiving Federal R&D support by selected Carnegie classification: 1971–97



NOTES: See “Carnegie Classification of Institutions” in Chapter 4 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 6-12. *Science & Engineering Indicators – 2000*

pared to 1971. (See figure 6-9.) Since most institutions currently designated as Carnegie research and doctorate-granting institutions were already receiving Federal support in 1971, most of the increase has occurred among the group containing comprehensive; liberal arts; two-year community, junior, and technical; and professional and other specialized schools.[16] The number of such institutions receiving Federal support just about doubled between 1971 and 1994, rising from 341 to 676. Since 1994, although the number of Carnegie research and doctorate-granting institutions receiving Federal R&D support has remained constant, there has been a rather substantial drop in the number of other institutions—from their peak of 676 to only 604 in 1997. However, most of the drop occurred in institutions receiving less than $100,000 in Federal R&D obligations. The number of other institutions receiving $100,000 or more in obligations was about 400 in both 1994 and 1997. The non-research and non-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—about 13 percent between 1993 and 1997. 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 support going to institutions below the top 100 reported in the earlier section on “Distribution of R&D Funds Across Academic Institutions.”

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[16] See chapter 4 sidebar, “Carnegie Classification of Institutions” for a brief description of the Carnegie categories.

EPSCoR—the Experimental Program to Stimulate Competitive Research

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

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

But EPSCoR did not officially begin at NSF until 1978, when Congress authorized NSF to conduct EPSCoR in response to broad public concerns about the extent of geographical concentration of Federal funding of R&D. Eligibility for EPSCoR participation was limited to those jurisdictions that have historically received lesser amounts of Federal R&D funding and have demonstrated a commitment to develop their research bases and to improve the quality of science and engineering research conducted at their universities and colleges.

Eighteen states and the Commonwealth of Puerto Rico currently participate in the NSF program. 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. As part of EPSCoR, NSF actively cooperates with state leaders in government, higher education, and business to establish productive long-term partnerships capable of effecting lasting improvements to the state's academic research infrastructure and increased national R&D competitiveness.

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

Since 1979, other Federal agencies have adopted their own EPSCoR or EPSCoR-like programs with goals similar to those of NSF. In Fiscal Year 1993, Congressional direction precipitated the formation of the EPSCoR Interagency Coordinating Committee (EICC). A Memorandum of Understanding (MOU) was signed by officials of those agencies with EPSCoR or EPSCoR-like programs agreeing to participate in the EICC. The major objective of the MOU focused on improving coordination among and between the Federal agencies in implementing EPSCoR and EPSCoR-like programs consistent with the policies of participating agencies. The agencies included: DOD, DOE, the Environmental Protection Agency (EPA), NASA, NIH, NSF, and USDA. They agreed to the following objectives:

- Coordinate Federal EPSCoR and EPSCoR-like programs to maximize the impact of Federal support while eliminating duplication in states receiving EPSCoR support from more than one agency.
- Coordinate agency objectives with state and institutional goals, where appropriate, to obtain continued non-Federal support of S&T research and training.
- Coordinate the development of criteria to assess gains in academic research quality and competitiveness and in S&T human resource development.

In 1998, the seven EICC agencies spent a total of $89 million on EPSCoR or EPSCoR-like programs, up from $82 million in 1995. (See text table 6-1.)

Text table 6-1.
EPSCoR and EPSCorR-like program budgets, by agency
(Millions of dollars)

Agency	Fiscal year 1995	1996	1997	1998	1999^a
Total	82.0	79.1	81.7	88.5	109.7
Department of Agriculture	13.6	11.1	11.0	13.6	13.0
Department of Defense	20.0	18.6	17.0	18.0	19.0
Department of Energy	6.1	6.5	6.3	6.4	6.8
Environmental Protection Agency	1.0		2.5	2.5	2.5
National Aeronautics and Space Administration	5.0	5.0	4.6	4.6	10.0
National Institutes of Health	0.9	2.2	1.9	5.0	10.0
National Science Foundation	35.4	35.7	38.4	38.4	48.4

EPSCoR = Experimental Program to Stimulate Competitive Research

[a] Figures for 1999 are estimates or authorized amounts.

SOURCES: EPSCoR Interagency Coordinating Committee: FY 1999,"unpublished report; and selected members of the EPSCoR Interagency Coordinating Committee.

Science & Engineering Indicators – 2000

Academic R&D Facilities and Equipment[17]

Physical infrastructure for academic R&D, especially the state of research facilities and equipment and levels and sources of funding for these two key components, remains a serious concern today.

Facilities[18]

Total Space. The amount of academic S&E research space has grown continuously over the decade. Between 1988 and 1998, total academic science and engineering research space increased by almost 28 percent, from about 112 million to 143 million net assignable square feet (NASF).[19] (See appendix table 6-13.) Doctorate-granting institutions account for most of the growth in research space over this period.

There was little change in the distribution of academic research space across fields of science and engineering between 1988 and 1998. (See appendix table 6-13.) About 90 percent of current academic research space continues to be concentrated in six S&E fields:

- the biological sciences (21 percent in 1988 and 22 percent in 1998),
- the medical sciences (17 percent in both years),
- engineering (from 14 to 16 percent),
- the agricultural sciences (from 16 to 17 percent),
- the physical sciences (from 14 to 13 percent), and
- the environmental sciences (6 percent in both years).

New Construction. The total cost of new construction projects has fluctuated over time. New construction projects begun in 1996 and 1997 for academic research facilities are expected to cost $3.1 billion. (See appendix table 6-14.) New construction projects initiated between 1986 and 1997 were expected to produce over 63 million square feet of research space when completed—the equivalent of about 45 percent of estimated 1998 research space. A significant portion of newly created research space is likely to replace obsolete or inadequate space rather than actually increase existing space. This is indicated by the fact that the total amount of research space increased by 31 million NASF between 1988 and 1998, a period in which new construction activity was expected to produce almost 54 million NASF. (See appendix table 6-13.) Thirty percent of all research-performing colleges and universities started new construction projects during 1996–97.

Science and Public Policy (Steelman report)
Part One—Science for the Nation, I.
Science and the National Interest

6. That a program of Federal assistance to universities and colleges be developed in the matters of laboratory facilities and scientific equipment as an integral part of a general program of aid to education. (Steelman 1947, p. 6.)

Part One—Science for the Nation, IV.
A National Science Program

The Need for New Facilities

A national research and development program of the size we require will necessitate a considerable expansion of research facilities. The extent and nature of this expansion cannot now be estimated, for the precise problems upon which we shall be engaged a few years from now cannot even be imagined today. Nor is it possible to determine, in view of the number of mixed-purpose facilities involved and the diversity of accounting methods, just what our present investment in such facilities may be. But we can make some informed guesses on this score as a bench-mark for the future.

The situation respecting the expansion of college and university facilities is altogether different. Existing facilities are relatively less adequate here than elsewhere and require substantial expansion. Additional libraries, laboratory space and equipment are urgently needed, not only in terms of the contemplated program of basic research, but to train scientists for research and development programs in the near future. Provision must, therefore, be made for Federal aid to educational institutions for the construction of facilities and the purchase of expensive equipment. A beginning was made on this in connection with the disposal of surplus property. It must now be put on a long-run basis.

Any such program for federally-financed research facilities should be part of a broader program of aid to higher education. In many cases, the expansion of laboratories is possible only if other expansions in plant occur. The whole problem of university and college facilities is a broad and integrated one and should be handled as such. (Steelman 1947, 36.)

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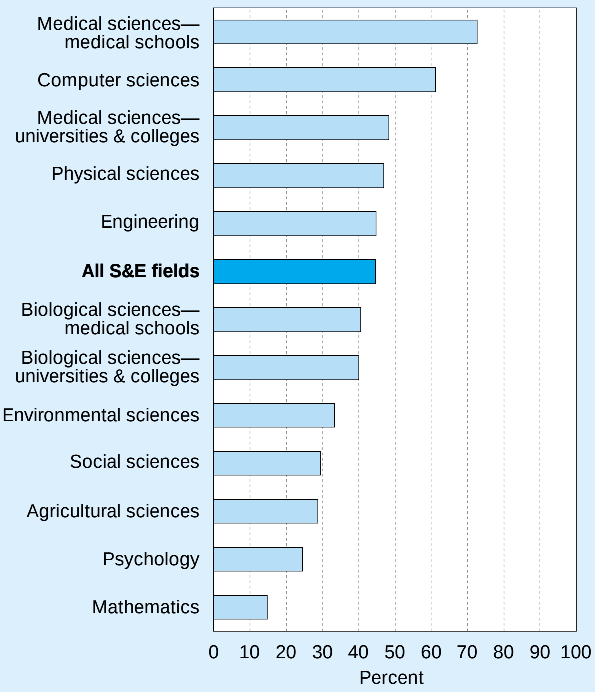
[17] Data on facilities and equipment are taken primarily from several surveys supported by NSF. Although terms are defined specifically in each survey, in general facilities expenditures (1) are classified as “capital” funds, (2) are fixed items such as buildings, (3) often cost millions of dollars,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

[18] The information in this section is derived from NSF’s biennial Survey of Scientific and Engineering Research Facilities at Colleges and Universities. For more detailed data and analysis on academic S&E research facilities (for example, by institution type and control), see NSF (2000b).

[19] “Research space” here refers to the net assignable square footage (NASF) of space 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 specific use, such as instruction or research. Multipurpose space within facilities, such as 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 (for example, 1987–88 data are for fiscal years 1987 and 1988). NASF data on total space are reported at the time of the survey and were not collected in 1986.

The ratio of planned new construction during the 1986–97 period to 1998 research space differs across S&E fields. More than half of the research space in the medical sciences at medical schools and in the computer sciences appears to have been built in the 1986–97 period. In contrast, less than 20 percent of the research space for mathematics appears to have been newly constructed during this period. (See figure 6-10.)

Figure 6-10.
Planned new construction between 1986 and 1997 as a percentage of 1998 research space, by S&E field



See appendix table 6-13. *Science & Engineering Indicators – 2000*

Repair and Renovation. The total cost of repair/renovation projects has also fluctuated over time. Expenditures for major repair/renovation (that is, projects costing over $100,000) of academic research facilities begun in 1996–97 are expected to reach $1.3 billion. (See appendix table 6-14.) Projects initiated between 1986 and 1997 were expected to result in the repair/renovation of almost 71 million square feet of research space.[20] (See appendix table 6-13.) Repair/renovation expenditures as a proportion of total capital expenditures (construction and repair/renovation) have increased steadily since 1990–91, rising from 22 percent of all capital project spending to 30 percent by 1996–97. More than half (52 percent) of all research-performing colleges and universities started new repair/renovation projects during 1996–97.

Sources of Funds. Academic institutions derive their funds for new construction and repair/renovation of research facilities from three major sources: institutional resources, state and local governments, and the Federal Government. Institutional resources consist of private donations, institutional funds, tax-exempt bonds, other debt sources, and other sources. (See text table 6-2.) In 1996–97:

- institutional resources accounted for 60 percent of all construction funds and 65 percent of all repair/renovation funds;
- state and local governments accounted for 31 percent of all construction funds and 26 percent of all repair/renovation funds; and
- the Federal Government directly accounted for only 9 percent of all construction funds and 9 percent of all repair/renovation funds.[21]

Public and private institutions draw upon substantially different sources to fund the construction and repair/renovation of research space. The relative distribution of construction funds between institutional types is as follows:

- Institutional resources accounted for 43 percent of all construction funds at public institutions and 91 percent at private institutions.
- State and local governments accounted for 47 percent of all construction funds at public institutions and 2 percent at private institutions.
- The Federal Government accounted for 10 percent of all construction funds at public institutions and 6 percent at private institutions.

The relative distribution of repair/renovation funds between institution types is as follows:

- Institutional resources accounted for 40 percent of all repair/renovation funds at public institutions and 91 percent at private institutions.
- State and local governments accounted for 49 percent of all repair/renovation funds at public institutions and 2 percent at private institutions.
- The Federal Government accounted for 11 percent of all repair/renovation funds at public institutions and 7 percent at private institutions.

Adequacy and Condition. Of those institutions reporting research space in a field, at least half reported inadequate amounts of space in every identifiable S&E field except math-

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[20] 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, since the same space could be repaired (especially) or renovated several times.

[21] 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 counted as institutional funding. A recent memo (Jankowski 1999) indicates that about 6 to 7 percent of indirect cost payments are a reimbursement for depreciation and use of R&D facilities and equipment.

ematics, where 44 percent of the institutions reporting indicated that the amount of research space was inadequate.[22] (See text table 6-3.) In some S&E fields, a larger percentage of academic institutions rate their research space as inadequate than in others. At least 60 percent of all institutions reported that their research space was inadequate in each of the following seven S&E fields: the biological sciences in medical schools (70 percent); the medical sciences in medical schools (67 percent); the biological sciences outside of medical schools (64 percent); the physical sciences (64 percent); the earth, atmospheric, and ocean sciences (62 percent); the social sciences (61 percent); and engineering (60 percent).

Text table 6-2.
Funds for new construction and repair/renovation of S&E research space, by type of institution and funding source: 1996–97
(Millions of dollars)

Institution type and funding source	New construction and repair/renovation	New construction	Repair/ renovation
Total, all institutions	4,435	3,110	1,325
Federal Government	392	271	121
State and local government	1,305	967	338
Institutional sources	2,739	1,873	866
Total, public institutions	2,657	1,988	669
Federal Government	273	201	72
State and local government	1,268	940	328
Institutional sources	1,116	847	269
Total, private institutions	1,776	1,121	655
Federal Government	118	70	48
State and local government	36	26	10
Institutional sources	1,622	1,025	597

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

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Scientific and Engineering Research Facilities at Universities and Colleges: 1998*, in press (Arlington, VA: 2000).

Science & Engineering Indicators – 2000

Text table 6-3.
Adequacy of the amount of S&E research space, by field: 1998

Field	Total number of institutions	Percentage of institutions reporting that their armount of space is: Adequate	Percentage of institutions reporting that their armount of space is: Inadequate
Physical sciences	556	36	64
Mathematical sciences	416	56	44
Computer sciences	395	44	56
Environmental sciences	365	38	62
Agricultural sciences	108	45	55
Biological sciences—universities and colleges	569	36	64
Biological sciences—medical schools	127	30	70
Medical sciences—universities and colleges	280	46	54
Medical sciences—medical schools	127	33	67
Psychology	474	49	51
Social sciences	428	39	61
Other sciences	149	56	44
Engineering	290	40	60

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Scientific and Engineering Research Facilities at Universities and Colleges: 1998,* in press (Arlington, VA: 2000).

Science & Engineering Indicators – 2000

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[22] Adequate space is defined as the space in the field being sufficient to support all the needs of the current S&E research program commitments in the field. Inadequate amount of space is defined as space in the field insufficient to support the needs of the current S&E research program commitments in the field or nonexistent but needed.

Survey respondents are asked to rate the condition of their space. Almost 40 percent of S&E research space was rated as “suitable for the most scientifically competitive research.” However, 18 percent of the research space was designated as needing major repair/renovation, and an additional 5 percent as needing replacement. The condition of this space differs across S&E fields. Fields with the greatest area of research space needing major repair/renovation or replacement include: the agricultural sciences (7.5 million NASF); the biological sciences outside medical schools (4.8 million NASF); the medical sciences in medical schools (4.6 million NASF); engineering (4.3 million NASF); and the physical sciences (3.9 million NASF). Fields with the largest proportion of research space needing major repair/renovation or replacement include the agricultural sciences (30 percent), and the environmental sciences, the biological sciences outside medical schools, the medical sciences in medical schools, and the medical sciences outside of medical schools (each with about 25 percent). (See text table 6-4 and appendix table 6-13.)

Unmet Needs. Determining what universities and colleges need with regard to S&E research space is a complex matter. In order to attempt to measure “real” as opposed to “speculative” needs, respondents to the survey were asked to report whether an approved institutional plan existed that included any deferred space needing new construction or repair/renovation.[23] 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 1998, 54 percent of the institutions reported that they had to defer needed S&E construction or repair/renovation projects that would support their current research program commitments because of insufficient funds. The vast majority of institutions that had deferred projects (87 percent) had included at least some of these projects in an approved institutional plan. The total estimated cost for deferred S&E construction and repair/renovation projects (both in and not in an institutional plan) was $11.4 billion in 1998. Deferred construction projects accounted for 61 percent of this cost and deferred repair/renovation projects for the other 39 percent.

Deferred construction costs exceeded $1 billion in each of three fields. Institutions reported deferred repair/renovation costs in excess of $500 million in the same three fields. These fields and the deferred costs are: the physical sciences ($1.6 billion construction, $0.9 billion repair/renovation); the biological sciences outside medical schools ($1.2 billion construction, $0.9 billion repair/renovation); and engineering ($1.0 billion construction, $0.7 billion repair/renovation). (See appendix table 6-15.)

Equipment

Expenditures.[24] In 1997, just under $1.3 billion in current fund expenditures were spent for academic research equipment. About 80 percent of these expenditures were con-

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[23] 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 being 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.

[24] Data used here are from the NSF Survey of R&D Expenditures at Universities and Colleges; they are limited to current funds expenditures for research equipment and do not include funds for instructional equipment. Current funds—as opposed to capital funds—are those in the yearly operating budget for ongoing activities. Generally, academic institutions keep separate accounts for current and capital funds.

Text table 6-4.
Condition of academic science and engineering research facilities by field: 1998
(Percentages of S&E research space)

Field	Suitable for use in most scientifically sophisticated research	Requires limited repair/renovation to be used effectively	Requires major repair/renovation to be used effectively	Requires replacement
All science & engineering	39.0	38.0	18.0	5.0
Physical sciences	36.2	42.3	16.5	4.9
Mathematical sciences	44.3	41.4	11.5	2.9
Computer sciences	44.1	40.0	10.8	5.0
Environmental sciences	33.5	41.0	17.5	8.0
Agricultural sciences	32.9	36.8	23.8	6.5
Biological sciences—universities and colleges	39.6	35.5	19.6	5.3
Biological sciences—medical schools	49.3	34.6	14.1	2.0
Medical sciences—universities and colleges	31.7	43.0	20.9	4.4
Medical sciences—medical schools	43.2	31.4	19.9	5.6
Psychology	40.5	41.0	16.3	2.2
Social sciences	38.8	45.2	14.5	1.5
Engineering	41.2	39.9	14.9	3.9

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Scientific and Engineering Research Facilities at Universities and Colleges: 1998*, in press (Arlington, VA: 2000).

Science & Engineering Indicators – 2000

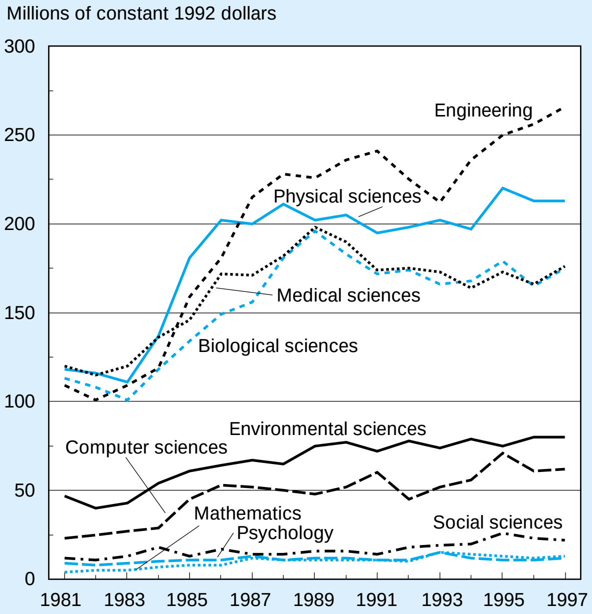
centrated in three fields: the life sciences (37 percent), engineering (23 percent), and the physical sciences (19 percent). (See figure 6-11.)

Current fund expenditures for academic research equipment grew at an average annual rate of 3.8 percent (in constant 1992 dollars) between 1981 and 1997. However, average annual growth was much higher during the 1980s (6.2 percent) than it was during the 1990s (0.7 percent). There were variations in growth patterns during this period among S&E fields. For example, equipment expenditures for mathematics (7.8 percent), the computer sciences (6.4 percent), and engineering (5.7 percent) grew more rapidly during the 1981–97 period than did those for the life sciences (2.2 percent) and psychology (2 percent). (See appendix table 6-16.)

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 1997, the social sciences received slightly less than 40 percent of their research equipment funds from the Federal Government; in contrast, Federal support accounted for over 60 percent of equipment funding in the physical sciences, computer sciences, environmental sciences, and psychology.

The share of research equipment expenditures funded by the Federal Government declined from 63 percent to 59 percent between 1981 and 1997, 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 computer and the environmental sciences. (See appendix table 6-17.)

Figure 6-11.
Current fund expenditures for research equipment at academic institutions, by field: 1981–97



NOTE: See appendix table 2-1 for GDP implicit price deflators used to convert current dollars to constant 1992 dollars.

See appendix table 6-16. *Science & Engineering Indicators – 2000*

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 1997 (5 percent) than it was in 1981 (6 percent) and at its peak in 1986 (7 percent). (See appendix table 6-18.) R&D equipment intensity varies across S&E fields. It tends to be higher in the physical sciences and the computer sciences (both about 10 percent in 1997) and engineering (8 percent); and lower in the social sciences (2 percent), psychology (3 percent), and the life sciences (4 percent). For the social sciences and psychology, these differences may reflect the use of less equipment and/or less expensive equipment. For the life sciences, the lower R&D equipment intensity is more likely to reflect use of equipment that is too expensive to be purchased out of current funds and therefore must be purchased using capital funds. (See footnote 24.)

Academic Doctoral Scientists and Engineers

This section examines major trends over the 1973–97 period regarding the composition of the academic science and engineering (S&E) workforce, its primary activities (teaching vis-àvis research), and the extent of its support by the Federal Government. For a discussion of the nature of the data used here, see sidebar, "Data Source."

The Academic Doctoral Science and Engineering Workforce[25]

Employment of science and engineering doctorates exceeded 60,000 by 1961[26] and reached 215,000 by 1973. Since 1973, the number has more than doubled, reaching 505,200 in 1997—a 135 percent increase. (See chapter 3, "Science and Engineering Workforce.") Over the 1973–97 period, the academic employment component increased from an estimated 118,000 to 232,500—a rise of 97 percent.[27] (See appendix table 6-19.) Consequently, the academic employment share declined over the period from an estimated 55 percent

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[25] The academic doctoral science and engineering workforce includes full, associate, and assistant professors and instructors—defined throughout this section as faculty—lecturers, adjunct faculty, research and teaching associates, administrators, and postdoctorates.

[26] NSF (1964).

[27] The trend data in this section refer to scientists and engineers with doctorates from U.S. institutions, regardless of their citizenship status. Comparable long-term trend data for Ph.D.-level scientists and engineers with degrees from non-U.S. institutions are not available. A 1993 U.S. Department of Education survey of academic faculty suggests that this component of the academic workforce numbers around 13,000. An estimate derived from NSF's National Survey of College Graduates, based on the 1990 Census, puts the number at about 21,000. The higher estimate (which includes postdoctorates not necessarily covered by the Department of Education's survey) is likely to more closely reflect the definitions used in this chapter.

Data Source

The data used in this section to describe the employment characteristics and activities of academic doctoral scientists and engineers derive from the biennial sample Survey of Doctorate Recipients (SDR). SDR has been conducted since 1973 under the sponsorship of the National Science Foundation and several other Federal agencies. It underwent several changes in 1991 and again from 1993 forward which affect the comparability of data from these years with those of earlier periods.

Through 1989, the sample included three major respondent segments: (1) recipients of S&E doctorates from U.S. institutions; (2) a small number of holders of doctorates in other fields working in science or engineering in the survey year; and (3) a small number of persons with S&E doctorates from non-U.S. institutions. Starting with the 1991 sample, only recipients of S&E doctorates from U.S. universities were retained, and persons over 75 years old were ruled out of scope. Furthermore, sampling strata and sample size were reduced in an effort to improve response rates within budget constraints. Other changes in data collection included the introduction of computer-assisted telephone interviewing, which resulted in much higher response rates than had been attained previously.

A 31-month interval between the 1989 and 1991 surveys, instead of the usual 24 months, had substantive effects on the 1991 data: for example, a lower-than-average proportion of respondents in postdoctoral status, a higher-than-average proportion in faculty ranks. The interval between the 1991 and 1993 surveys was also nonstandard, 20 months.

Methodological studies to assess the full impact of these changes on overall estimates and individual data items are unavailable. Preliminary investigations suggest that SDR data permit analysis of rough trends, provided comparisons are limited to recipients of S&E doctorates from U.S. institutions. This has been done herein, with data structured in accordance with suggestions offered by the National Research Council's Office of Scientific and Engineering Personnel, which conducted these surveys through 1995. Nevertheless, the reader is warned that small statistical differences should be treated with caution.

The academic doctoral science and engineering workforce discussed in this chapter includes full, associate, and assistant professors and instructors—defined throughout this section as faculty—lecturers, adjunct faculty, research and teaching associates, administrators, and postdoctorates. Any discussion herein of status or trends of particular fields is based on the field of doctorate.

in 1973 to 46 percent of the doctoral science and engineering workforce in the 1990s, where it remains—close to its 1945–47 level.

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. The resulting relationship in academia of teaching and research, and the balance between them, remains the subject of intense concern and discussion[28] at the national level, as well as in academic institutions. Trends in indicators relating to research funding have been presented above. Below follow indicators reflecting the personnel dimension of these discussions: the relative balance between faculty and nonfaculty positions; demographic composition of the faculty; faculty age structure and hiring of new Ph.D.s; and trends in work responsibilities as reported by S&E Ph.D.s employed in academia.

A Long-Term Shift Toward Nonfaculty Employment Continued During the 1990s

Academic employment growth of science and engineering doctorates was quite low during much of the 1990s, from an estimated 206,700 in 1989 to 217,500 in 1995—an average annual increase of less than 1 percent. But by 1997, it had reached 232,500, reflecting a much stronger average rate of increase—3.4 percent annually—reminiscent of the growth rates registered during the 1980s. (See figure 6-12 and appendix table 6-19.)

Full-time doctoral S&E faculty—full, associate, and assistant professors plus instructors—participated in the 1995–97 increase. Their number, which had been roughly stable during the first half of the 1990s, rose strongly from 171,400 in 1995 to 178,400 in 1997. (See figure 6-12.) Nevertheless, the share of full-time faculty among all doctoral scientists and engineers with academic employment continued to decline. It reached an all-time low of 77 percent in 1997, from 88 percent in 1973; and 82 percent in 1989. (See appendix table 6-19.)

Thus, a long-term shift toward nonfaculty employment continued, as those in nonfaculty ranks—adjunct faculty, lecturers, research and teaching associates, administrators, and postdoctorates—increased from 36,900 in 1989 to 54,200 in 1997. The 47 percent increase for this group stood in sharp contrast to the 5 percent rise in the number of full-time faculty. Much of the rise in the nonfaculty segment was due to

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[28] Some examples include *Presidential Directive for the Review of the Federal Government-University Partnership* (National Science and Technology Council 1999); *Challenges to Research Universities* (Noll 1998); "The American Academic Profession" (*Daedalus* 1997); *Science in the National Interest* (Clinton and Gore 1994); *Stresses on Research and Education at Colleges and Universities* (National Academy of Sciences 1994); *Renewing the Promise: Research-Intensive Universities and the Nation* (President's Council of Advisors on Science and Technology 1992); *Science and Technology in the Academic Enterprise: Status, Trends, and Issues* (National Academy of Sciences 1989); *Report of the White House Science Council: Panel on the Health of U.S. Colleges and Universities* (U.S. Office of Science and Technology Policy 1986).

Science and Public Policy (Steelman report)

Part One—Science for the Nation, III. Manpower:
The Limiting Resource

Under present conditions, the ceiling on research and development activities is fixed by the availability of trained personnel, rather than the amounts of money available. The limiting resource at the moment is manpower.

Those actually engaged in scientific research, technical development, and teaching comprise a much smaller group within this pool—about 137,000 persons today....But just as the share of the universities and colleges in the national research budget has been falling since 1930, so has their share in the trained manpower pool: from about 49 percent in 1930 to 41 percent in 1940 and 36 percent in 1947.

This is significant, because college and university scientists not only perform the major portion of basic research, but also because they teach. They are the source of further expansion in our pool of trained manpower. [Boldface in original]

There is a still smaller group within the 137,000 working scientists of which note should be taken: the 25,000 highly trained scientists with doctorates in the physical and biological sciences. As a general proposition, [their number] provides a measure of the size of the group on which we rely for leadership in research, and for advanced teaching in the sciences.

[The table below, reproduced from volume four, shows the estimated distribution of doctoral scientists by sector for 1937–47.]

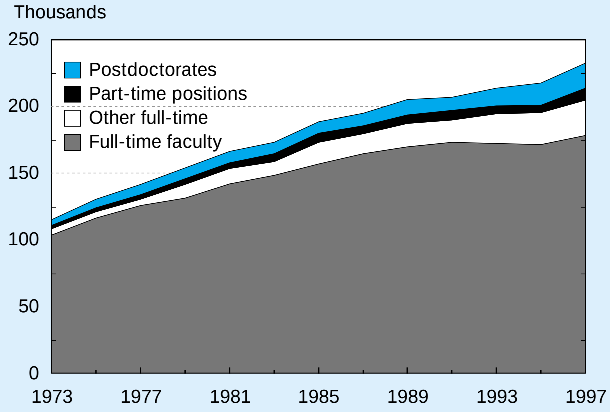
Year	Total	Colleges and universities	Industry	Government
1937	13,900	8,100	4,300	1,500
1945	23,200	10,000	10,000	3,200
1947	24,500	13,000	9,000	2,500

(Steelman 1947, 15.)

the growing use of postdoctorates.[29] Part-time employment—including faculty and other positions—accounted for between 2 and 4 percent of the total throughout. (See figure 6-12 and appendix table 6-19.)

This substantial shift during the 1990s toward nonfaculty employment touched most major fields. Except for computer sciences, continued growth in the nonfaculty segment was the rule. By 1997, full-time faculty percentages had dropped by as many as 10 percentage points (environmental sciences) since 1989 alone, with the other fields' declines falling into the 4–7 percentage points range. Over the entire period—1973 to 1997—the drops in the faculty share by field ranged from 8 to 18 percent. From 1989 to 1997, gains in the number of full-time faculty were largely confined to Ph.D.s in the life and computer sciences. For all other fields, their number remained essentially unchanged. (See appendix table 6-19.)

Figure 6-12.
Academic doctoral scientists and engineers by type of position: 1973–97



NOTE: Faculty includes full, associate and assistant professors plus instructors.

SOURCE: National Science Foundation, Division of Science Resources Studies, Survey of Doctorate Recipients, special tabulation.

See appendix table 6-19. *Science & Engineering Indicators – 2000*

Research Universities' Employment Grew More Slowly Than That of Other Academic Institutions

The Nation's largest research-performing universities—Carnegie Research I and II institutions[30]—are widely regarded as a vital resource in U.S. science and engineering research and teaching. The number of doctoral scientists and engineers they employ rose steadily after 1973 but has essentially been static since 1989, at an estimated 113,600 in 1997. (See appendix table 6-20.) In contrast, employment at other institutions has grown uninterruptedly, especially after 1995. Since 1989, the research universities experienced a 6 percent decline in the number of their full-time doctoral S&E faculty, which was roughly offset by a 24 percent increase in nonfaculty personnel. Over the same period, other institutions' doctoral S&E employment expanded by 26 percent, with faculty rising by 7 percent and nonfaculty appointments more than doubling.

Behind these trends lie very different hiring patterns practiced by these institutions, as illustrated by an examination of their hiring of cohorts of recent doctorates—defined as those with a doctorate awarded within the last three years. (See fig-

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[29] For more information on this subject, see "Postdoctoral Appointments" in chapters 3 and 4.

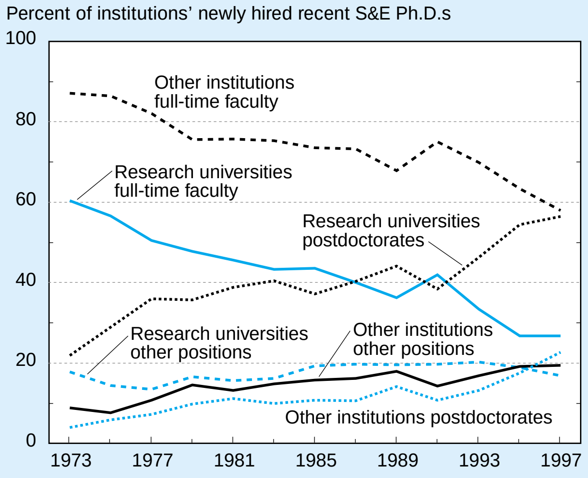
[30] Carnegie Classification Research I and II universities. This periodically revised classification describes research universities as institutions with a full range of baccalaureate programs, commitment to graduate education through the doctorate, annual award of at least 50 doctoral degrees, and receipt of Federal support of at least $15.5 million (average of 1989 to 1991). These criteria were met by 127 universities. (Carnegie Foundation for the Advancement of Teaching 1994).

ure 6-13 and appendix table 6-21.) Except for the early 1970s, the research universities have consistently hired more recent Ph.D.s than all other universities and colleges combined. But their hiring has slowed in the 1990s, while that of the other institutions has increased. More telling is the distribution of these new hires by type of appointment. In recent years, fewer than 30 percent of recent doctorates hired by the research universities obtained a full-time faculty position—down from 60 percent in 1973. In contrast, almost 60 percent of those hired by other academic institutions received faculty appointments (compared to nearly 90 percent in 1973).

In the research universities, employment growth of S&E doctorates has largely been driven by those identifying research as their primary activity. (See appendix table 6-20.) Their number, 22,900 in 1973, had risen to an estimated 60,700 by 1997; their percentage among the research universities' doctoral S&E workforce rose from 35 to 53 percent. In contrast, the number of those for whom teaching was the primary activity rose from 32,300 in 1973 to a high of 39,200 in 1981 before declining to 33,400 in 1997—a decline from 50 to 29 percent of the total. Those identifying other functions as their primary work responsibility—including research management—grew from 9,200 to 19,600 over the period—staying well below 20 percent of the total for virtually the entire period.

In other types of universities and colleges, the number of doctoral scientists and engineers who identified research as their primary work activity grew from 4,900 in 1973 to 27,900 in 1997. Their share over the period rose from 9 to 23 percent, steeply increasing from the mid-1980s onward. The number of those for whom teaching was the primary work responsibility increased less rapidly, from 41,000 in 1973 to 72,000 in 1997. (See appendix table 6-20.)

Figure 6-13.
Recent S&E Ph.D.s hired by research universities and other academic institutions, by type of institution and appointment: 1973–97



NOTES: Recent Ph.D.s have earned their doctorates in the three years preceding the survey year. Faculty includes full, associate, and assistant professors plus instructors. "Other positions" include part-time, research associate, adjunct, and other types of appointments outside the faculty track. Research universities are Carnegie Research I and II institutions.

SOURCE: National Science Foundation, Division of Science Resources Studies, Survey of Doctorate Recipients, special tabulations.

See appendix table 6-21. *Science & Engineering Indicators – 2000*

Employment patterns also differed among full-time doctoral S&E faculty. At the research universities, full-time faculty overall fell by 6 percent between 1989 and 1997, with those reporting primary responsibility for research declining by 3 percent, and those with primary teaching responsibility by 9 percent. Developments were different in the other institutions, where full-time faculty rose by 7 percent over the same period, largely reflecting an increase of 4,300—40 percent—among those with primary research responsibility.

Women Are Increasingly Prominent in Academic S&E, but Not in All Fields[31]

The academic employment of women with a doctorate in science or engineering has risen dramatically over the past quarter century, reflecting the steady increase in the proportion of S&E doctorates earned by women. Since 1973, when this type of employment information was first collected, the number of women has increased more than fivefold, from 10,700 to an estimated 59,200 in 1997. Their proportion of the doctoral academic S&E workforce has increased from 9 to 25 percent over the period. (See appendix table 6-22.)

A similar rapid growth was registered in the number of women in full-time faculty positions.[32] (See figure 6-14.) However, even with this strong growth, their proportion of full-time faculty continues to lag their share of Ph.D. degrees. This underscores the long time lag involved in changing the composition of a large employment pool—in this instance, the academic faculty. Women represented 7 percent of the full-time doctoral academic S&E faculty in 1973. The effect of a growing proportion of doctorates earned by women, bolstered by their somewhat greater likelihood of choosing early academic careers, had pushed this proportion to 22 percent by 1997. By rank, they represented 12 percent of full professors, 25 percent of associate professors, and 37 percent of the junior faculty—the latter approximately in line with their recent share of Ph.D.s earned. (See appendix table 6-22.)

Among full-time doctoral S&E faculty, the number of men declines as one moves from senior ranks—full and associate professors—to junior-faculty ranks—assistant professors and instructors. In contrast, the distribution of women is inverted: more women hold junior faculty positions than are associate professors, and more are the latter than are full professors. This pattern is indicative of the recent arrival of significant

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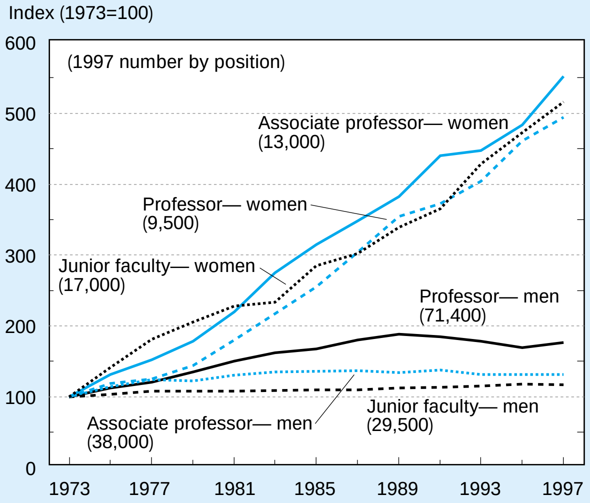
[31] Also see "Women Scientists and Engineers" in chapter 3 and "New Ph.D.s Enter Academia, but the Nature of Their Appointments Has Changed" later in this chapter.

[32] These numbers differ from those published in *Women, Minorities, and Persons with Disabilities in Science and Engineering: 1998* (NSF 1999k). That report's tables 5-9 through 5-12 show data on employment in four-year colleges and universities only, excluding faculty in other types of academic institutions, such as medical schools, two-year colleges, and specialized colleges. All of the latter are included here.

Figure 6-14.
Index of growth in full-time doctoral science and engineering faculty, by rank and sex: 1973–97



NOTES: Junior faculty includes assistant professors and instructors. Postdoctorate, nonfaculty, and part-time positions are not shown.

See appendix table 6-22. *Science & Engineering Indicators – 2000*

numbers of women doctorates in full-time academic faculty positions. It indicates that the trend toward increasing numbers of women among the faculty will continue—assuming that women stay in academic positions at an equal or higher rate than men—but also, that this process will continue to unfold slowly.

Since 1973, when these data on doctoral scientists and engineers were first collected, women in academic employment have been heavily concentrated in a few fields. Fully 84 percent of women scientists and engineers in 1997 had earned their doctorates in three broad fields: life sciences (42 percent), social sciences (22 percent), and psychology (20 percent); in contrast, only 58 percent of men were in these fields in 1997. Conversely, only 9 percent of women had degrees in the physical and environmental sciences in 1997—a steep decline from 14 percent of women in these fields in 1973—compared to 19 percent of men. Only 3 percent of all women had doctorates in engineering, versus 14 percent of men. (See appendix table 6-22.)

Concentration notwithstanding, when viewed over the entire 1973–97 period, women's doctoral field choices have undergone some changes. Among the academically employed, smaller proportions were found to hold doctorates in the physical and environmental sciences and mathematics in 1997 than in the early 1970s; these fields experienced a combined drop from 20 to 12 percent. Women's 37 percent life sciences share in 1973 rose to 42 percent in 1997, and larger percentages of women were also found with a Ph.D. in engineering and computer science by 1997. However, the proportion of women in academic employment with degrees in these latter fields remains very low. (See appendix table 6-22.)

Minorities See Large Growth Rates in Ph.D.s in Academic Employment, but Low Absolute Numbers[33]

The U.S. Bureau of the Census's demographic projections have long indicated an increasing prominence of minority groups among future college and working-age populations. With the exception of Asians and Pacific Islanders—who have been quite successful in earning science and engineering doctorates—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 governmental activities seek to broaden the opportunities of American Indians, Alaskan Natives, blacks, and Hispanics to enter these fields. Many target advanced scientific, engineering, and mathematics training, including doctoral-level work. What are the trends and status of these minority groups among S&E Ph.D.s employed in academia?

The story for these doctoral-level scientists and engineers is one of two trends, one dealing with rates of increase in hiring, the second with the slowly changing composition of the academic workforce. Rates of increase in employment have been remarkably steep. (See figure 6-15.) They far outpaced those for the majority population and have generally reflected the increased earning of science and engineering doctorates by minority group members.[34] However, a signal feature of these steep increases is the low bases from which they are calculated. As a result of the large majority population in the initial academic S&E doctoral pool,[35] American Indians, Alaskan Natives, blacks, and Hispanics remain a small minority in academia. Changing the structure of a large employment pool by changing the composition of the new participants requires a long time, unless the size of the inflow relative to the existing pool is large. (See appendix table 6-23.)

Academic employment of underrepresented minorities with S&E doctorates—American Indians, Alaskan Natives, blacks, and Hispanics—rose to 13,700 in 1997 from a mere 2,400 in 1973. Over this period, their employment share rose from 2 to 6 percent, approximately the same as their share of full-time faculty positions. By 1997, underrepresented minorities represented about 8 percent of the academic doctoral employment of those with degrees in psychology and the social sciences, 5–6 percent in the physical and life sciences, mathematics, and engineering, but only 3 percent in computer and environmental sciences. Their faculty percentages were quite similar. (See appendix table 6-23.) The overall field distribution of underrepresented minorities broadly parallels that of the majority population, with two exceptions. In 1997, underrepresented minorities were distinctly *less* likely than whites to possess Ph.D.s in the life sciences—

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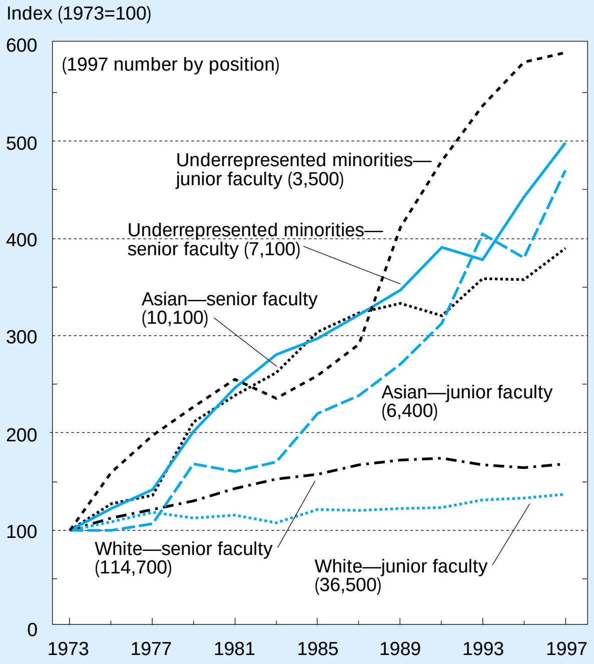
[33] Also see "Racial or Ethnic Minority Scientists and Engineers" in chapter 3 and "New Ph.D.s Enter Academia, but the Nature of Their Appointments Has Changed" later in this chapter.

[34] This in turn, of course, reflects their increasing participation in higher education and graduate school training. See chapter 4 sections, "Master's Degrees, by Race/Ethnicity" and "Doctoral Degrees, by Race/Ethnicity."

[35] Here measured from 1973 onward; data covering longer periods are not readily available.

Figure 6-15.
Index of growth in full-time doctoral science and engineering faculty, by rank and race/ethnicity: 1973–97



NOTES: Senior faculty includes full and associate professor; junior faculty includes ranks of assistant professor and instructor. Underrepresented minorities include American Indians, Alaskan Natives, blacks, and Hispanics.

SOURCE: National Science Foundation, Division of Science Resources Studies, Survey of Doctorate Recipients, various years, special tabulations.

See appendix table 6-23. *Science & Engineering Indicators – 2000*

28 versus 34 percent—and *more* likely to hold social sciences doctorates—26 versus 20 percent.

Asians and Pacific Islanders as a group have been quite successful in entering the academic doctoral workforce in science and engineering, as their number rose from 5,000 in 1973 to 25,400 in 1997. As a consequence of this rapid growth, their employment share nearly tripled, from 4 to 11 percent since 1973. In 1997, Asians and Pacific Islanders represented 27 percent of academically employed computer science Ph.D.s, 20 percent of engineers, and 14 percent of physical scientists and mathematicians. Their academic employment share among environmental and social science Ph.D.s, and especially psychologists, remained low—7 percent for the two former fields, less than 3 percent in the latter.[36] (See appendix table 6-23.)

Asian and Pacific Islander S&E doctorates in academic employment were much more concentrated in a few fields than other population groups. In 1997, 51 percent held degrees in the physical, environmental, and computer sciences; mathematics; or engineering—a much higher proportion than for whites (34 percent) or underrepresented minorities (28 percent). In part, this reflects the degree-taking choices of temporary visa-holders, who tend to favor engineering and mathematics-based sciences over less quantitative fields, and who often remain in the United States and gain academic employment. They have constituted more than half of the Asian and Pacific Islanders' total during the 1990s.

The Physical Sciences'Employment Share Declined; Life Sciences'Increased

The field composition of science and engineering Ph.D.s in academic employment over the 1973–97 period has been remarkably stable, with two notable exceptions: The academic employment share of Ph.D.s in the physical sciences declined from 19 to 13 percent, while that of doctorates in the life sciences rose slightly from 30 to 33 percent. Employment growth of physical sciences doctorates—rising 37 percent from 22,100 to 30,200—was much slower than that of other fields, which grew by a combined 107 percent overall; similar discrepancies were evident for growth in the full-time faculty segment. Both physics and chemistry shared this slow growth trajectory. In contrast, employment of Ph.D.s in the life sciences increased by more than 120 percent over the period, rising from 34,900 to 77,300. A large share of this gain reflected increases in the nonfaculty segment.[37] (See appendix table 6-19.)

The Average Age of the Academic S&E Faculty Continues to Increase

The rapid pace of hiring of young Ph.D.s into academic faculty positions during the 1960s to accommodate soaring enrollments, combined with slower hiring in later years, has resulted in a continuing increase in the average age of the U.S professorate. (See figure 6-16.) In 1973, 62 percent of the doctoral, full-time S&E faculty were under 45 years old, and only 13 percent were 55 or older. The under-45 group had shrunk to 50 percent by 1985 and constituted only 38 percent of the total in 1997. Those 55 or older were 21 percent of the total by 1985 and 26 percent in 1997. (See appendix table 6-24.)

Starting in 1994, provisions of the Age Discrimination in Employment Act became fully applicable to universities and colleges; academic institutions could no longer require faculty to retire at a set age.[38] This development led to concerns about the potential ramifications of an aging professorate for universities' organizational vitality, institutional flexibility, and

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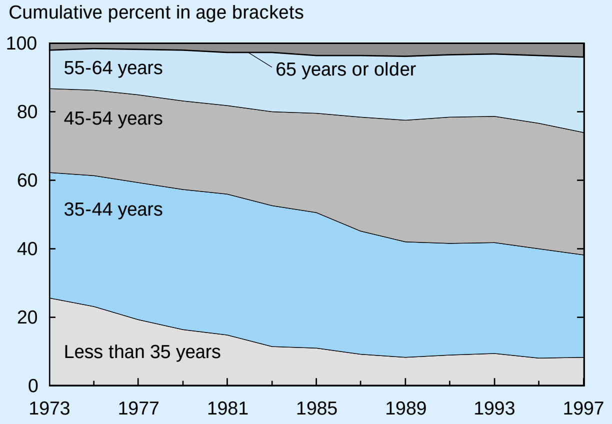
[36] Pre-1985 estimates are unreliable because of the low number of computer science degree-holders in the sample.

[37] These trends may have been influenced by the relative field balances in academic R&D funds. See "Expenditures by Field and Funding Source" earlier in this chapter.

[38] 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.

Figure 6-16.
Age distribution of full-time doctoral science and engineering faculty: 1973–97



NOTE: Faculty includes full, associate, and assistant professors plus instructors.

See appendix table 6-24. *Science & Engineering Indicators – 2000*

financial health. These concerns were the focus of study by the National Research Council (NRC). 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, 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, 38).

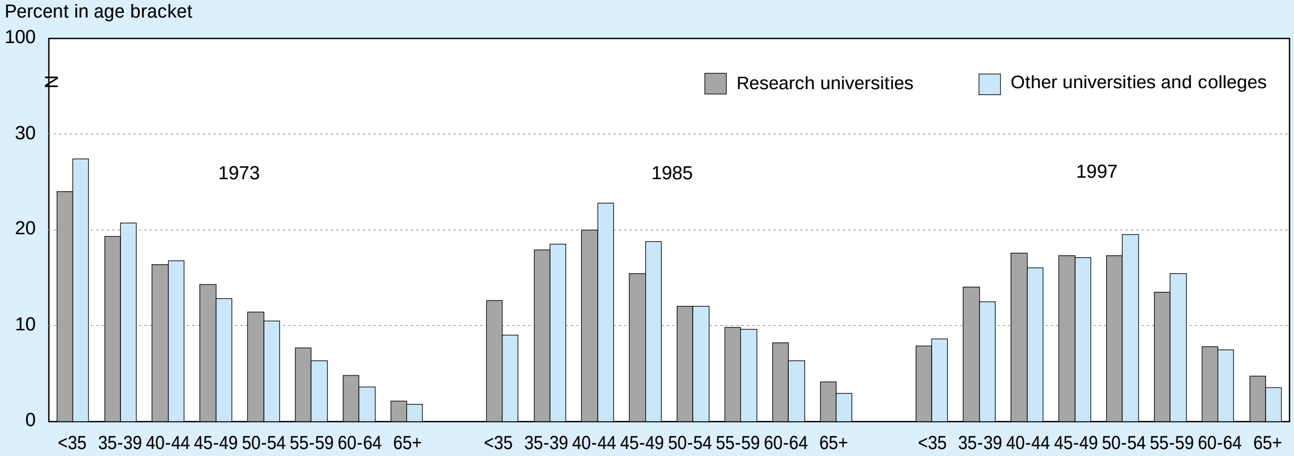
Data available now suggest that, for the system as a whole over the past decade, there has been little substantial change in terms of retirement behavior. Across all of higher education, about 3–4 percent of full-time faculty stays on beyond age 64, without any major changes over the past decade. As anticipated by the NRC study, on average, faculty at research universities tend to keep working somewhat longer than those elsewhere, but this has been the case for the entire 1973–97 period. The 1995–97 estimate of 4–5 percent for those older than 64 is in the estimated range for the entire past decade.[39] (See appendix table 6-25.)

It is also worth noting that research universities have managed to work toward a relatively more balanced age structure among their full-time faculty than is seen in other types of universities and colleges. (See figure 6-17.) The faculty age distribution in research universities tended to be older, on average, than that of other academic institutions through the early 1980s, but that tendency has since reversed. By 1997, research universities had a greater share of their full-time faculty in the under-45 age brackets than other institutions, and a slightly greater share in the above-59 brackets as well. (See appendix table 6-25.)

New Ph.D.s Enter Academia, but the Nature of Their Appointments Has Changed[40]

The hiring by universities and colleges of people with newly earned S&E doctorates provides a leading indicator of the composition of the future academic teaching and research workforce. However, the small number of new entrants rela-

Figure 6-17.
Age distribution of full-time doctoral science and engineering faculty in research universities and other institutions: 1973, 1985, and 1997



NOTES: Faculty includes full, associate, and assistant professors and instructors. Research universities are defined by the Carnegie Corporation for the Advancement of Teaching by their program scope, Ph.D. production, and Federal funding volume.

See appendix table 6-25. *Science & Engineering Indicators – 2000*

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[39] See also "Age and Retirement" in chapter 3.

[40] No trend data exist on detailed in- and outflows. The data reported here are "snapshots" of the number and demographic characteristics of doctorate-holders in academic employment who had earned their degree in the three years preceding the survey.

tive to the size of the existing academic employment pool ensures that coming changes will unfold gradually.

The number of recent S&E Ph.D.s—defined as those who had earned their doctorate in the three years preceding the survey year—who were hired into academic positions declined gradually from 25,000 in 1973 through the early 1980s, when it reached a low of 20,500. Starting in 1987, it rose again and reached 29,000 in 1997. These new entrants into academia represented approximately half of all recent S&E doctorate-holders entering U.S. employment. (See appendix table 6-26.)

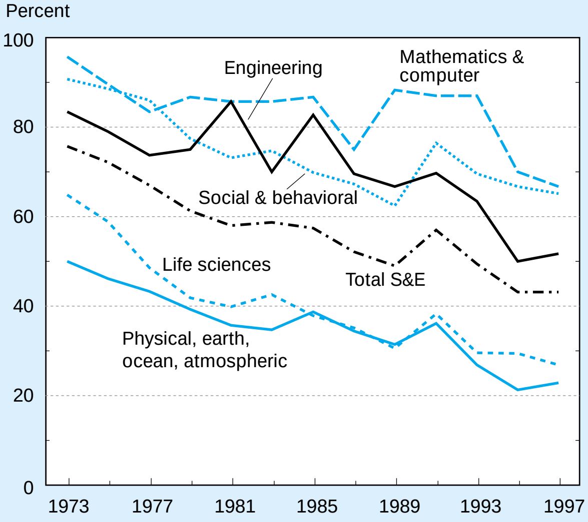
But the nature of academic employment for these young Ph.D.s has shifted considerably over this period. In 1997, only 41 percent reported full-time faculty appointments, compared with 76 percent in the early 1970s. Concurrently, the proportion holding postdoctorate positions increased steeply, rising from 13 percent to 41 percent;[41] other types of appointments have risen from 10 to 18 percent. (See appendix tables 6-26 and 6-27.)

The decline in the proportion of new S&E doctorate-holders with full-time faculty positions affected all fields. To some extent, these trends reflect the growing importance of early-career postdoctoral appointments in a number of fields; but the declines were also evident in those degree fields with relatively small numbers of postdoctorates. (See figure 6-18.) In the combined physical and environmental sciences, roughly one in five received a faculty appointment; in the life sciences, one in four. This compared with half or more than half of those with doctorates in engineering, mathematics and computer sciences, and social and behavioral sciences. (See appendix table 6-27.)

These changes have also affected the ability of recent S&E Ph.D.s hired into academia to enter the tenure track. While about three-quarters of all those hired into a *faculty* position were on the tenure track, few recent S&E doctorates received such an appointment. Overall, only one out of every three recent S&E doctorates hired into academia received such an offer.

The composition of these recent academic doctorate-holders has shifted noticeably over the more than two decades covered here, reflecting the changes in the population earning doctorates in science and engineering.[42] The proportion of women has risen from 12 to 39 percent. The proportion of underrepresented minorities has grown from 2 to 8 percent, of Asians and Pacific Islanders from 5 to 21 percent, and of non-citizens[43] from 8 to 27 percent. Similar trends are evident among those in full-time faculty positions, with these differences: Underrepresented minorities are somewhat better represented in the faculty segment than in overall employment, while Asian and Pacific Islander and non-citizen doctorate-holders are less well represented, especially since 1993. (See appendix table 6-26.)

Figure 6-18.
Percentage of academically employed recent S&E Ph.D.s with full-time faculty status, by major field group: 1973–97



NOTES: Recent Ph.D.s have earned their doctorate in the three years preceding the survey year. Faculty positions include full, associate, and assistant professor and instructor.

See appendix table 6-27. *Science & Engineering Indicators – 2000*

The field composition of these recent Ph.D.s reflects the larger employment changes. In 1997, 37 percent were in the life sciences (up from 28 percent in 1973), 12 percent were in the physical sciences (after dropping from 16 percent in 1973 to 10 percent in 1983), 6 percent were in mathematics (down from 9 percent in 1973), and 17 percent were in the social sciences (down from 23 percent in 1973). But their field distribution in full-time faculty and postdoctoral positions differs from this total employment picture, reflecting the fields' different propensities to hire new Ph.D.s into the faculty-track, as well as the general rise of postdoctoral appointments. Among postdoctorates, 54 percent were in the life sciences (compared to a life sciences share of 37 percent in total employment); 19 percent were in the physical sciences (versus a physical sciences share of 12 percent in total employment). Conversely, among those with faculty positions, 29 percent were in the social sciences, versus a 17 percent social sciences share of all recent academic S&E Ph.D.s. (See appendix table 6-27.)

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[41] An accurate count of postdoctorates is elusive, and the reported increase may be understated. A postdoctoral appointment is defined here as a temporary position awarded primarily for gaining additional training in research. The actual use of the term, however, varies among disciplines and sectors of employment. In academia, some universities appoint postdoctorates to junior faculty positions which carry fringe benefits; in others, the appointment may be as a research associate. Some postdoctorates may not regard themselves as genuinely "employed." Also see "Postdoctoral Appointments" in chapters 3 and 4.

[42] The consequences of these demographic trends in the hiring of recent Ph.D.s for the composition of the broader academic doctoral S&E workforce are discussed in earlier sections of this chapter dealing with women and minorities.

[43] Includes those in permanent and temporary visa status at time of doctorate.

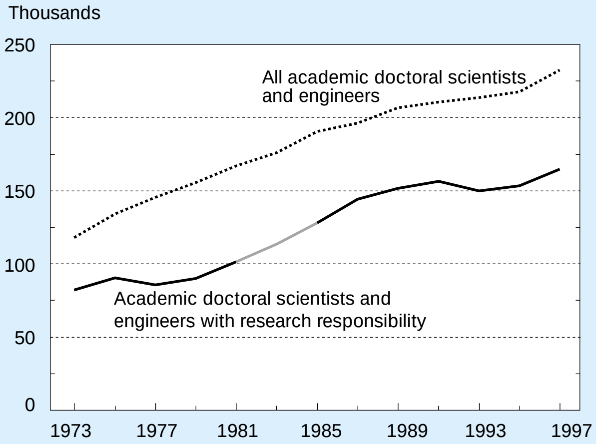
Research and Teaching Activities[44]

In academic settings, teaching, research, and research training are often inextricably intertwined. The conduct of academic research contributes to the production of new knowledge, educated students, and highly trained research personnel. Most academic scientists and engineers pursue teaching, research, and other duties in a mix that may change with the time of year and the course of their careers.

Participation in Academic Research and Development Is Once Again Increasing

U.S. universities and colleges are an indispensable resource in the U.S. R&D system, not only for their education and training functions: they conduct 12 percent of the Nation's total R&D, 27 percent of its basic and applied research, and 48 percent of its total basic research. (For more detail, see chapter 2.) A measure of the degree of faculty and staff participation in academic R&D can be constructed from S&E doctorate-holders' designation of one of four research functions[45] as a primary or secondary work responsibility. This yields a lower-bound estimate of the size of the academic doctoral research workforce broadly defined.[46] By this measure, in 1997 an estimated 164,700 academic doctoral scientists and engineers were engaged in some form of R&D,[47] up from a range of 80,000 to 90,000 during the 1970s. (See figure 6-19.) Between 1995 and 1997, the number of academic researchers, which had been essentially stable since the late 1980s following earlier robust growth, increased by 7 percent—by far its strongest increase in the decade. (See appendix table 6-28.)

Figure 6-19.
Total employed academic doctoral scientists and engineers and those with research responsibility: 1973–97



Note. Research responsibility is defined as reported primary or secondary responsibility for R&D. Numbers for 1981–85 are extrapolated: some respondents were not asked their secondary work responsibility (13, 7, and 13 percent, respectively).

SOURCE: National Science Foundation, Division of Science Resources Studies, Survey of Doctorate Recipients, special tabulation.

See appendix table 6-28. *Science & Engineering Indicators – 2000*

Approximately 71 percent of all academic doctoral scientists and engineers in 1997 were engaged in research or development activities, but this varied by field. At the high end—75 to 79 percent—were engineering, environmental sciences, and life sciences. Mathematics, psychology, and the social sciences reported the lowest levels of research activity, ranging from 59 to 66 percent. These field differences in the levels of research intensity have been fairly consistent over time.

The field composition of academic researchers has remained generally stable, with one exception: The relative employment shift noted earlier away from doctorates in the physical sciences and toward the life sciences is also evident in the research workforce. The share of physical science degree-holders among academic researchers (as defined here) has declined from 20 to 13 percent since 1973; that of the life science Ph.D.s has increased from 32 to 35 percent over the period. Other fields have experienced marginal gains or losses. (See appendix table 6-28.)

A rough indicator of the relative balance between teaching and research may be obtained by an examination of responses of academic doctoral scientists and engineers to a question about their primary work responsibility. The number of those reporting teaching as their primary work responsibility rose from 73,300 in 1973 to 101,000 in 1985 and fluctuated around the 100,000 mark before rising to 105,400 in 1997. In contrast, the number of those identifying research as their primary work responsibility increased without interruption from 27,800 in 1973 to 88,600 in 1997. (See appendix table 6-29.)

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[44] This material is based on individual respondents' reports of their primary and secondary work responsibilities. The data series—which is drawn from SDR—is reasonably consistent for the 1973–89 period: respondents were asked to designate primary and secondary work responsibilities from a list of items, the core majority of which remained unchanged. Since 1991, however, primary and secondary work responsibility has had to be inferred from reports of the activities on which respondents spent the most and the second-most amount of their average weekly work time. These two methods yield close—but not identical—results, so the SDR must be considered to produce a rough indicator only. In addition, some respondents in 1981–85 (13, 7, and 13 percent, respectively) were sent a shortened version of the questionnaire that did not ask about secondary work responsibility. For these respondents and these years, secondary work responsibility was estimated using full-form responses, based on field and type of position held.

[45] The choices, based on NSF's Survey of Doctorate Recipients, and for which definitions are provided, include basic and applied research, development, and the design of equipment, processes, structures, and models.

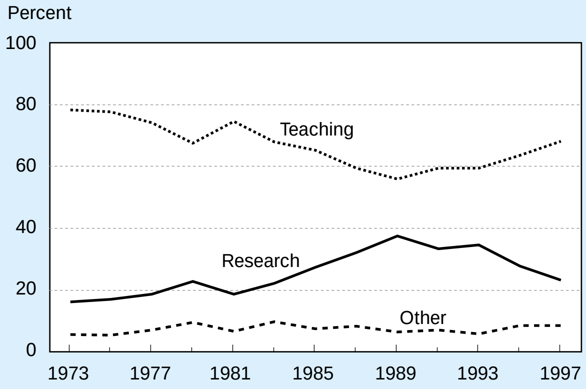
[46] The estimate fails to account for respondents who ranked research third or lower in their ordering of work responsibilities. Additionally, for 1981 through 1985, some respondents who received short forms of the survey questionnaire could not record a secondary work responsibility, thus resulting in a definite undercount for these years. All estimates are calculated based on individuals who provided valid responses to this item.

[47] An approximate 1993 estimate of the nondoctoral researcher component, excluding graduate research assistants, was derived from the U.S. Department of Education's National Survey of Postsecondary Faculty (NCES 1994). This component was estimated to be approximately 10 percent the size of the doctoral research workforce, and to be concentrated in the life sciences (75 percent) and engineering (10 percent). However, an estimate not restricted to that survey's definition of faculty, derived from SESTAT, NSF's data system on scientists and engineers, puts the number at about 21,000 (NSF 1999j).

In 1997, fewer than half of all respondents—45 percent—selected teaching as their primary work responsibility, a decline from 63 percent in 1973. While some of this decline is driven by the increasing number of postdoctorates on campus, a similar drop—from 69 to 53 percent—is observed for those in full-time faculty ranks. The increasing designation of research activities as primary work responsibility strongly suggests that the relative balance between teaching and research has shifted toward the latter, at least in the perception of these respondents. Those with other types of primary work responsibility—for administrative or managerial functions, service activities, and the like—constituted 13 to 19 percent of the total, and 11 to 17 percent among full-time faculty over the period, and thus have little influence on the apparent shift toward increased research emphasis. (See appendix table 6-30.)

S&E doctorates in full-time faculty positions who earned their Ph.D. in the three years preceding the survey year show an interesting variation of this trend. From 1973 through the late 1980s, their percentage reporting teaching as primary responsibility declined from 78 to 56 percent, while that reporting research as primary rose from 16 to 38 percent. In the 1990s, these trends have reversed, with 68 percent choosing teaching and 23 percent designating research in 1997. (See figure 6-20 and appendix table 6-31.)

Figure 6-20.
Distribution of primary work activity of recent S&E Ph.D.s in full-time academic faculty positions: 1973–97



NOTE: Recent Ph.D.s have earned their doctorate in the three years preceding the survey year.

See appendix table 6-31. *Science & Engineering Indicators – 2000*

Federal Support of Academic Researchers

In 1997, 39 percent of the academic doctoral scientists and engineers reported receiving Federal funding for their research. (See appendix table 6-32.) This was in line with 1993 and 1995 findings, even as the number of academic researchers has expanded. These 1990s numbers reflect reports based on a question about the week of April 15 of the SDR survey year; those from earlier years (except 1985) were based on Federal support received over an entire year. If the volume of academic research activity is not uniform over the entire academic year, but varies to accommodate teaching and other activities, a one-week or one-month reference period will understate the number supported over an entire year.[48] Thus, the 1993–97 numbers (and 1985) cannot be compared directly to results for the earlier years. This earlier—1973–91—series indicates a decline in the proportion of federally supported researchers that coincided with stagnant real Federal R&D funds to academia during much of the 1970s (see chapter 2), followed by a rise in the proportion supported during the 1980s, especially during the latter half when Federal academic R&D funds again rose robustly.

Notable and persistent field differences exist in the proportion of researchers supported by Federal funds.[49] Above the overall S&E average are those with doctorates in the life, environmental, and physical sciences and engineering. Clearly below the mean are those in mathematics, psychology, and the social sciences. The relative position of these fields has not changed substantially over the past two decades. (See appendix table 6-32.)

Science and Public Policy (Steelman report)
Part One—Science for the Nation, I.
Science and the National Interest

Areas for United States Action

In light of the world situation and the position of science in this country, this report will urge:…

5. That a Federal program of assistance to undergraduate and graduate students in the sciences be developed as an integral part of an overall national scholarship and fellowship program. (Steelman 1947, 6.)

Financial Support for S&E Graduate Education

U.S. research universities have traditionally coupled advanced education with research—in the process providing scientific and engineering personnel as well as generating new knowledge. This integration of research and advanced training in S&E has served the country well as U.S. research universities attract graduate students from across the nation and the world. Upon receipt of their advanced degrees, these students set out to work in many sectors of the U.S. and other

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

[49] The relative field shares of federally supported researchers appear to be stable across recent survey years, that is, they are relatively unaffected by changes in the survey reference period. The distribution (but not the estimated number) based on NSF estimates is quite similar.

economies, using the skills and knowledge they have acquired to meet a broad range of challenges.

This close coupling of education and research is reflected in the variety of forms in which financial support is provided to S&E graduate students, and particularly to those who are 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 "Definitions and Terminology" below for fuller descriptions of both mechanisms and sources of support. Most graduate students, especially those who go on to receive a Ph.D. degree, are supported by more than one source and one mechanism during their time in graduate school, and individual graduate students may even receive support from several different sources and mechanisms in any given academic year.

This section focuses on both sources and mechanisms of financial support, with special emphasis on the role of the research assistantship, since this form of support is so closely linked to the availability of academic R&D funds. Financial support is examined both for students who have just received their S&E doctorate degree and for all full-time S&E graduate students, since different types of information are available for these two distinct groups (see footnotes 51 and 52). Many of the discussions about U.S. graduate education focus on the appropriateness of the mechanisms currently used to support graduate students.[50] Documentation of the current structure and how it has evolved over time helps facilitate these discussions. For a more in-depth treatment of graduate education in general, see chapter 4, "Higher Education in Science and Engineering." For discussion of the relationships between financial support and graduate educational outcomes, see "Graduate Modes of Financial Support and Time to Degree" and "Relationship Between Support Modes and Early Employment of Recent S&E Ph.D.s." sidebars later in this chapter.

Definitions and Terminology

♦ **Fellowships** include any competitive award (often from a national competition) made to a student that requires no work of the recipient.

♦ **Traineeships** are educational awards given to students selected by the institution.

♦ **Research assistantships** are support given to students for which assigned duties are primarily devoted to research.

♦ **Teaching assistantships** are support given to students for which assigned duties are primarily devoted to teaching.

♦ **Other mechanisms of support** include work/study, business or employer support, and support from foreign governments that is not in the form of one of the earlier mechanisms.

♦ **Self-support** is support derived from any loans (including Federal loans) or from personal or family contributions.

♦ **Federal support** is support received from Federal agencies including through the GI bill and members of the Armed Forces whose tuition is paid by the Department of Defense.

♦ **Non-Federal support** is support received from the student's institution, from state and local government, from foreign sources, from nonprofit institutions, and from private industry.

Support of S&E Graduate Students[51] and S&E Doctorate Recipients[52]

Trends in Support

Full-time S&E graduate student enrollment registered a slight decline in 1997 for the third consecutive year, as did the number of such students whose primary source of support was the Federal Government.[53] The number of those whose primary source of support was from non-Federal sources rose slightly after declines in 1995 and 1996. (See appendix table 6-33.)

The proportion of graduate students with research assistantships (RAs) as their primary support mechanism increased from 22 to 28 percent between 1980 and 1989, a level about where it has since remained. This shift toward the use of RAs

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[50] See COSEPUP (1995), NSB (1996), and NSF (1996a).

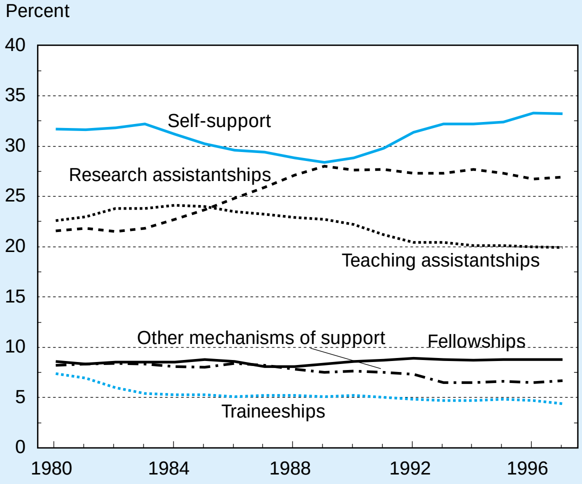
[51] The data presented on mechanisms and sources of support for S&E graduate students are from the NSF-NIH annual fall Survey of Graduate Students and Postdoctorates in Science and Engineering (NSF 1999f). In this survey, departments report the primary (largest) source and mechanism of support for each full-time degree-seeking S&E graduate student. No financial support data are collected for part-time students. Many of the full-time students may be seeking master's degrees rather than Ph.D. degrees, particularly in fields such as engineering and computer sciences. Since departments are aware of both primary sources and mechanisms of support for their students, both of these can be examined. Throughout this section, S&E includes the health fields (medical sciences and other life sciences).

[52] The data presented on mechanisms of support for S&E doctorate recipients are from the annual Survey of Earned Doctorates (NSF 1999i). Students who have just received their Ph.D.s are asked to respond to this survey. They are asked to identify their primary and secondary sources of support during graduate school as well as to check all other sources from which support was received. Validation studies on the quality of the data received from respondents to this survey indicate that the information on mechanisms of support is much better than that on sources. (See NRC 1994.) This is especially true for students whose primary support is a research assistantship, since they may not always know who is providing the funds that are supporting them. For this reason, the discussion of doctorate recipients is confined to mechanisms of support except for self-supported students. Twelve percent of the respondents in 1997 did not report a primary mechanism of support.

[53] Total Federal support of graduate students is underestimated since reporting on Federal sources includes only direct Federal support to a student and support to research assistants financed through the direct costs of Federal research grants. This omits students supported by departments through the indirect costs portion of research grants; such support would appear as institutional (non-Federal) support, since the university has discretion over how to use these funds.

was offset by a decline in the proportions supported by traineeships and self-support. During the 1990s, the proportion of students with traineeships as their primary support mechanism continued to decline, and the proportion of those with teaching assistantships (TAs) also began to decline. The relative decline in the use of these two mechanisms was balanced by an increase in the proportion reporting self-support. (See figure 6-21.)

Figure 6-21.
Primary support mechanisms for full-time S&E graduate students: 1980–97



NOTE: S&E also includes the health fields (medical sciences and other life sciences).

See appendix table 6-33. *Science & Engineering Indicators – 2000*

These overall shifts in the relative importance of primary RA support occurred for both students supported primarily by Federal sources and for those supported by non-Federal sources (this excludes students whose primary source of support is self-support). Among students whose primary source of support was the Federal Government, the rise in the proportion of those with an RA was offset by a fall in the proportion of those with a traineeship. Among students whose primary source was non-Federal, the shift toward RAs was balanced by a shift away from TAs.

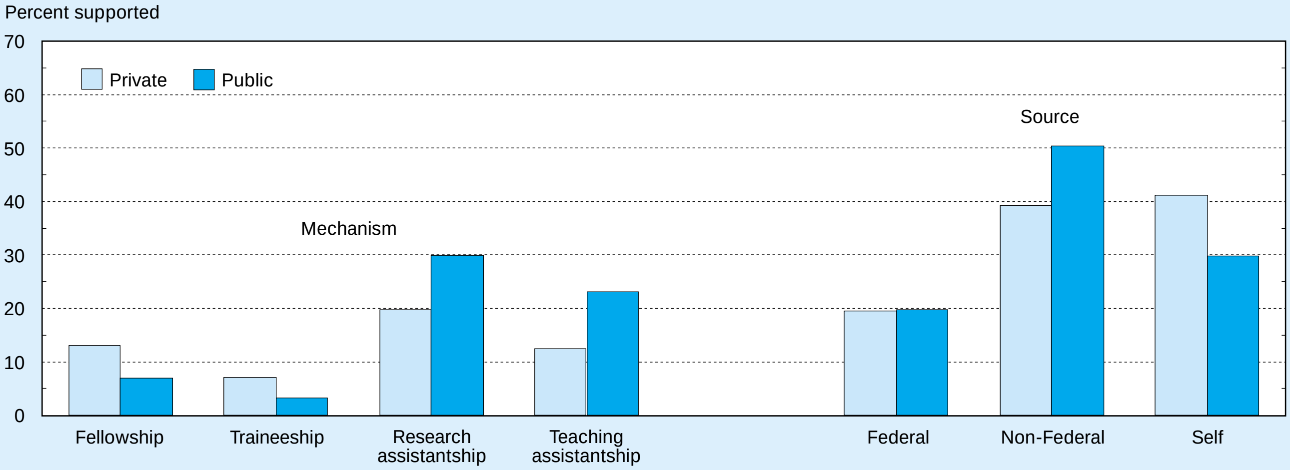
Patterns of Support by Institution Type

The proportion of full-time S&E graduate students with primary support from various sources and mechanisms differs for private and public universities. (See figure 6-22 and appendix table 6-34.) A larger proportion of full-time graduate students rely primarily on self-support in private academic institutions as opposed to those in public institutions—41 versus 30 percent in 1997.

Non-Federal sources are the primary source of support for a larger proportion of students in public institutions (50 percent) than in private ones (39 percent). About 20 percent of students in both private and public institutions receive their primary support from the Federal Government.

A larger proportion of students attending public academic institutions rely on research assistantships and teaching assistantships as their primary support mechanism (30 percent and 23 percent, respectively) than those attending private institutions (20 percent and 12 percent, respectively). This is balanced by greater reliance on fellowships and traineeships in private institutions (13 percent and 7 percent, respectively) than in public ones (7 percent and 3 percent, respectively).

Figure 6-22.
Primary support of full-time S&E graduate students, by mechanism and source for private and public universities: 1997



NOTES: Mechanism percentages do not total to 100 percent because other mechanisms are not included. S&E also includes the health fields (medical sciences and other life sciences).

See appendix table 6-34. *Science & Engineering Indicators – 2000*

Graduate Modes of Financial Support and Time to Degree

There is considerable interest in whether the amount and type of financial support given to graduate students has an effect on outcomes such as degree completion rates, time to degree, and productivity and success in the labor market. Unfortunately, it is extremely difficult to examine many of these impacts analytically either because of the absence of data, the subjective nature of the data that is available, or the inability to capture the outcomes quantitatively. In addition, most graduate students depend on multiple sources and mechanisms of support while in graduate school, and frequently on different sources and mechanisms in different phases of graduate work. This makes it quite difficult, if not impossible, to identify a one-to-one relationship between a student and a support source or mechanism.

Despite these difficulties, various studies have looked at some aspects of graduate support and student outcomes. A recent review of this literature summarized the results as follows (Bentley and Berger 1998a):

- The bulk of the evidence suggests that students receiving financial support enjoy higher completion rates and shorter time to degree than students without financial support.
- The evidence of the differential effects of alternative support mechanisms on completion rates is inconsistent. However, students holding fellowships appear to finish doctoral programs more quickly than teaching and research assistants.

A recent analysis prepared for NSF (Bentley and Berger 1998b) examined the effects of primary graduate support mechanisms reported by science and engineering research doctorate recipients on time to degree. Early on in this analysis it was found that the primary graduate support mechanisms identified by these doctorate recipients are not randomly distributed across factors that are likely to affect outcomes. Students majoring in some fields are more likely to receive one type of support than those majoring in others. Nonrandom assignment of primary support mechanisms across personal characteristics was also observed. For example, older students who are married and have dependents are more likely than other groups to report being self-supported. Men are more likely than women to report primary support from research assistantships. Students who do not switch fields between degrees are more likely to rely on research assistantships for primary support, while field switchers are more likely to be self-supporting. Because of this nonrandom assignment, it was necessary to use multivariate analyses to measure the impacts of support mechanisms on outcomes. Variables included in this analysis in addition to primary support mechanism include doctoral field, personal characteristics (for example, age, race/ethnicity, citizenship, marital status), parents' education, field and institution paths (that is, how often individuals switch academic fields and institutions), and cumulative debt.

The study found relatively large differences in the simple averages of time to degree* computed across alternative support mechanisms before the variables mentioned above were included in the analysis. For example, the mean total time to degree for students primarily supported by fellowships was 7.86 years, significantly less than the 10.33 years for self-supporting students. However, much of the differences in average time to degree across support mechanisms disappear when the effects of the additional variables are accounted for in the multivariate analysis. In the example above, after controlling for those other factors affecting time to degree, students primarily supported by fellowships complete their Ph.D. just 0.65 years faster than self-supporting students, rather than 2.47 years faster. The multivariate analysis also showed relatively small differences in time to degree across alternative types of support. For example, students supported by fellowships complete doctorates only about one-third of a year faster than students supported by teaching assistantships, and the latter complete degree requirements nearly as fast as research assistants.

Even after controlling for a number of variables, the study had several limitations that need to be considered in interpreting the findings. One of the main difficulties is a selection problem that is not easily overcome. Fellowships and assistantships are probably awarded on the basis of ability and achievement. Some of the measured effects of these types of support may be due to student characteristics, rather than to the receipt of the award. For example, if students awarded fellowships have better academic credentials than others do, one might expect them to finish their doctorates more quickly. To the extent that graduate support allocation decisions are successful in sorting students by merit and aptitude, it becomes more difficult to statistically isolate the effect of receiving graduate support from the effects of other student differences.

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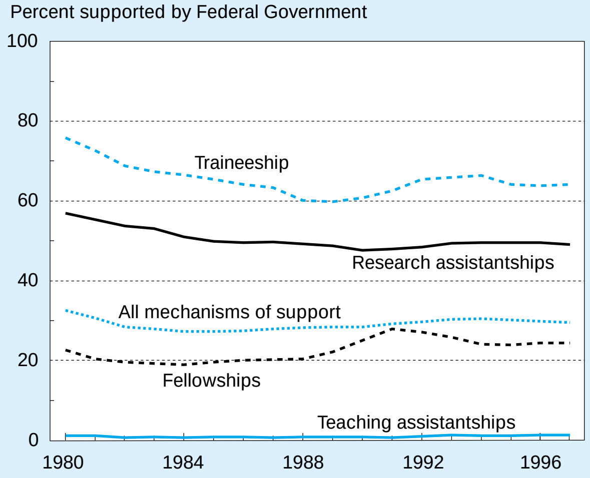
*The discussion below refers to total time to degree, which is defined as years elapsed between the date of the bachelor's degree and the date of the doctorate. There are alternative measures of time to degree that can be analyzed including graduate time to degree (years elapsed between the date of entry into the first graduate program and the date of the doctorate) and registered time to degree (number of years registered in the graduate program before receiving the doctorate).

The Federal Government plays a larger role as the primary source of support for some mechanisms than for others. (See figure 6-23.) A majority of traineeships in both private and public institutions (54 percent and 73 percent, respectively) are financed primarily by the Federal Government, as are 60 percent of the research assistantships in private institutions and 46 percent in public institutions. The Federal Government provides the primary support for less than 30 percent of fellowships and less than 2 percent of teaching assistantships in both public and private institutions.

Support Patterns for All S&E Graduate Students Versus Doctorate Recipients

Most full-time S&E graduate students do not go on to receive a Ph.D., and many never intend to do so. Consequently, it is likely that the financial support patterns of full-time S&E graduate students will differ from those of S&E Ph.D. recipients. While the data from the two surveys are not strictly comparable, it is useful to compare the primary support patterns of those students who do earn a Ph.D. with the patterns for all full-time S&E graduate students to see if they provide a rough indicator of differences among these two groups.[54] Thirty-four percent of the students receiving their science and engineering Ph.D.s in 1997 reported that their primary mechanism of support during their time in graduate school was a research assistantship. This is somewhat higher than the percentage (27 percent) of full-time science and engineering students for whom a research assistantship was reported as the primary mechanism of support. Fellowships and teaching assistantships were reported less frequently as a primary mechanism of support by those students who earned an S&E Ph.D. (2 percent and 15 percent, respectively) than for all full-time S&E graduate students (9 percent and 20 percent, respectively). Traineeships, however, were reported more frequently by those receiving an S&E Ph.D. (7 percent) than for graduate students in general (4 percent). A considerably smaller percentage of students receiving an S&E Ph.D. reported self-support as their primary means of support (20 percent) than did graduate students in general (33 percent). (See appendix tables 6-35 and 6-36.) For a brief discussion of overall rather than primary support for S&E Ph.D.s see sidebar, “Multiple Modes of Financial Support for S&E Ph.D.s.”

Figure 6-23.
Percentage of full-time S&E graduate students with the Federal Government as primary source of support, by primary mechanism of support: 1980–97



NOTES: Data shown here do not include students for whom self-support is their primary source of support. S&E also includes the health fields (medical sciences and other life sciences).

See appendix table 6-33. *Science & Engineering Indicators – 2000*

Support Patterns for S&E Doctorate Recipients by Citizenship, Sex, and Race/Ethnicity

The data on financial support for S&E Ph.D.s also permit one to look at differences in support patterns by citizenship status, sex, and race/ethnicity;[55] this is not possible with the graduate student data.[56] (See appendix table 6-37.) Foreign S&E Ph.D. recipients—whether on temporary or permanent visas—were more likely than U.S. citizens to report a research assistantship (44 and 45 percent versus 32 percent) or a teaching assistantship (20 and 19 percent versus 14 percent) as their primary support mechanism and less likely than U.S. citizens to report a fellowship (1 percent versus 3 percent), traineeship (5 and 8 percent versus 9 percent), or self-support (11 and 15 percent versus 27 percent).[57]

Among U.S.-citizen doctorate recipients, men were much more likely than women to report a research assistantship (35 versus 27 percent) and much less likely to report self-support (22 versus 33 percent) as their primary support modes. Although sex differences also existed in the use of fellowships, traineeships, and teaching assistantships, these were much smaller than the above-mentioned differences.

Also, among U.S.-citizen S&E Ph.D.s, underrepresented minorities (American Indians, Alaskan Natives, blacks, and Hispanics) were less likely than either Asians and Pacific Islanders or whites to report research assistantships (21 percent versus 41 and 32 percent) and teaching assistantships (8 percent versus 10 and 15 percent) as their primary support mechanism and more likely to report fellowships (6 percent versus 4 and 3 percent) and traineeships (16 percent versus 9 and 8 percent). They were also more likely to report self-support (26 percent) than Asians and Pacific Islanders (17 percent), but less likely than whites (28 percent). (See figure 6-24.) See “The Debt Burden of New Science and Engineer-

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[54] As noted earlier, the data for these two groups are derived from two distinct surveys with different reporting entities and different time frames.

[55] Since the Survey of Earned Doctorates obtains data from individual respondents, information is available about demographic characteristics such as citizenship, race/ethnicity, and sex.

[56] For information on the distribution of and trends in S&E Ph.D.s by sex, race/ethnicity, and citizenship status, see chapter 4, “Higher Education in Science and Engineering.”

[57] Foreign S&E Ph.D. recipients, especially those on temporary visas, are often not eligible for either Federal loan programs (included in self-support) or Federal fellowships.

Multiple Modes of Financial Support for S&E Ph.D.s

A recent NSF study (NSF 2000a) examined the entire matrix of support patterns of science and engineering (S&E) research doctorates in 1995 (not only their primary forms of support), showing the distribution of various modes of support to individuals. The Survey of Earned Doctorates, which served as the main source of data for this study, allowed new Ph.D.s to select from 32 separate support options all the forms of support that they may have used during graduate school. In the study, these 32 support options were combined into 7 modes of support:

- fellowship,
- traineeship,
- research assistantship (RA),
- teaching assistantship (TA),
- own funds,
- loans, and
- other.

The study found that 1995 S&E Ph.D.s commonly relied on more than one mode of support. The average number of modes of support was 2.5 and varied by field, sex, race/ethnicity, and citizenship. Women tended to rely on more support modes than men in S&E as a whole and in most fields. Asians and Pacific Islanders and noncitizens reported fewer modes of support on average than did other groups.

Among S&E Ph.D.s as a whole (looking at all forms of support reported rather than only the primary mode of support), women were more likely to report having used traineeships, their own funds, or loans than were men. Men were more likely than women to receive support in the form of RAs. For the most part, differences between women’s and men’s reliance on own funds and RAs are related to differences in field of doctorate. Women are more likely than men to be in psychology and in health sciences—fields in which reliance on one’s own funds is common—and men are more likely than women to be in engineering and physical sciences—fields in which reliance on RAs is common.

Among both Asian and Pacific Islander and noncitizen S&E Ph.D. recipients, RAs were the most frequently reported modes. In contrast, the support mode identified by the largest percentage of both underrepresented minorities (American Indians, Alaskan Natives, blacks, and Hispanics) and whites was their own funds. Whites and underrepresented minorities were also more likely to report the use of loans than were Asians and Pacific Islanders or noncitizens, and underrepresented minorities were more likely to report the use of both fellowships and traineeships than other groups. Although some of these variations in modes of support were found to be due to field differences, field differences did not explain all of the racial/ethnic variations. For instance, Asians and Pacific Islanders reported the largest use of RAs in every field except the computer sciences and psychology. Also, in every field, a larger percentage of both underrepresented minorities and whites reported using their own funds and loans than did Asians and Pacific Islanders or noncitizens. Further, in almost every field, higher percentages of underrepresented minorities than other groups reported using fellowships and traineeships.

Five combinations of support modes out of a possible 127 were reported by slightly less than half of all 1995 S&E Ph.D. recipients. Two combinations—RA+TA and RA+own funds—accounted for about 20 percent of all combinations of modes. RA+TA+own funds and RA alone were the third and fourth most frequent combinations. TA+own funds was the fifth most frequently used combination. Combinations of support modes differ by sex within some fields. For example, in the health sciences, 12 percent of women and 6 percent of men reported using their own funds as their only mode of support. In mathematics, women and men have the same top four combinations of support but the predominant combination for men was RA+TA and for women TA+own funds.

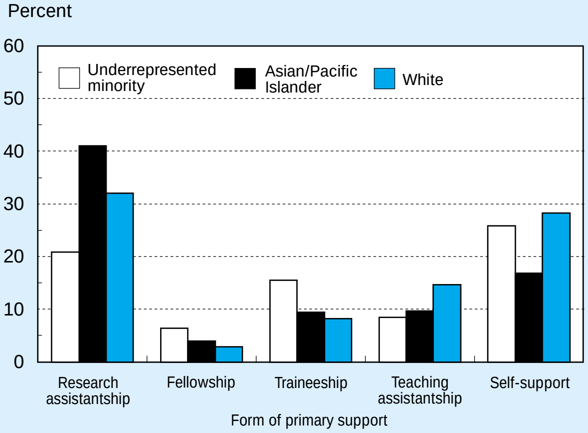
Underrepresented minorities were found to use a wider range of funding combinations and relied more on loans and own funds than did Asians and Pacific Islanders and noncitizens. Each of the five top combinations of modes of support of underrepresented minorities involved use of their own funds and accounted for only 22 percent of minority Ph.D. recipients. In contrast, just under 40 percent of those of Asian or Pacific Islander background received their support from the RA+TA combination or RA alone, and the top five combinations accounted for the support of about 60 percent of those Ph.D.s.

ing Ph.D.s” later in this chapter for differences in the debt situation of U.S. citizen and foreign Ph.D. recipients, among racial/ethnic groups, and between men and women.

Since the field distribution of S&E Ph.D. degrees varies across demographic groups, and the patterns of support differ by S&E field, some of the differences reported above could be mainly the result of degree field distribution differences. However, the data indicate that although degree field distribution does explain a great deal of the difference in relative importance of primary support mechanisms between men and women, it does not account for the differences across either citizenship status or race/ethnicity. (See appendix tables 6-38, 6-39, and 6-40.)

In the case of foreign S&E Ph.D. recipients, the relative importance of RAs and TAs as primary support mechanisms

Figure 6-24.
Primary forms of support for 1997 U.S. citizen S&E Ph.D. recipients, by race/ethnicity



NOTES: Percentages do not total to 100 due to omission of other nonspecified forms of support, nonrespondents, and rounding. Underrepresented minorities include American Indians, Alaskan Natives, blacks, and Hispanics. S&E also includes the health fields (medical and other life sciences).

See appendix table 6-37. *Science & Engineering Indicators – 2000*

found in the aggregate compared to U.S. citizens also holds for most S&E fields, and is particularly strong in both engineering and the computer sciences. Similarly, the lesser relative reliance on self-support holds in all the broad disciplinary areas, while the comparatively minor roles of fellowships and traineeships for foreign doctorate recipients holds in about half of these fields. (See appendix table 6-38.)

Although among U.S. citizens female S&E doctorate recipients were less likely than males to report an RA as their primary support mechanism at the aggregate level, this was not the case in many S&E fields. In five broad fields—mathematics, environmental sciences, biological sciences, psychology, and social sciences—women were either more or equally likely as men to report an RA as their primary support mechanism. (See appendix table 6-39.) In addition, in many fields, differences between men and women in the percentage reporting an RA as their primary support mechanism were in the 1 to 3 percentage point range rather than the 8 percentage point aggregate differential. Only in the computer sciences was this differential large—20 percent of the women reported an RA, compared to 34 percent of the men.

The level of the aggregate difference in reliance on RAs between men and women can be explained by the fact that a much larger percentage of women (29 percent) received their Ph.D. degrees in psychology—a field where RAs are not a very important primary means of financial support—than did men (9 percent). The level of the aggregate difference between sexes in the reliance on self-support as a primary mode of support can be similarly explained. Once again, in this case, individual fields do not follow the aggregate pattern. In the environmental sciences, agricultural sciences, biological sciences, and engineering, women were less likely than men to identify self-support as their primary means of support. And in the fields where women were more likely to rely on self-support than men, only in the health sciences was the difference between them (52 percent versus 39 percent) as large as the aggregate difference reported. In the other fields, differences ranged between 1 and 5 percentage points.

In the case of U.S.-citizen underrepresented minority S&E Ph.D. recipients, the aggregate findings also hold for most broad disciplinary areas. (See appendix table 6-40.) For example, only in the health sciences is the percentage of underrepresented minorities higher than the percentage of white Ph.D. recipients reporting RAs as their primary mechanism of support. And only in the social sciences is the percentage of underrepresented minorities higher than the percentage of Asian and Pacific Islander Ph.D. recipients reporting RAs as their primary mechanism of support.

Science and Public Policy (Steelman report)
Part One—Science for the Nation, IV.
A National Science Program

Scientists for the Future

Our scientific strength depends neither solely upon our present supply of scientists, nor upon those students now being trained. It depends ultimately upon a steady flow of able students into our colleges and universities. What we require as a Nation is to extend educational opportunities to all able young people, leaving it to them to determine the field of study they desire to pursue. In normal times, freedom of choice must be allowed to operate in education, as well as elsewhere, if we are to preserve our free institutions. No agency of the Government is sufficiently far-seeing—nor ever likely to be—to foretell 15 or 20 years in advance the fields in which we shall need most trained people. In free competition, the physical and biological sciences will get their share.

The expanding grants in support of basic research will provide an opportunity for the employment of more graduate students in such research programs. This will enable the universities themselves to choose the best of their present students as research assistants and will in turn result in better scientific training. (Steelman 1947, 35-6.)

Research Assistantships as a Primary Mechanism of Support

Graduate Research Assistantships by S&E Field

Research assistantships accounted for 27 percent of all support mechanisms for full-time S&E graduate students in 1997. However, the mix of support mechanisms, and thus the

Relationship Between Support Modes and Early Employment of Recent S&E Ph.D.s

A recent NSF Issue Brief (NSF 1998a) examined the relationships between the primary mechanism of financial support reported by recent science and engineering (S&E) Ph.D.s* and the sector in which they were employed and their primary work activity within one to two years after conferral of their doctorate.

Since 1979, in every year of the biennial Survey of Doctorate Recipients (odd years), about half of recent S&E Ph.D.s with primary research assistantship, fellowship, traineeship, or teaching assistantship support were working in academic institutions. However, with a few minor exceptions, since 1979 those with primary RA support had a relatively greater propensity for industry employment—and a lower propensity for academic jobs—than those with primary fellowships, traineeships, and teaching assistantships. (See text table 6-5.) For example, in 1995 industry employed a third of those with RA support, but only 21 percent of those with TA support, 19 percent of those with fellowships, and 15 percent of those with traineeships. Academic institutions employed 51 percent of those with RA support, but 61 percent of those with fellowship, 65 percent of those with traineeship, and 66 percent of those with TA support.

A small number of universities—about 125**—dominate the conduct of academic research, while a much larger number—about 1,600—award four-year and advanced degrees in science and engineering. The study found that RA- and fellowship-supported S&E Ph.D.s who did enter academic employment disproportionately ended up working at these research universities. From 1979 to 1995, these institutions employed from 59 to 68 percent of all the recent S&E Ph.D.s who were working in colleges and universities, but 71 to 84 percent of those in academic employment who had primary RA support, and 72 to 90 percent of those with primary fellowship support.

The study also found that although recent S&E Ph.D.s tended to designate research as their primary activity more frequently than teaching, their responses differed with primary support mode. (See text table 6-5.) In 1995, 73 to 75 percent of recent S&E Ph.D.s with research assistantships and fellowships identified research as their primary job activity, compared to 56 percent overall, 54 percent of those with traineeships, and 40 percent of those with a teaching assistantship. This pattern also has been quite consistent since 1979, although 1995 is anomalous for the relationship between traineeships and work activity that appeared to hold during 1979–93.

A significantly greater percentage of those with teaching assistantships as primary support and a significantly smaller percentage of those with a research assistantship were likely to report teaching as their primary work activity than the overall population of recent S&E Ph.D.s. This was true throughout the 1979–95 period. For S&E Ph.D.s with fellowships or traineeships, the propensity to report teaching as their primary work activity varied over these years.

The available data do not provide any information about the causes of these patterns. Therefore it is not clear whether students who desire careers as researchers or in industry seek out RA support or whether the experiences associated with RA support influence the choice of employment sector and type of work sought by recent S&E Ph.D.s. In addition, the relationships between primary support mechanism, employment sector, and primary work activity may in part reflect factors not examined here, particularly distribution of support mechanisms across specific fields and sectoral employment differences across these fields.

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*Data for this analysis were from NSF's annual Survey of Earned Doctorates (primary support mode) and its biennial Survey of Doctorate Recipients (sector of employment and primary work activity). For this analysis, recent S&E Ph.D.s are defined as those receiving their doctorate degree in the two years preceding the biennial Survey of Doctorate Recipients.

**The Carnegie Commission calls them the Research Universities.

role of research assistantships as the primary support mechanism, differs by S&E field. (See appendix table 6-36.) RAs comprise more than 50 percent of the primary support mechanisms for graduate students in atmospheric sciences, oceanography, agricultural sciences, chemical engineering, and materials engineering. They account for less than 20 percent in all the social sciences, mathematics, and psychology.

The number of graduate students with a research assistantship as their primary mechanism of support increased from just over 50,000 in 1980 to a peak of 92,000 in 1994, and by 1997 fell to 88,000. (See appendix table 6-41.) In just about every S&E field, the percentage of graduate students with a research assistantship as their primary means of support was higher in 1997 than in 1980. The largest increases were in the biological sciences (14 percentage points), in both the agricultural and the medical sciences (10 percentage points each), and in a number of engineering fields—electrical/electronic engineering (11 percentage points), chemical engineering (10 percentage points), and civil and industrial engineering (9 percentage points each). (See figure 6-25.)

All S&E Graduate Students Versus Doctorate Recipients

Although not strictly comparable, data from the Ph.D. and graduate student surveys suggest that the relative utilization of a research assistantship as a primary mechanism of sup-

Text table 6-5.

Percent of recent S&E Ph.D.s working in academe or industry, or with research or teaching as primary work activity, by selected primary mechanism of support: 1979–1995

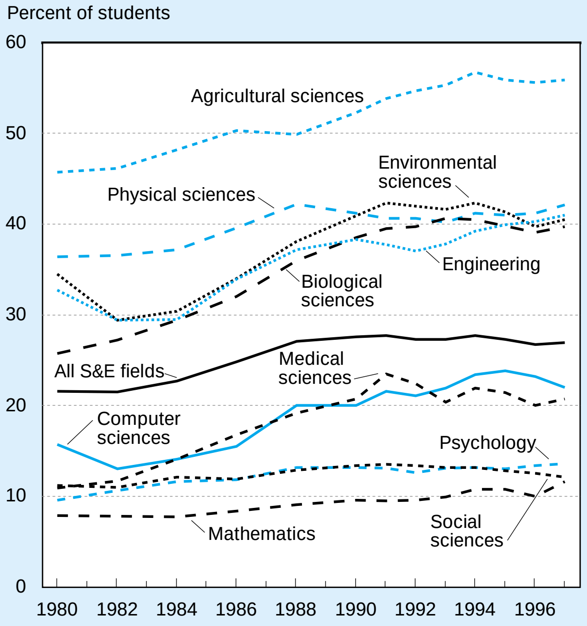
	All	Research assistantship	Teaching assistantship	Traineeship	Fellowship
Work sector					
Academe					
1979	52	49	60	68	56
1981	50	44	61	62	55
1983	49	48	58	60	59
1985	50	49	59	55	65
1987	47	45	60	55	43
1989	49	45	57	68	75
1991	49	46	58	62	63
1993	51	49	71	58	62
1995	54	51	66	65	61
Industry					
1979	21	30	24	14	20
1981	27	39	23	13	27
1983	26	35	26	16	17
1985	25	32	22	17	23
1987	24	31	18	19	26
1989	25	30	23	13	17
1991	26	32	23	20	19
1993	28	34	16	21	28
1995	27	33	21	15	19
Primary work activity					
Research					
1979	47	60	47	52	56
1981	51	76	44	54	73
1983	53	70	50	63	73
1985	53	73	50	71	60
1987	56	76	55	74	66
1989	59	78	59	73	79
1991	56	75	46	64	75
1993	58	75	47	69	80
1995	56	75	40	54	73
Teaching					
1979	24	15	34	24	24
1981	22	11	35	21	17
1983	21	15	28	17	9
1985	20	15	31	12	26
1987	19	12	30	7	21
1989	18	8	31	11	17
1991	19	11	34	17	13
1993	17	8	38	14	11
1995	18	9	35	20	15
Average N	28,487	7,958	4,290	2,833	746

NOTES: Recent S&E Ph.D.s are those receiving their degrees in the two years preceding the survey year of the biennial Survey of Doctorate Recipients. Percentages represent the percent of recent S&E Ph.D.s in each year that work in academe and industry or that report research and teaching as primary work activity, but do not sum to 100 percent since employment sectors other than academe and industry and work activities other than research and teaching are not shown. Industry includes self employment. “Average N” is average number of recent S&E Ph.D.s across the nine survey years for each primary support mechanism and for the “All” category includes all recent S&E Ph.D.s including those with mechanisms not shown (own/family resources, loans, other nonspecified, and missing).

SOURCES: National Science Foundation, Division of Science Resources Studies (NSF/SRS), Survey of Earned Doctorates and Survey of Doctorate Recipients, various years, special tabulations.

Science & Engineering Indicators – 2000

Figure 6-25.
Percentage of full-time S&E graduate students with a research assistantship as primary mechanism of support, by field: 1980–97



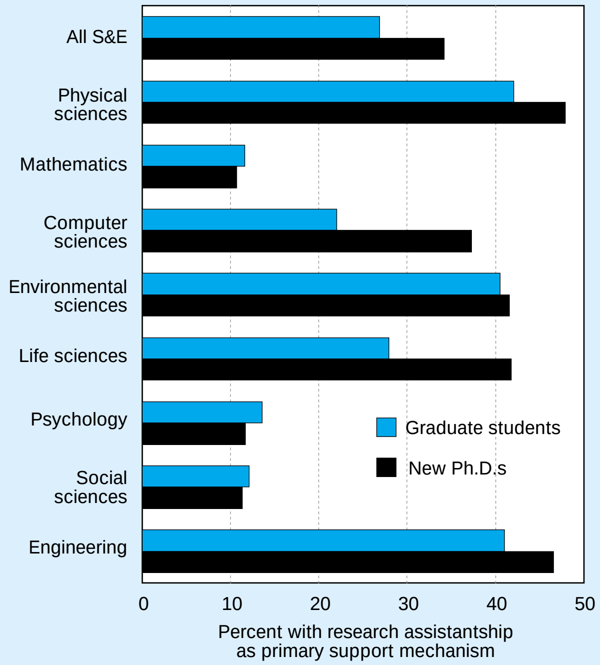
See appendix table 6-41. *Science & Engineering Indicators – 2000*

port was rather similar at a broad disciplinary level between full-time S&E graduate students and S&E Ph.D. recipients. (See figure 6-26.) Research assistantships were once again quite prominent in the physical sciences, environmental sciences, and engineering and much less prominent in mathematics, social sciences, and psychology. However, in both the life sciences and the computer sciences, research assistantships played a much larger role as a primary support mechanism for those receiving their doctorate than for the average full-time S&E graduate student.

Sources of Support

In 1997, about one-third of graduate research assistants were in the life sciences, with an additional 30 percent in engineering and 13 percent in the physical sciences. The Federal Government was the primary source of support for about half of all graduate students with a research assistantship as their primary mechanism of support. (See appendix table 6-42.) This proportion declined from 57 percent in 1980 to about 50 percent in 1985, where it has since remained. (See figure 6-27 and appendix table 6-43.) The Federal role, however, differs by S&E field. The Federal Government was the primary source of support for considerably more than half of the research assistants in the physical sciences (72 percent), the environmental sciences (61 percent), and the computer sciences (60 percent), and for considerably less than half in the social sciences (21 percent) and psychology (31 percent).

Figure 6-26.
Indicator of relative importance of research assistantships as primary mechanism of support for full-time S&E graduate students and S&E Ph.D. recipients, by field: 1997



NOTES: Since the data for graduate students and Ph.D.s are derived from two distinct surveys with different reporting entities and different time frames, these percentages are not strictly comparable. They are only intended to serve as a rough indicator of the similarities and differences between relative use of RAs as a primary support mechanism by the two groups. Life sciences also includes the health fields (medical sciences and other life sciences).

See appendix tables 6-35 and 6-36.
Science & Engineering Indicators – 2000

Federal Agency Support[58]

During most of the 1980s NSF was the Federal agency that was the primary source for the largest number of graduate research assistantships. It was surpassed by the entire HHS in 1989 and by NIH in 1993. (See appendix table 6-44.) Between 1980 and 1997, the percentage of Federal graduate research assistantships financed primarily by NIH increased from about 19 percent to 26 percent, while the percentage financed primarily by NSF increased from 26 percent to a peak of 28 percent in 1984, then fell to 24 percent. The DOD share has fluctuated between 10 and 16 percent over the same period and the USDA share between 6 and 7 percent (since it was first reported in 1985). NASA's share in 1997 (only the second year it was reported) was just under 5 percent.

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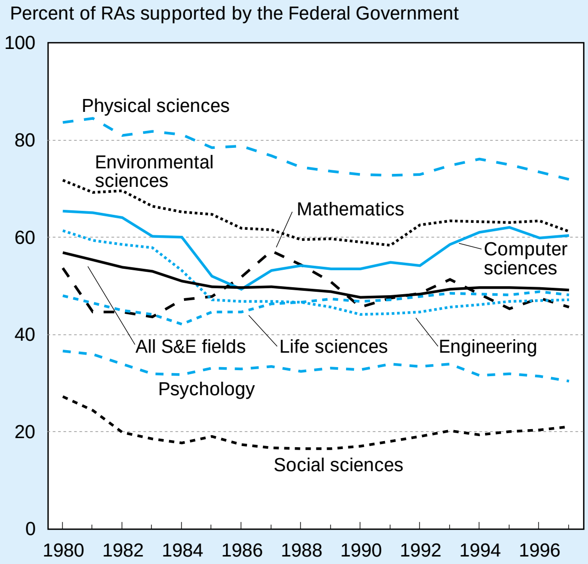
[58] Only five Federal agencies are reported on individually as primary sources of support to S&E graduate students in the Survey of Graduate Students and Postdoctorates in Science and Engineering: DOD, NSF, USDA, NASA, and HHS, with the latter being reported as two distinct units—NIH and other HHS. DOE has been added to the 1999 survey.

Figure 6-27.
Percentage of full-time S&E graduate students with a research assistantship as primary support mechanism whose primary source of support is the Federal Government, by field: 1980–97



NOTE: Research assistants (RAs) are students for whom a research assistantship is reported as their primary mechanism of support. Life sciences also includes the health fields (medical sciences and other life sciences).

See appendix table 6-43. *Science & Engineering Indicators – 2000*

Just as Federal agencies emphasize different S&E fields in their funding of academic research, it is not surprising to find that they also emphasize different fields in their support of graduate research assistants. HHS and especially NIH concentrate their support in the life sciences (70 percent and 73 percent, respectively), as does USDA (74 percent). DOD concentrates its support in engineering (58 percent). NSF, on the other hand, has a more diversified support pattern, with just over one-third in engineering, 29 percent in the physical sciences, and 10 percent each in the environmental and the life sciences. (See figure 6-28 and appendix table 6-45.) Although an agency may place a large share of its support for research assistants in one field, it may not necessarily be a leading contributor to that field. (See figure 6-29 and appendix table 6-46.) NSF is the lead supporting agency in mathematics (41 percent of federally supported RAs), the environmental sciences (41 percent), the physical sciences (37 percent), and in engineering (29 percent). NIH is the lead support agency in the life sciences (60 percent), psychology (56 percent), and sociology (36 percent). DOD is the lead support agency in the computer sciences (43 percent) and in electrical engineering (45 percent), and also provides an almost identical level of support as NSF for total engineering. USDA is the lead support agency in the agricultural sciences (56 percent) and economics (52 percent). NASA is the lead support agency in astronomy (45 percent) and aeronautical/astronautical engineering (36 percent).

The Spreading Institutional Base

During the 1980–97 period, the number of universities and colleges reporting at least one full-time S&E graduate student with a research assistantship as his or her primary mechanism of support has fluctuated between 400 and 435, with a slight upward trend, reaching its highest level in 1993. Not surprisingly, however, there was basically no change in the number of currently designated Carnegie research or doctorate-granting institutions reporting at least one graduate student with primary research assistantship support during this period; this number fluctuated between 219 and 224. Since these institutions had probably been receiving research funds over the entire period, it is likely that they were supporting graduate students with research assistantships as their primary support mechanism. Thus, most of the fluctuation and the entire increase in the number of institutions reporting at least one graduate student receiving a research assistantship as their primary support mechanism occurred among comprehensive; liberal arts; two-year community, junior, and technical; and professional and other specialized schools. (See appendix table 6-47.) Only 46 percent of this group of schools reported at least one graduate student with an RA as primary support mechanism in 1980, compared to 57 percent in 1997.[59]

Throughout this period, considerably fewer institutions reported students with primary RA support financed primarily by the Federal Government than reported students with such support financed primarily from non-Federal sources. This difference is particularly pronounced among the “other” Carnegie institutions, 114 (32 percent) of which report RAs supported by the Federal Government in 1997 compared to 185 (51 percent) that report RAs financed by non-Federal sources. Why so many fewer other institutions report the Federal Government as a primary source of funds for research assistantships than receive R&D funds from the Federal Government is unclear.

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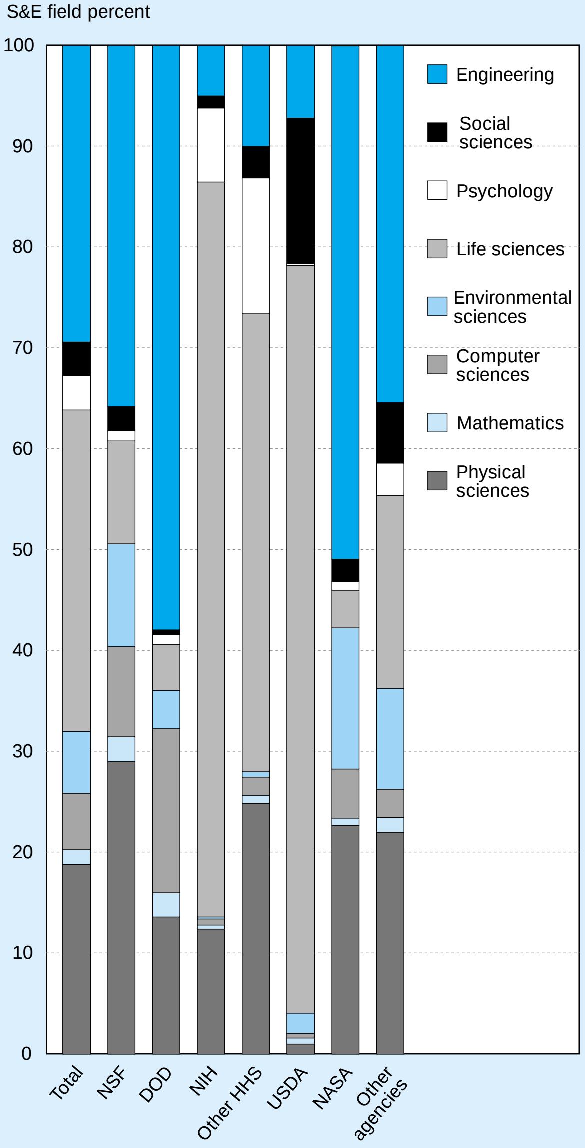
[59] Percentages are calculated by dividing the number of schools reporting at least one RA into the number of schools responding to the survey. If an institution does not report any full-time graduate students with an RA as their primary support mechanism, it does not necessarily mean that the institution does not have any graduate students being supported by research assistantships. It simply indicates that the research assistantship is not the primary mechanism of support for any of the students attending that institution.

Figure 6-28.
Field distribution of full-time S&E graduate students with a research assistantship as primary support mechanism, by federal agency of primary support: 1997

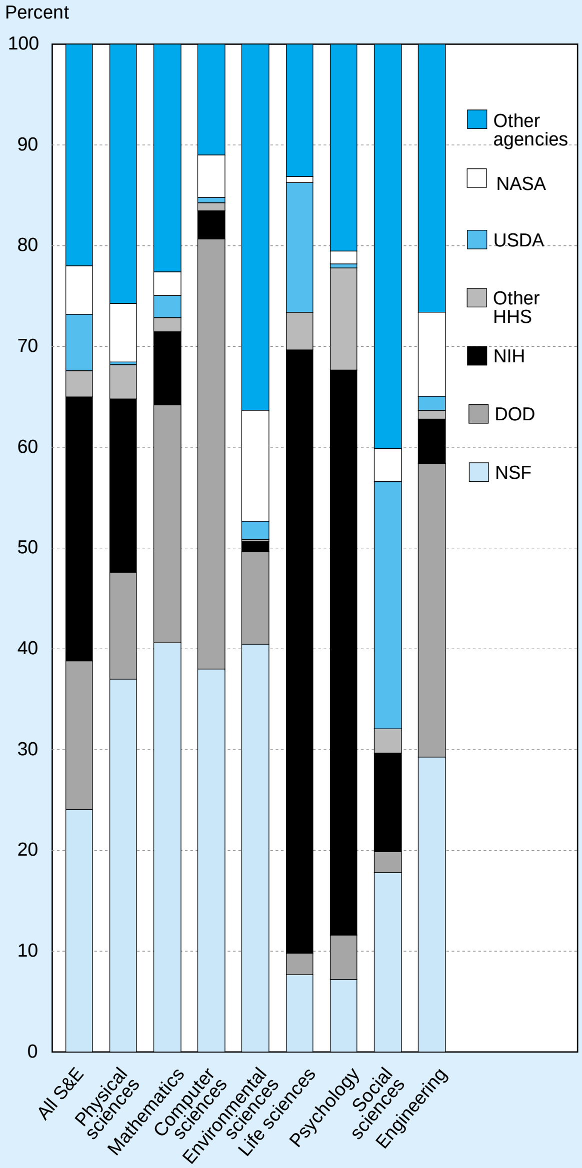


NSF = National Science Foundation; DOD = Department of Defense; NIH = National Institutes of Health: HHS = Department of Health and Human Services; USDA = Department of Agriculture; NASA = National Aeronautics and Space Administration

NOTE: The agencies cited here are the only ones for which graduate support data are reported in 1997. Life sciences also includes the health fields (medical sciences and other life sciences).

See appendix table 6-45. *Science & Engineering Indicators – 2000*

Figure 6-29.
Federal agency distribution of full-time S&E graduate students with a research assistantship as primary support mechanism, by field: 1997



NSF = National Science Foundation; DOD = Department of Defense; NIH = National Institutes of Health: HHS = Department of Health and Human Services; USDA = Department of Agriculture; NASA = National Aeronautics and Space Administration

NOTE: The agencies cited here are the only ones for which graduate support data are reported in 1997. Life sciences also includes the health fields (medical sciences and other life sciences).

See appendix table 6-46. *Science & Engineering Indicators – 2000*

The Debt Burden of New Science and Engineering Ph.D.s

Two NSF Issue Briefs (NSF 1998b and 1999c) examined the debt owed by 1993–96 science and engineering (S&E) doctorate recipients at the time of Ph.D. conferral for undergraduate and/or graduate education expenses (data do not allow them to be separated) for tuition and fees, living expenses and supplies, and transportation to and from school. Differences were highlighted in the debt situation of U.S. citizen and foreign Ph.D. recipients, among racial/ethnic groups, and between men and women.

The main findings of these studies were:

- U.S. citizens were more likely to report at least some debt, and to owe larger amounts, than were foreign students.
- Among U.S. citizens, a smaller percentage of underrepresented minority (American Indian, Alaskan Native, black, and Hispanic) S&E Ph.D. recipients were debt free compared to whites or Asians and Pacific Islanders. Among those with debt, underrepresented minorities reported higher levels of debt than their white or Asian and Pacific Islander counterparts.
- Among U.S. citizens there was little difference between the debt situation of men and women at the aggregate S&E level, but these aggregate findings actually masked some field differences in the debt situation between male and female S&E Ph.D. recipients.*

Data for 1997 S&E doctorate recipients show similar results to the earlier studies. (See text table 6-6.) Overall, just under half of those who received their S&E Ph.D.s in 1997 reported having no debt at the time of Ph.D. conferral. An additional 29 percent reported total debt burdens of $20,000 or less and another 14 percent reported debt levels exceeding $20,000.** Only 40 percent of U.S. citizen Ph.D.s reported being free of debt compared to two-thirds of those without U.S. citizenship. Nineteen percent of U.S. citizens reported debt burdens exceeding $20,000, and 37 percent reported debt of less than $20,000; for foreign Ph.D. recipients, comparable percentages were 9 and 21 percent, respectively.

Among U.S. citizens, only 28 percent of underrepresented minority S&E Ph.D. recipients reported not having any debt, compared to 41 percent for whites and 44 percent for Asians and Pacific Islanders. They also reported higher levels of debt than their white or Asian and Pacific Islander counterparts. Even though underrepresented minorities are more likely to receive their Ph.D.s in fields subject to greater likelihood and higher levels of debt (psychology and the social sciences), the aggregate differences are not primarily the result of field distribution differences. In each of the fields presented in text table 6-6, except for the environmental sciences, a smaller percentage of underrepresented minorities reported not having any debt than either whites or Asians and Pacific Islanders. In addition, in each field the percentage of underrepresented minorities reporting debt greater than $20,000 is always greater than the percentage of Asian and Pacific Islanders or whites reporting such debt.

Once again, in 1997, there was little difference at the aggregate level between the debt situation of men and women. Forty percent of each group reported having no debt. Thirty-six percent of the women reported debt less than $20,000 compared to 37 percent of the men; 20 percent reported debt exceeding $20,000 compared to 18 percent of men. However, in all but two of the fields presented in the text table—the computer sciences and the environmental sciences—a larger proportion of women reported not having any debt than did men. Some of the differences reported are substantial. Also, in most fields a smaller percentage of women than men reported debt exceeding $20,000.

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*A major reason that aggregate data show similarities in the debt situation of men and women is that psychology, the field with the highest percentages and levels for educational debt, accounts for about 30 percent of women's S&E Ph.D.s compared to 10 percent of men's.

**Some respondents failed to furnish this information.

Text table 6-6.
Cumulative debt related to the education of S&E doctorate recipients, by citizenship status, sex, race/ethnicity, and field: 1997

Ph.D. field	Status	Number of Ph.D.s	Percent with No debt	Percent with < or = $20K	Percent with >$20K
All S&E fields	All	28,241	47	29	14
	U.S. citizen	16,686	40	37	19
	Foreign	9,530	67	21	9
	Male (U.S. citizen)	9,948	40	37	18
	Female (U.S. citizen)	6,738	40	36	20
	Asian/Pacific Islander (U.S. citizen)	1,043	44	32	14
	White (U.S. citizen)	13,902	41	37	19
	Underrepresented minority (U.S. citizen)	1,238	28	40	27
Physical sciences	All	3,711	51	32	9
	U.S. citizen	2,112	40	43	12
	Foreign	1,376	73	19	6
	Male (U.S. citizen)	1,644	40	43	12

Page 1 of 2

Text table 6-6.

Cumulative debt related to the education of S&E doctorate recipients, by citizenship status, sex, race/ethnicity, and field: 1997

		Number of	Percent with		
Ph.D. field	Status	Ph.D.s	No debt	< or = $20K	>$20K
Physical sciences	Female (U.S. citizen)	468	41	44	11
	Asian/Pacific Islander (U.S. citizen)	155	45	38	8
	White (U.S. citizen)	1,779	41	44	12
	Underrepresented minority (U.S. citizen)	106	29	43	18
Mathematics	All	1,112	58	26	7
	U.S. citizen	516	50	36	9
	Foreign	516	73	18	5
	Male (U.S. citizen)	378	48	36	11
	Female (U.S. citizen)	138	55	37	4
	Asian/Pacific Islander (U.S. citizen)	34	44	26	9
	White (U.S. citizen)	440	52	37	9
	Underrepresented minority (U.S. citizen)	22	32	32	23
Computer sciences	All	889	59	22	9
	U.S. citizen	417	58	28	10
	Foreign	403	69	18	9
	Male (U.S. citizen)	336	58	29	10
	Female (U.S. citizen)	81	58	26	10
	Asian/Pacific Islander (U.S. citizen)	42	57	29	2
	White (U.S. citizen)	337	60	28	10
	Underrepresented minority (U.S. citizen)	20	40	40	20
Environmental sciences	All	862	51	30	9
	U.S. citizen	518	46	40	11
	Foreign	281	70	16	7
	Male (U.S. citizen)	380	47	39	11
	Female (U.S. citizen)	138	42	41	12
	Asian/Pacific Islander (U.S. citizen)	18	33	50	0
	White (U.S. citizen)	458	46	41	11
	Underrepresented minority (U.S. citizen)	23	57	22	22
Life sciences	All	8,077	47	32	12
	U.S. citizen	5,032	42	39	15
	Foreign	2,539	65	23	8
	Male (U.S. citizen)	2,589	37	41	18
	Female (U.S. citizen)	2,443	47	37	12
	Asian/Pacific Islander (U.S. citizen)	314	50	30	13
	White (U.S. citizen)	4,234	42	40	15
	Underrepresented minority (U.S. citizen)	351	29	46	22
Psychology	All	3,489	25	28	32
	U.S. citizen	2,886	26	32	37
	Foreign	217	53	28	18
	Male (U.S. citizen)	944	23	30	42
	Female (U.S. citizen)	1,942	28	32	35
	Asian/Pacific Islander (U.S. citizen)	101	31	24	39
	White (U.S. citizen)	2,422	27	32	37
	Underrepresented minority (U.S. citizen)	319	19	34	40
Social sciences	All	4,049	40	32	19
	U.S. citizen	2,517	34	37	25
	Foreign	1,209	58	27	11
	Male (U.S. citizen)	1,399	32	39	24
	Female (U.S. citizen)	1,118	37	35	25
	Asian/Pacific Islander (U.S. citizen)	94	33	36	19
	White (U.S. citizen)	2,106	36	37	24
	Underrepresented minority (U.S. citizen)	222	22	44	33
Engineering	All	6,052	57	25	10
	U.S. citizen	2,688	50	34	11
	Foreign	2,989	68	20	10
	Male (U.S. citizen)	2,278	49	33	12
	Female (U.S. citizen)	410	51	37	9
	Asian/Pacific Islander (U.S. citizen)	285	45	32	12
	White (U.S. citizen)	2,126	51	34	11
	Underrepresented minority (U.S. citizen)	175	42	36	17

NOTES: Percentages do not total to 100 due to rounding and omission of nonrespondents from table. Underrepresented minorities include American Indians/Alaskan Natives, blacks, and Hispanics. Debt is for undergraduate and/or graduate education expenses for tuition and fees, living expenses and supplies, and transportation to and from school.

SOURCE: National Science Foundation, Division of Science Resources Studies, Survey of Earned Doctorates, various years, special tabulations.

Outputs of Scientific and Engineering Research: Articles and Patents

The products of academic research include trained personnel and advances in knowledge. Trained personnel have been 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.

While 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, as reflected in a set of major international scientific and technical journals whose contents are covered in the Institute of Scientific Information's (ISI) Science Citation Index (SCI) and Social Science Citation Index (SSCI).

The *output volume* of research—*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 these organizations' relative prominence 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.

Scientific *collaboration* in all fields increasingly crosses organizational and national boundaries. Articles with *multiple authors* in different venues or countries provide an indicator of the degree of collaboration across sectors and nations. Scientific collaboration has risen with the actions of governments 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 cost or scope of the issue, provides intellectual cross-fertilization and ready access to work done elsewhere.

The perceived *usefulness* of research results to further advancement of the state of knowledge is reflected in *citations*. Both domestic and international citation patterns will be examined. A related indicator, references to scientific and technical articles on patents, suggests the relatedness of the research to presumed practical application.

Data Sources for Article Outputs

The *article counts, coauthorship data,* and *citations* discussed in this section are based on scientific and engineering 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) Science Citation Index (SCI) and Social Science Citation Index (SSCI). Fields in this database are determined by the classification of the journals in which articles appear; journals in turn are classified based on the patterns of their citations, as follows:

Field	Percent of journals
Clinical medicine	24
Biomedical research	11
Biological sciences	10
Chemistry	7
Physics	5
Earth and space sciences	5
Engineering and technology	8
Mathematics	3
Psychology	6
Social sciences	11
Other	10

For the first time, journals in psychology, the social sciences, and certain other applied social science fields are included in the analysis, to provide a fuller examination of all science and engineering fields. The "other" category includes ISI-covered journals in professional fields and health whose citation patterns indicate their strong links to the social sciences or psychology. Appendix table 6-48 lists the constituent subfields of the journals covered here.

The 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 engineering and technology, psychology, social sciences, and "other" categories, as well as for nations with a small or applied science base.

Articles are attributed to countries and sectors by their authors' institutional affiliations at time of authorship. Thus, coauthorship as used here refers to corporate 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 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.

Finally, *patents issued to U.S. universities* will be examined. They provide another indicator of the *perceived utility* of the underlying research, with trends in their volume and nature indicating the universities' interest in seeking commercialization of its results.

U.S. Articles: Counts, Collaboration, and Citations

The complexity and breadth of a nation's science and engineering infrastructure is frequently described in terms of the financial resources it consumes and its personnel base. Article outputs provide another indicator that is particularly well suited to the mapping of the basic and applied research activities carried out in the United States—that is, activities for which articles are often the prime output. What is the contribution of scientists and engineers in the different sectors to the production of U.S. research articles, and in what fields?

All U.S. sectors contribute to the published, refereed science and technology (S&T) literature, albeit in different proportions, with academia providing the bulk of the article output. During 1995–97, an annual average of 173,200 articles were published by U.S. authors in a set of scientific and technical journals covered by the Science and Social Science Citation Indexes since 1985. (See appendix table 6-49.) Over the period, academic researchers contributed almost three-fourths of the total output; industry, the Federal Government, and the nonprofit sector (mainly health-related organizations publishing in life sciences fields) contributed 7–8 percent each. The output of federally funded R&D centers (FFRDCs) added another 3 percent to the total. (See figure 6-30 and appendix table 6-50.)

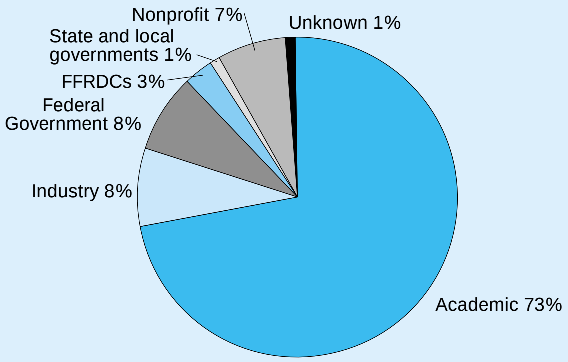
More than half of this U.S. portfolio of scientific and technical research articles—55 percent—covered subjects in the life sciences; another 26 percent dealt with physical sciences, earth and space sciences, and mathematics; 6 percent with engineering and technology; and the remainder with the social and behavioral sciences, including health and professional fields with close ties (based on citations) to the latter two fields. (See figure 6-31.)

Different sectors have different relative emphases. In the portfolios of academia, government, and nonprofit institutions, articles in life sciences fields are prominent, especially in clinical medicine and biomedical research. Industry articles focus on clinical medicine, physics, chemistry, and engineering and technology, with a growing emphasis on the life sciences. FFRDC articles focus on physics, chemistry, earth and space sciences, and engineering and technology. (See appendix tables 6-49 and 6-50.)

Viewed across all performer sectors, little change is evident in the field distribution of these articles—earth and space science registered marginal gains, as did biomedical research and clinical medicine, while biology lost some ground. Likewise, the overall contribution of the different sectors has changed little, except for a marginal percentage-point gain of academia offsetting a marginal decline in industry's share. However, over the 1988–97 decade, some changes in the field mix within specific sectors are worthy of note:

- Among *industry articles*, the number of physics articles declined by half during the 1990s, causing their share to decline steeply, from 21 percent a decade ago to less than 15 percent. Article volume in clinical medicine and biomedical research rose by 20 percent, bringing about share gains from 18 to 24 percent and from 10 to 13 percent, respectively. These numbers clearly indicate a shift in publishing activity (though not necessarily R&D—see chapter 2) from traditional physical-sciences- and engineering-oriented industry segments toward those in pharmaceuticals and other life-science-related areas. (See appendix table 6-49.)

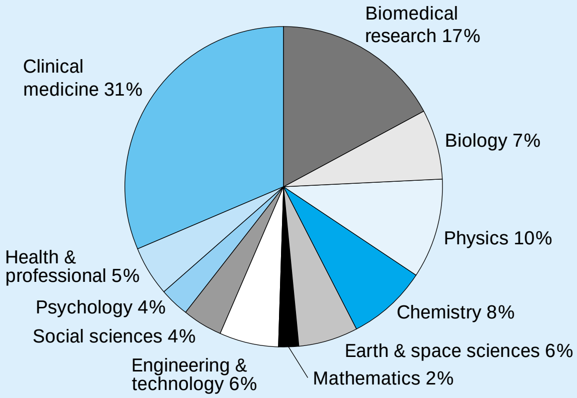
Figure 6-30.
Distribution of U.S. scientific and technical articles, by sector: 1995–97



FFRDC = Federally Funded Research and Development Center

See appendix table 6-50. *Science & Engineering Indicators – 2000*

Figure 6-31.
Distribution of U.S. scientific and technical articles, by field: 1995–97



See appendix table 6-49. *Science & Engineering Indicators – 2000*

- Changes in *academia's portfolio* were more gradual, showing gains of 1 percentage point each in physics, earth and space sciences, and biomedical research publications, with declines in biology and the social sciences. (See appendix table 6-49.)
- The *Federal Government's output* showed mixed trends. The relative balance of in-house articles shifted modestly toward physics and earth and space sciences, with some decline in clinical medicine and biology. However, among articles from university-affiliated FFRDCs, the share of physics papers fell by nearly 3 percentage points, accompanied by a growing share for earth and space sciences articles. (See appendix table 6-49.)

Scientific Collaboration

Developments in science and engineering have led to broader collaboration among researchers. As the scale, cost, and complexity of attacking many problems have increased, research teams have become common, changing the structure of the research. Single-investigator work, as evidenced by single-author publications, is in decline in virtually all fields. The Federal Government has long sought to stimulate this trend, for example, by promoting collaboration across sectors: for example, industry-university or FFRDC-industry activities. (See chapter 2.) 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.

Two trends predominate in the collaborative activities of U.S. researchers:

- strong cross-sectoral collaboration, and
- increasing international collaboration.

The proportion of U.S. scientific and technical articles with multiple institutional authors has continued to rise. In 1997, 57 percent of all S&E articles had multiple authors, up from 49 percent a decade earlier. This resulted from a falling number of U.S. single-author articles, accompanied by a rise in the number of multi-author articles. This general pattern held for all but mathematics, psychology, and the social sciences, where falling single-author output was accompanied by static counts of multi-author papers. (See appendix table 6-51.) Coauthorship was highest in clinical medicine, biomedical research, earth and space sciences, and physics (ranging from 59 to 66 percent), lowest in the social and behavioral sciences and chemistry (from 36 to 44 percent).

The bulk of the increase in corporate[60] coauthorship of U.S. articles reflected rising international collaboration. By the mid-1990s, nearly one article in five—18 percent—had at least one non-U.S. author, up from 12 percent at the beginning of the decade. Physics, earth and space sciences, and mathematics had the highest rates of international coauthorship, ranging from 27 to 30 percent of all U.S. articles. International collaboration rates were much lower in the social and behavioral sciences—9–10 percent. (See appendix table 6-51.)

Academia was at the center of cross-sector collaborations in every sector and field. Coauthorship rates with academia—the percentage of a sector's coauthored papers with an academic collaborator—were above 70 percent for the Federal Government, university-managed FFRDCs, and nonprofit institutions. For other sectors, they ranged from 59 percent for industry-managed FFRDCs to 66 percent for industry itself. In mathematics, 80–90 percent of cross-sector collaborations were with authors in higher education institutions, underlining the key role of academia in mathematics research, where 93 percent of U.S. articles in that field are published. (See appendix table 6-52.)

Other collaborative patterns vary by field, depending on different sectors' relative strengths and foci. For the industry sector, joint work with the Federal Government was prominent in earth and space science, as was collaboration with nonprofit authors in clinical medicine and biomedical research. For the Federal Government, industry collaboration in physics, chemistry, earth and space sciences, and engineering and technology was prominent, as were university-managed FFRDCs in earth and space sciences. The nonprofit sector's collaborations focused heavily on academia and the Federal Government, except in engineering and technology, where nearly one-third of cross-sector articles were coauthored with industry researchers. (See appendix table 6-52.)

Academic scientists had strong collaborative ties with industry in physics, chemistry, mathematics, and engineering and technology (ranging from 31 to 55 percent of academic cross-sector collaborations in these fields). More than half of academia's cross-sector articles in biology had Federal Government authors, while collaboration with nonprofit institutions was heavy in clinical medicine and biomedical research (44 and 38 percent, respectively), in the social and behavioral sciences (48 and 42 percent, respectively), and in the health and professional fields (37 percent). In the physical sciences, academic collaboration with authors in university-managed FFRDCs was pronounced. (See appendix table 6-52.)

Citations

In their articles, scientists cite prior research on which their own work builds. These citations, aggregated by field and sector, provide a rough indicator of the use of these articles by researchers working in different sectors.

The distribution of citations to U.S. scientific and technical articles largely—but not entirely—reflects that of the articles themselves, with the bulk of citations going to academic papers. Citation to same-sector articles generally exceeded sector shares, only somewhat for the dominant academic publishing sector, three- to fourfold for most other sectors, tenfold for articles from FFRDCs. The share of citations from each of these sectors to academic publications grew over the decade. (See appendix table 6-53.)

The academic sector received 72 percent of all 1994–97 U.S. citations. Its share of citations in chemistry, engineering

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[60] Throughout the chapter, coauthorship refers to *corporate* coauthorship: that is, joint authors with different institutional affiliations. See sidebar, "Data Sources for Article Outputs," above.

and technology, and the social sciences exceeded the sector's share of U.S. articles in these fields.[61] Differences between academic article and citation shares in other fields were generally minor. For other sectors and fields, the relative citation volume was generally what would be expected on the basis of output shares. Exceptions were higher-than-expected biomedical research citations to nonprofit sector publications, and lower-than-expected citation frequency of industrial articles in chemistry and engineering and technology. (See appendix tables 6-50 and 6-53.)

Care must be taken to avoid misinterpretation of these differences: they are not indicators of quality differentials. In ongoing research, basic research will tend to be cited with relatively greater frequency than applied research. To the extent that industry articles tend to be less basic than those from academia, the comparison of article output and citation shares is a very rough one indeed.

Linkages Among Disciplines

Research on many challenging scientific problems draws on knowledge and perspectives of a multitude of disciplines and specialties. Citations in scientific and technical articles that cross disciplinary boundaries are one indicator of the multidisciplinary nature of the conduct of research. Of course, frequency of citations only hints at how essential a particular piece of work was to the research being reported. The indicator used here is relatively weak, because of its reliance on a journals-based field classification. Data for other, stronger indicators of multidisciplinary research activities are not readily available: collaboration of researchers across disciplinary boundaries, multidisciplinary centers, and major multidisciplinary projects—for example, global climate research—lack readily available representative data. Nevertheless, cross-disciplinary citations do provide an insight into connections among major fields and fine fields. They demonstrate the relevance to progress in a given field of advances in a range of other fields.

Citations in U.S. articles published in 1997 were aggregated by field.[62] There were approximately 1.3 million such references: 71 percent to the life sciences; 22 percent to mathematics, the physical, and earth and space sciences combined; 5 percent to the social and behavioral sciences and related health and professional fields combined, and just under 2 percent to engineering. (See appendix table 6-54.)

The distribution of citations across broad fields shows the expected concentration of references to articles in the same broad field. Biology and engineering have the lowest rates of self-citation (in this broad-field sense): 62 percent each. Physics and the earth and space sciences have the highest rates: 82 and 83 percent, respectively. Citations in life sciences articles—biology, biomedical research, and clinical medicine—were particularly heavily focused on these three fields: 92 percent of all citations in biology, 97 percent of those in biomedical research, and 98 percent of those in clinical medicine were to articles in the life sciences. A greater proportion of citations in the other sciences and engineering focus on the life sciences fields than vice versa. (See appendix table 6-54.)

Examination of fine fields generally underscores the tight connection among the life science fields, but also reveals the strength of their connections which extend into other fields. For example, one-fifth of all citations in marine and hydrobiology are to fields outside the life sciences, particularly to earth and space sciences and physical sciences. In clinical medicine, nearly one-fifth of the citations found in articles on addictive diseases are to articles in the behavioral and social sciences and related health and professional fields. Especially strong links to fields outside the life sciences also characterize agricultural and food sciences, ecology, biomedical engineering, biophysics, microscopy, pharmacy, and environmental and occupational health.

Citations for the physical and earth and space sciences show strong links to other physical science fields, engineering, and especially to biomedical research. The social and behavioral sciences are linked among themselves but also to specific areas in clinical medicine, biomedical research, and biology. (See appendix table 6-54.)

International Article Production: Counts, Collaboration, and Citations

The world's key scientific and technical journals exercise a degree of quality control by requiring articles submitted for publication to undergo peer review. Thus, the volume of different countries' articles in these peer-reviewed journals is a rough indicator of their level of participation in the international S&T arena. In addition, the distribution of their articles across fields reveals national research foci.[63]

Worldwide publication of scientific and technical articles averaged about 515,700 per year during 1995–97, a 12 percent increase over the 1986–88 period.[64] The largest category, clinical medicine, accounted for 29 percent of the total, about the same as for physics and chemistry combined; biomedical research (15 percent), biology, and engineering and technology (7 percent each) accounted for the bulk of the remainder. (See figure 6-32 and appendix table 6-55.) Note that this field distribution differs from that of the United States shown in figure 6-31—it is lower in the life sciences areas and distinctly higher in physics and chemistry.

Over the 1995–97 period, five nations produced approximately 62 percent of the articles published in the 1985 SCI set of journals: the United States (34 percent), Japan (9 per-

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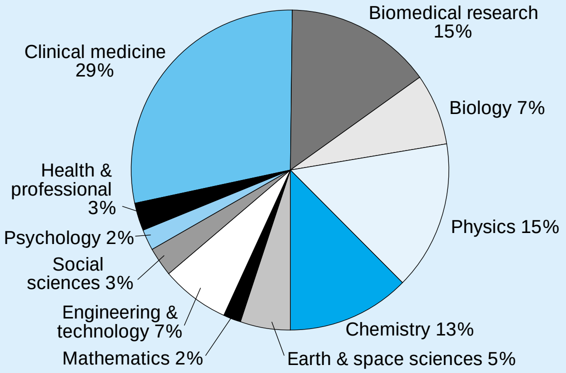
[61] The comparison made here is based on the 1989–94 publications data in appendix table 6-50.

[62] Specifically, citations in 1997 U.S. articles covered in the ISI Science and Social Science Citation Indexes to articles published in 1993–95.

[63] The numbers reported here are based on the 1985 ISI set of core journals, to facilitate comparisons over the countries. Counts are fractional: an article with multinational authors is assigned to the participating countries in proportion to their share of authors. Percentages reflect fractional counts. 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 sidebar, "Data Sources for Article Outputs" in this chapter.

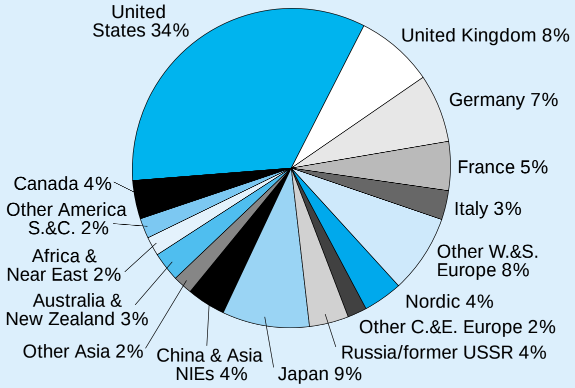
[64] This is a minimum estimate: an expanded 1991 journal set yields a slightly higher growth rate for the 1990s.

Figure 6-32.
Distribution of the world's scientific and technical articles, by field: 1995–97



See appendix table 6-55. *Science & Engineering Indicators – 2000*

Figure 6-33.
Distribution of the world's scientific and technical articles in major journals, by region/country: 1995–97



NIE = newly industrialized Asian economics

See appendix table 6-56. *Science & Engineering Indicators – 2000*

cent), the United Kingdom (8 percent), Germany (7 percent), and France (5 percent).[65] No other country's output reached 5 percent of the total. (See figure 6-33.) These countries possess relatively large and wealthy economies, extensive scientific and technical infrastructure, and large pools of scientists and engineers,[66] which undergird their continuing large share of the world's scientific and technical publications (as captured in the ISI database). Nevertheless, the five countries' collective proportion of the world's article output declined slightly over the past decade, from 64 percent in 1986–88 (and from 38 percent for the United States). This trend reflected the development or strengthening of scientific capabilities in several countries and world regions—in Asia and Southern Europe—following the end of the Cold War. (See appendix table 6-56.)

Over the last decade, the article share of Western and Southern European countries rose from 31 to 35 percent, reaching a level similar to that of the United States. It is likely that these gains reflect, at least in part, these nations' concerted policies to strengthen the science base in individual countries and across Europe as a whole.[67] The article volume of the Central European states as a group—Bulgaria, the Czech Republic, Hungary, Poland, Romania, and Slovakia—declined somewhat through the early 1990s, but by 1995–97 it had rebounded to 10,400 articles, slightly above its 1986–88 level. In contrast, the output for the nations of the former Soviet Union declined during the 1990s, dropping from about 31,200 in 1986–88 to 26,600 in 1992–94 and further to 22,200 in the 1995–97 period. This numerical decrease led to a decline in world share from 7 to 4 percent; especially sharp drops occurred in clinical medicine and biomedical research. The ongoing decline in these countries' output during the 1990s points to continuing difficulties that affect their scientific activity. (See appendix tables 6-55 and 6-56.) These trends roughly parallel those in R&D spending in the region (see chapter 2), especially in Russia, which experienced large decreases over the period.

Recent economic problems notwithstanding, Asia has emerged as a potent high-technology region.[68] Its output of scientific and technical articles in refereed journals grew rapidly over the past decade, providing evidence of a robustly developing indigenous S&E base. From 1986–88 to 1995–97, the Asian nations' world share of publications rose from 11 to 14 percent, amid contradictory trends. Japan's output rose 35 percent, while China's more than doubled; that of the four newly industrialized Southeast Asian economies—Taiwan, South Korea, Singapore, and Hong Kong—more than quadrupled, accounting for more than one-third of the continent's entire net increase. However, India's output continued to decrease, a matter of concern to that nation.[69] (See appendix tables 6-55 and 6-56.)

The conduct of research reflected in these article outputs requires financial, physical, and human resources. The empirical relationship between the size of a nation's

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[65] Totals do not add because of rounding.

[66] Also see chapter 2, "U.S. and International Research and Development: Funds and Alliances"; chapter 4, "Higher Education in Science and Engineering"; and chapter 7, "Industry, Technology, and the Global Marketplace."

[67] These include five-year Framework Programmes of the European Union (EU), EU funding provided through Structural Funds, Community Initiatives Programmes, and efforts outside the EU framework such as EUREKA, a program to stimulate industry-university-research institutes partnerships. See NSF (1996b) for a brief discussion, European Commission (1997) for a fuller treatment.

[68] See NSF (1993 and 1995a). Also see chapter 2, "U.S. and International Research and Development: Funds and Alliances"; chapter 4, "Higher Education in Science and Engineering"; and chapter 7, "Industry, Technology, and the Global Marketplace."

[69] See Raghuram and Madhavi (1996). 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 Indian articles. They speculate that an aging scientific workforce may be implicated, along with a "brain drain" of young Indian scientists whose articles would be counted in the countries in which they reside, not in their country of origin.

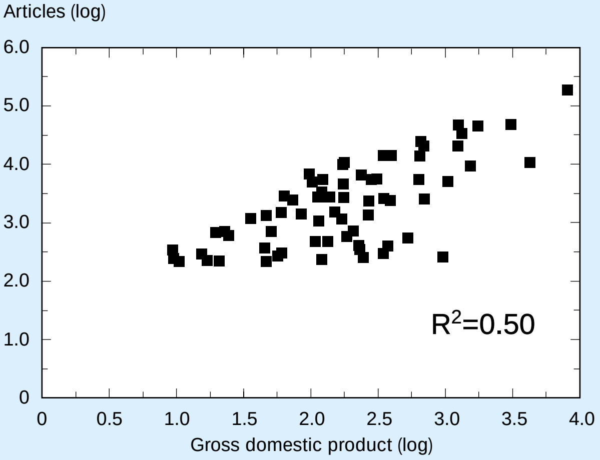
economy—its gross domestic product (GDP)—and its article output volume is moderately high.[70] (See figure 6-34.) Clearly, however, some countries produce output well in excess of what would be expected, based on raw economic size. (See appendix table 6-57.) For example, Israel, the Nordic countries, Switzerland, and New Zealand rank particularly high; the United States is in the middle range. Nations with fast-developing economies tend to have smaller-than-expected article outputs, based on their estimated GDPs.

The Science and Technology Portfolios of Nations

Nations make implicit or explicit choices about the nature of their science and technology portfolios through the allocation of resources; the results of these choices are roughly reflected in their article output data. It is clear that different nations have very different choice patterns, and also that these patterns can—and do—change over time.[71] (See appendix table 6-58.)

Figure 6-35 shows the 1995–97 portfolio mix of selected countries, arrayed by the fraction of their total output devoted to the life sciences (which account for about half of these articles worldwide). The differences in emphasis are striking. Europe's Nordic countries and many of Western Europe's smaller nations heavily emphasize the life sciences.

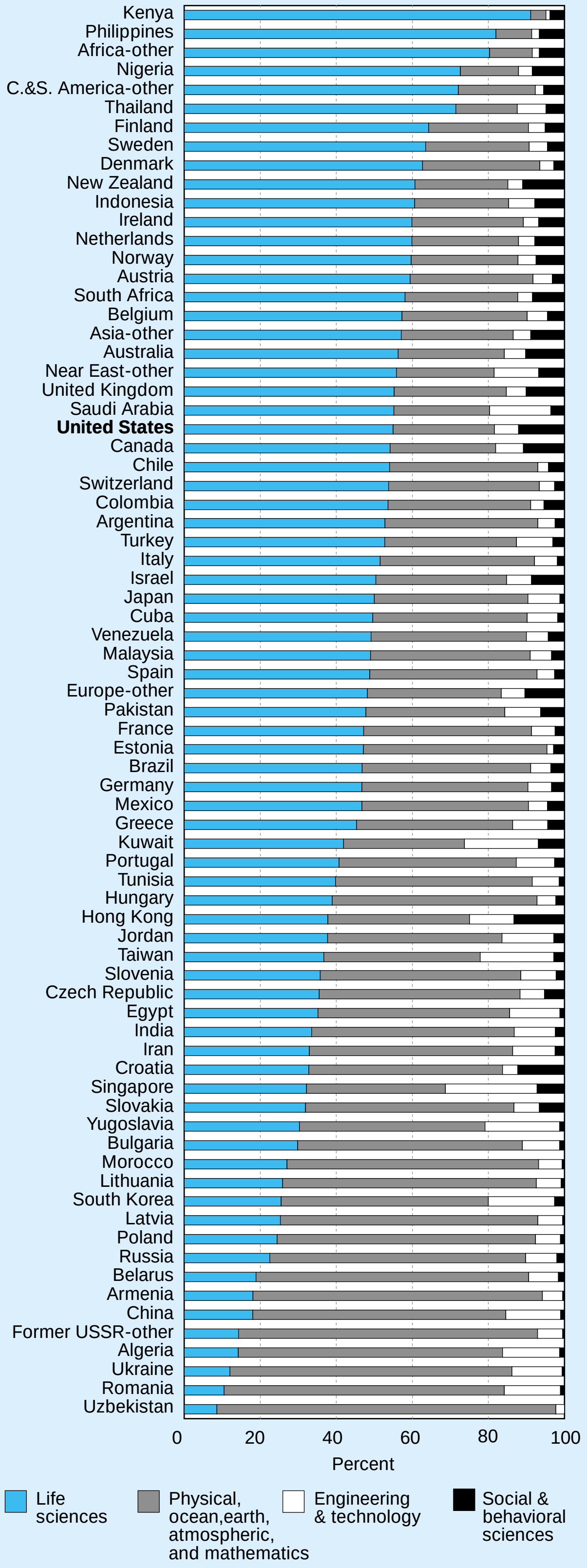
Figure 6-34.
Relationship of volume of scientific and technical articles to gross domestic product for selected countries: 1997



NOTE: Pearson correlation coefficient based on log-normalized article counts and gross domestic product.

See appendix table 6-57. *Science & Engineering Indicators – 2000*

Figure 6-35.
Distribution of selected countries' scientific and technical articles, by aggregated fields: 1995–97



See appendix table 6-58. *Science & Engineering Indicators – 2000*

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[70] The correlation of a nation's estimated GDP and number of articles in the ISI database produces an r^2 of 0.50. Because both GDP and number of articles are highly unevenly distributed, their logarithms have been used in this calculation.

[71] See also the discussion in chapter 4, "International Comparison of First University Degrees in S&E," on the field distributions of S&E degrees of various nations.

China and Asia's newly industrializing economies emphasize the physical sciences and engineering and technology. The focus of Central and Eastern European nations and states of the former Soviet Union—reflecting historical patterns—rests heavily on the physical sciences. The world's biggest article-producing nations fall along a broad middle range: the United States, Canada, and the United Kingdom with slightly greater-than-average weight on the life sciences, Italy and Japan near the world average, and France and Germany weighted somewhat more toward the physical sciences. (See figure 6-35.)

Countries may shift the focus of their scientific activities. (See appendix table 6-59.) Since 1986–88, a large number of countries have increased their relative emphasis on physics while to some extent shrinking the shares of clinical medicine and, to a lesser extent, the other life sciences fields. Note that declining shares resulted sometimes, but not always, from falling absolute numbers of publications; in other instances, they reflected differential growth patterns. Perhaps not surprisingly, nations with long-established, large S&T systems exhibited greater stability in the field distribution of their articles than developing nations. Two things must be noted, however. First, the field designations used here are very broad, possibly obscuring larger changes even in the highly developed nations' portfolios. Second, moderate numerical shifts in low-volume countries' outputs can result in relatively large percentage changes across fields.

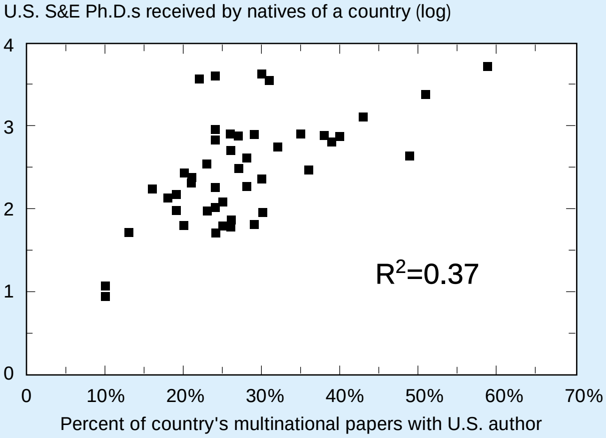
International Scientific Collaboration

Cutting-edge science in many fields increasingly involves a broad range of knowledge, perspectives, and techniques that extend beyond a given discipline or institution. This has generated increasing collaboration across disciplinary and institutional boundaries. Moreover, the scope, cost, and complexity of some of today's scientific problems (for example, mapping the human genome, constructing a coordinated array of widely spaced detection devices, or studying global environmental trends) invite—often even compel—international collaboration. In addition, developments in information technology reduce some of the geographic barriers to collaboration. For established scientific nations, this offers various benefits, including cost savings, the potential for faster progress, the application of different approaches to a problem, and the ability to stay abreast of information developed elsewhere. For nations with smaller or less-developed science and technology systems, it is a means of boosting the capabilities of their indigenous S&T base.

The past decade was marked by vigorous increases in international collaboration, as indicated by multicountry authors of scientific and technical articles. This phenomenon can be observed for every field and for most countries. From 1986–88 to 1995–97, the total number of articles in the ISI databases increased by 12 percent; coauthored papers rose by 46 percent (from an average of 177,100 to 258,500); and internationally coauthored articles increased by almost 115 percent (from 35,700 to 76,200). In 1995–97, half of the world's papers were coauthored (in the multi-institution sense), and 15 percent (30 percent of all coauthored articles) were written by international teams.[72] (See appendix table 6-60.) A web of intergovernmental agreements has developed that invites or requires multinational participation in some research activities. But the rise in international collaboration also appears to reflect the extent of advanced training students receive outside their native countries.[73] Figure 6-36 displays this relationship for the United States.

The incidence of coauthorship varied by field. In the United States in 1995–97, an average of 57 percent of all articles were coauthored. Clinical medicine was well above that with 66 percent; chemistry, engineering and technology, biology, mathematics, and the social and behavioral sciences had lower rates. (See appendix table 6-60.) Similar patterns are evident in many countries, suggesting field-specific publishing behaviors. In *international* collaboration, physics and earth and space sciences rank especially high; for some countries, mathematics also well exceeds the average, for others, biomedical research.

Figure 6-36.
Relationship of volume of U.S.-coauthored multinational articles to U.S. S&E Ph.D.s received by natives of foreign authors' countries



NOTE: Articles published in 1991–95; Ph.D.s awarded in 1986–90.

SOURCES: Articles: Institute for Scientific Information, Science and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, special tabulation. Ph.D.s: National Science Foundation, Survey of Earned Doctorates.

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[72] The international coauthorship percentage for the world's papers appears low—15 percent—when compared to that of most individual countries, due to a counting artifact. *National* rates are based on total counts: each collaborating country is assigned one paper—that is, a paper with three international coauthors may contribute to the international coauthorship of three countries. However, for the world category, each internationally coauthored paper is counted only once. (In 1997, an average of 2.22 countries were involved in each internationally coauthored paper.)

[73] See chapter 4, "Higher Education in Science and Engineering."

Who Collaborates With Whom?

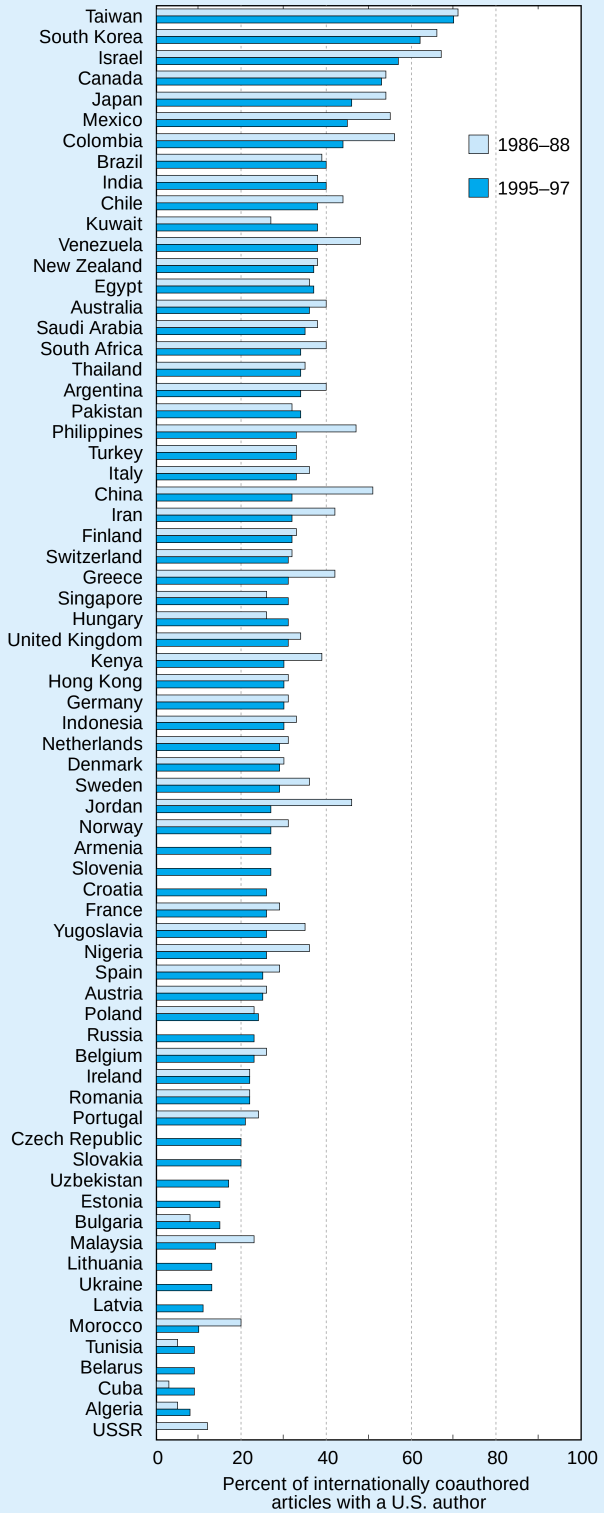
Patterns of international coauthorship provide one indicator of the extent of collaborative ties among nations. By this indicator, the United States' position in international collaboration was characterized by two trends:

- From 1986–88 to 1995–97, most nations had increasing *numbers* of articles with at least one U.S. author.
- But the U.S. *share* of all their internationally coauthored articles declined.[74]

International scientific collaboration, as measured by the percentage of a country's multi-author articles involving international coauthorship, centers to a considerable degree on the United States. (See figure 6-37.) Worldwide, 44 percent of all internationally coauthored papers published in 1995–97 had at least one U.S. author. In that period, with few exceptions, from 25 to 33 percent of European countries' internationally coauthored papers involved collaboration with the United States.[75] For major science-producing Asian nations, coauthorship with U.S. researchers ranked higher. Japan and India—both nations with relatively low overall rates of international collaboration—shared 46 and 40 percent, respectively, of their internationally coauthored articles with United States researchers. Collaboration rates of other major article-producing Asian nations with the United States ranged from a high of 70 percent for Taiwan to a low of 31 percent for Singapore. China's rate was 33 percent (30 percent for Hong Kong)—but down sharply from 51 percent a decade earlier. For major South and Central American countries, rates ranged from 34 to 46 percent. The countries of Central Europe (except Hungary) and, especially, those of the former Soviet Union had lower rates of collaboration with the United States. (See appendix table 6-61.[76])

Comparison of these data with 1986–88 shows that, for most nations, the number of papers authored collaboratively with U.S. researchers rose strongly over the decade; however, the U.S. share of internationally coauthored articles declined from 51 to 44 percent of the world's total. This pattern—rising numbers of U.S. coauthored articles accompanied by declining U.S. shares—held for most countries, as they broadened the range of their international partnerships. In general, the higher the initial degree of collaboration with the United States, the greater the U.S. drop in collaboration share ($r^2 = 0.26$). Some examples (in percentage point terms): China, 19 percentage points; Israel and Mexico, 10 percentage points each; Japan, 8 percentage points; and 6 percentage points each for Chile and Argentina. (See appendix table 6-61.) These

Figure 6-37.
Percentage of internationally coauthored articles involving one or more U.S. authors for selected countries: 1986–88 and 1995–97



SOURCE: Institute for Scientific Information, Science and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; NSF, special tabulation

See appendix table 6-61. *Science & Engineering Indicators – 2000*

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[74] The first data column in appendix table 6-61 provides the percentages that U.S.-coauthored articles represent in a given country's internationally coauthored papers.

[75] These percentages are based on total article counts: a paper with one author each in two countries is counted as one article in each of the countries.

[76] The table is read as follows: The distribution of a given country's international collaborations with others is read along the rows. The prominence of a given country's coauthors in other countries' literatures is read down the columns.

data suggest that new centers of activity and patterns of collaboration are evolving.

In the Asian region, the main trend indicates the development of regional collaborative patterns involving—especially—China and the newly industrialized economies. Overall, intraregional collaboration increased from 15 percent of all Asian foreign collaborations in the late 1980s to 24 percent a decade later. Regional collaboration rates—measured by the proportion of internationally coauthored articles published in 1986–88 and 1995–97 with an author from another Asian country—are shown in text table 6-7.

Text table 6-7 shows large increases in the overall number of articles, and of internationally coauthored articles, for a number of Asian countries, along with a rise in intra-Asian collaboration. For China, intra-Asian collaboration rose from 16 to 35 percent of its internationally coauthored papers (for Hong Kong from 25 to 47 percent) and for Singapore from 19 to 37 percent. However, regional collaboration remained relatively low for Japan, India, and Pakistan—12–15 percent of their internationally coauthored articles. Intra-Asian collaboration of Taiwan and South Korea—21 and 29 percent, respectively—was hardly changed since the mid-1980s.

Intraregional ties among the Central European states remain modest; in 1995–97 they shared 5 to 15 percent of their internationally coauthored articles. The bulk of their collaborations—roughly half for most nations—were with countries in the north, west, and south of Europe. Ties to the countries of the former USSR generally dwindled during the 1990s. Collaboration with U.S. scientists ranged from 14 to 27 percent and 31 percent for Hungary. (See appendix table 6-61.)

The collaborative ties of most countries of the former Soviet Union centered on Russia, Germany, and the United States. Almost one-half of Russia's coauthorships were with Germany and the United States, split evenly. Other major former constituent states—Ukraine, Belarus, Uzbekistan, and Armenia—shared 26–43 percent of their collaborations with Russia, and similarly large fractions with Germany and the United States combined. The Baltic nations have lower collaborative ties with Russia—11–17 percent. They have developed strong collaborative ties to the Nordic states, in particular to Finland and Sweden, reflecting the reestablishment of historical cultural and regional ties. (See appendix table 6-61.)

United States researchers partner with authors in a very large number of countries. In 1995–97, they collaborated with colleagues in more than 170 nations. German researchers were coauthors of 13 percent of U.S. internationally coauthored articles, and investigators from Canada and the United Kingdom of 12 percent each. Seven to 10 percent had authors from Japan, France, and Italy, respectively. The Netherlands, Switzerland, Israel, and Australia, with about 4 percent each, rounded out the top 10 collaborating nations.

The scope of different countries' collaborative ties with other nations can be seen in text table 6-8. It shows the total number of countries with any collaborating nondomestic author on a given nation's papers. The table reveals a dramatic expansion of cross-national collaboration over a mere decade. Virtually all countries expanded the number of nations with which they have some coauthorship ties, and a number of Asian nations more than doubled them.

Figure 6-38 shows the number of countries which shared at least one percent of their internationally coauthored articles with a given nation. The sharp drop-off in number of countries illustrates the practice of nations with relatively restricted S&T establishments to concentrate their collaborations in a relatively few countries. These smaller countries also tend to have higher levels of international coauthorship, as a percentage of their total article output, than do those with larger,

Text table 6-7.
Intra-Asian research collaboration—coauthorships among Asian countries: 1986–88 and 1995–97

	Number of articles		Internationally coauthored		Intra-Asia coauthored	
	1986–88 (sum)	1995–97 (sum)	1986–88 (sum)	1995–97 (sum)	1986-88 (sum)	1995–97 (sum)
Japan	101,553	142,548	8,259	21,608	1,009	3,308
China	11,480	27,706	2,626	7,982	415	2,808
Hong Kong	1,518	6,741	333	2,694	83	1,253
South Korea	2,338	14,091	686	3,892	191	1,139
India	29,492	28,520	2,791	4,473	244	684
Taiwan	3,807	15,874	754	2,813	157	599
Singapore	1,344	3,874	318	1,147	62	423
Thailand	1,019	1,552	493	976	134	381
Indonesia	328	732	215	631	57	277
Malaysia	722	1,292	249	554	70	270
Philippines	542	695	247	454	96	219
Pakistan	695	998	237	420	22	49

NOTE: Internationally coauthored articles with authors from at least two Asian countries. Papers are counted in each author's country.

SOURCES: Institute for Scientific Information, Science Citation Index and Social Science Citation Index; CHI Research, Inc., Science Indicators database; and National Science Foundation, special tabulation.

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Text table 6-8.
Breadth of international coauthorship ties for selected countries: 1986–88 and 1995–97

Country	Number of countries	
	1986–88	1995–97
United States	142	173
United Kingdom	121	163
France	116	157
Germany	116	147
Canada	101	136
Netherlands	88	133
Switzerland	92	131
Italy	94	128
Belgium	81	128
Sweden	90	127
Japan	80	127
Australia	84	126
Spain	62	118
Brazil	66	114
Denmark	73	111
India	87	109
China	54	107
South Africa	58	100
Austria	58	99
Israel	58	98
Norway	53	96
Finland	58	94
Thailand	49	94
Mexico	54	89
Hungary	54	89
Poland	57	86
Turkey	31	85
Egypt	63	85
Indonesia	39	84
New Zealand	57	83
South Korea	33	83
Hong Kong	35	82
Kenya	52	81
Nigeria	57	77
Argentina	47	77
Malaysia	32	76
Chile	42	76
Ireland	47	76
Philippines	44	75
Greece	47	75
Saudi Arabia	40	75
Colombia	32	72
Portugal	35	71
Morocco	30	70
Bulgaria	38	70
Romania	38	69
Taiwan	34	67
Singapore	42	65
Venezuela	37	60
Algeria	24	59
Kuwait	36	57
Cuba	29	56
Pakistan	40	53
Iran	23	49
Tunisia	21	48
Jordan	22	46
Czechoslovakia	49	NA
Czech Republic	na	90
Slovakia	na	68
USSR	61	NA
Russia	na	106
Ukraine	na	70
Belarus	na	55
Armenia	na	46
Lithuania	na	46
Estonia	na	45
Latvia	na	37
Yugoslavia	56	60
Slovenia	na	67
Croatia	na	58

NA = not applicable; na = not available

NOTE: Number of countries with which country indicated shares any coauthored articles. Countries of the former Soviet bloc and Yugoslavia shown at end of table.

SOURCES: Institute for Scientific Information, Science Citation and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, special tabulations.

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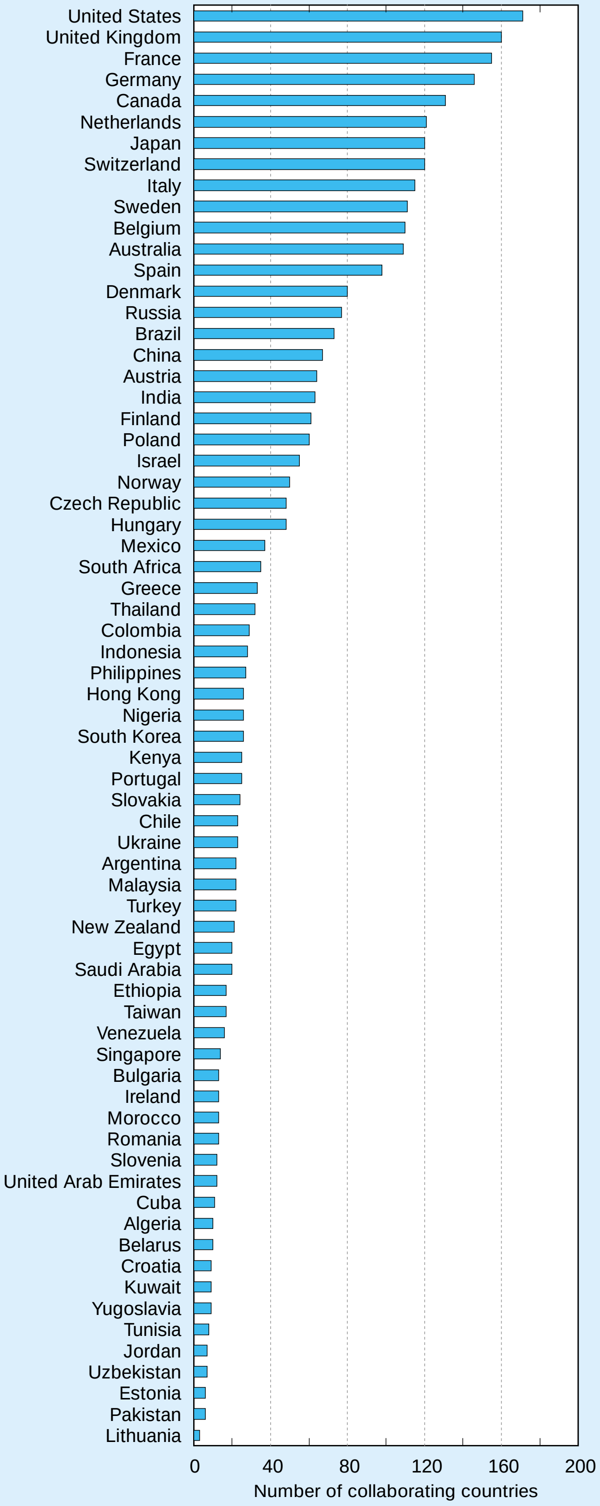
more mature systems. Rather than collaborating regionally, scientists from developing nations tend to work with those from major science-producing nations—in part based on student-mentor ties, as illustrated earlier by figure 6-36 for the United States.

International Citations to Scientific and Technical Articles

The global dimensions of the conduct of scientific activity, discussed above in terms of international research collaboration, are also reflected in the patterns of citations to the literature. Scientists and engineers around the world cite prior work done elsewhere to a considerable extent, thus acknowledging the usefulness of this output for their own work. Citations to one's own country's work are generally prominent and show less of a time lag than citations to foreign outputs. Regional citation patterns are evident as well, but citations to research outputs from around the world are extensive. Citations, aggregated here by country and field, thus provide an indicator of the perceived utility of a nation's science outputs in other countries' scientific and technical work. The discussion will cover:

- the high and rising proportion of citations to nondomestic publications; and
- the status of U.S. science—as indicated by citations to it—in the context of other countries' total citations to nondomestic articles.

Figure 6-38.
Number of countries which shared at least one percent of their internationally coauthored articles with nation indicated: 1995–97



SOURCE: Institute for Scientific Information, Science Citation Index; CHI Research, Science Indicators database; NSF, special tabulation.

See appendix table 6-61. *Science & Engineering Indicators – 2000*

The international nature of scientific research is underscored by the high volume of citations to work done abroad. Averaged across all countries and fields, close to 60 percent of all citations in 1997 were to foreign research. This average had stood at 53 percent only 7 years earlier, a rather rapid rate of change. The increases could be seen for most countries and most fields. The world averages include the relatively lower rate of foreign citations found in U.S. papers, which in turn reflects the very large U.S. share of total world article output. (See beginning of "International Article Production: Counts, Collaboration, and Citations," above.) Many other countries, especially those with small indigenous science establishments, cited foreign works with higher frequency than these averages would indicate. (See appendix table 6-62.)

Particularly high rates of foreign citations were found in physics, a field noted for its high rate of international collaboration. In contrast, foreign citation rates of articles in engineering and technology and the social and behavioral sciences were well below the average, reflecting greater reliance on domestic research. (See appendix table 6-62.)

In a number of Asian countries, declines were registered in the share of citations to foreign sources overall. This was accompanied by a rise in citations to the scientific and technical literatures of other Asian nations. Intraregional citations increased from 6 percent of all references to nondomestic articles to 9 percent in less than a decade, from 1990 to 1997. As noted previously (see "Who Collaborates With Whom?" above), regional collaboration in Asia has been expanding over the period, from 13 percent to 18 percent of all Asian foreign collaborations. Seen in this light, these citation data point to continued growth of a more broad-based regional science capacity. (See appendix table 6-62.)

Citations to the U.S. literature in other nations' scientific and technical articles nearly always exceed the volume of citations to domestic research. (See Figure 6-39.) In most developed nations, such citations also run above the U.S. world article share. They drop below that mark for developing nations and for the former Soviet Bloc states, where access may be an issue.

Eliminating from consideration all countries' citations to their domestic articles adjusts for the well-documented tendency to favor domestic literature.[77] From the menu of available world science (not their own), to what extent do researchers in these nations select U.S. articles to read and cite? The proportion of U.S. articles among all citations to nondomestic literatures is very high and in most instances exceeds the U.S. share of world articles. (See figure 6-40.) For example, the U.S. article share in physics has declined from 28 to 22 percent since 1990, and the citations share (the average in all other countries' nondomestic citations) has dropped from 49 to 39 percent over the same period. (See text table 6-9.) However, after an approximate allowance is

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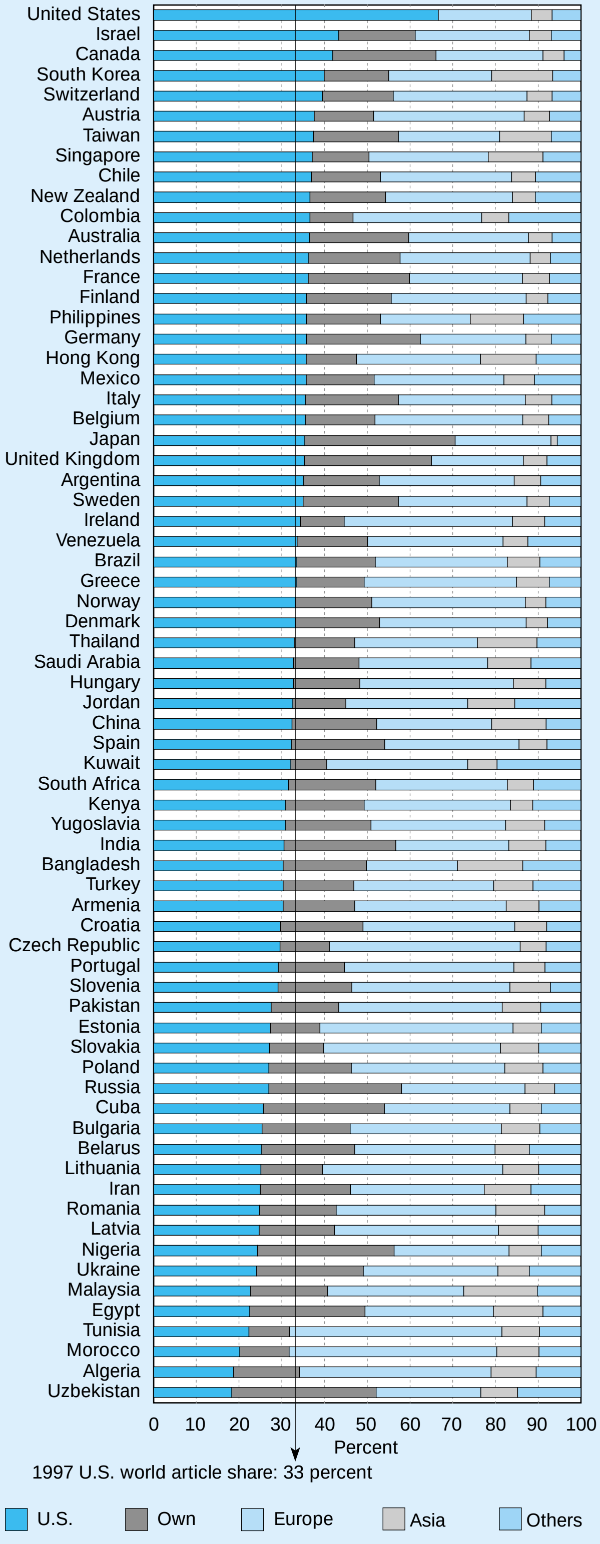
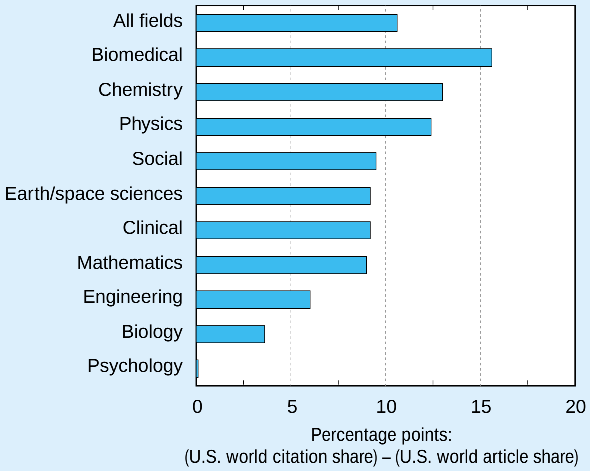
[77] After summing all countries' (except the United States') citations to nondomestic articles and calculating what percentage of these refer to U.S. articles, this percentage is compared to the U.S. world article share.

Figure 6-39.
Citations in selected countries' scientific and technical literature to U.S., own, and major regions' articles: 1997



See appendix table 6-61. *Science & Engineering Indicators – 2000*

Figure 6-40.
Citations to U.S. research in other nations' scientific and technical articles, relative to U.S. world article shares, by field



NOTE: Plotted values are the difference between the 1993 U.S. share of the world literature and the 1997 U.S. share of other nations' citations to foreign literature. For example, foreign citations to U.S. mathematics articles are about 9 percentage points higher than would be expected on the basis of the U.S. article share in the field.

SOURCE: Institute for Scientific Information, Science and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; NSF, special tabulation.

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made for time lags between publication and citation—here by comparing the 1997 citations share (39 percent) with the 1993 article share (27 percent)—U.S. physics articles remain cited well above the share expected based on article volume alone. (See appendix table 6-63.)

Citations on U.S. Patents to the Scientific and Technical Literature

Patent applications cite "prior art" that contributes materially to the product or process to be patented. Citations to such prior art have traditionally been to other patents; increasingly, these citations include scientific and technical articles. The percentage of U.S. patents which cited at least one such article increased from 11 percent in 1985 to 14 percent in 1990 and 25 percent in 1996.[78] This development attests to both the growing closeness of some research areas to practical applications and an increasing willingness of the U.S. Patent and Trademark Office (PTO) to award upstream patents. Thus, citations of scientific and technical articles on patents provide a good indicator of the growing linkage between research and innovative application, as judged by the patent applicant and recognized by PTO.[79]

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[78] Personal communication with Francis Narin, CHI Research, Inc., and National Science Board (1998).

Text table 6-9.
Citations to foreign articles in the world's major scientific and technical journals, by field: 1990–97

	Citations to foreign articles (percent)			Citations to U.S. articles (percent of foreign citations)			U.S. share of articles (percent of world total)		
Field	1990	1993	1997	1990	1993	1997	1990	1993	1997
All fields	53	56	59	52	50	47	37	36	33
Physics	58	63	64	49	44	39	28	27	22
Chemistry	54	57	60	40	39	36	22	23	20
Earth/space sciences	52	54	58	53	51	49	39	40	36
Mathematics	50	53	56	50	50	47	41	38	32
Biology	50	53	57	42	42	37	37	33	30
Biomedical research	54	57	59	57	56	55	39	39	38
Clinical medicine	55	57	61	52	50	48	39	39	36
Engineering/technology	47	51	55	48	46	40	38	34	29
Psychology	37	38	42	66	63	58	60	58	55
Social sciences	33	35	40	66	64	62	55	53	49
Health/professional fields	23	25	31	71	68	65	70	69	63

NOTES: Citations are for a three-year period with a two-year lag; for example, 1997 citations are to 1993–95 articles. Foreign citations exclude those in U.S. journals.

SOURCES: Institute for Scientific Information, Science Citation and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, special tabulation. *Science & Engineering Indicators – 2000*

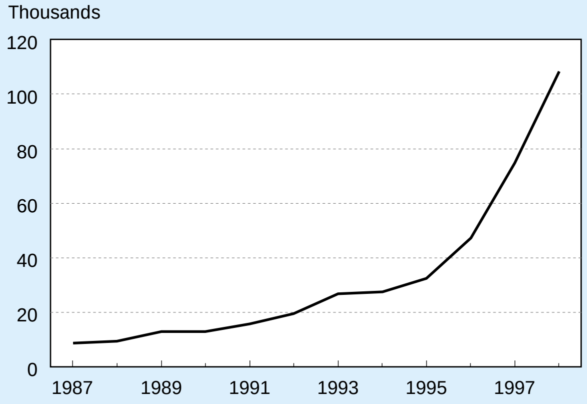
Citations to U.S. research articles included in the SCI set of journals were identified and classified by field and performer sector for all U.S. patents issued from 1987 through 1998. The number of such citations stood at 8,600 in 1987, more than doubled over five years, doubled again in less than four years (1996: 47,000), then doubled again in less than two years to reach 108,300 in 1998.[80] (See figure 6-41 and text table 6-10.) The rise in the number of citations held for all fields and for papers from all sectors. (See appendix table 6-64.)

The explosive growth of article citations on patents was rooted in enormous increases in the life sciences: from 2,400 to 55,900 in biomedical research in little more than a decade, and from 2,200 to 33,400 in clinical medicine. Consequently, even as the number of citations increased to articles in every field, the field shares shifted dramatically:

- Biomedical research rose from 28 percent in 1987 to 52 percent in 1998; clinical medicine from 26 to 31 percent.
- The combined share of physics, chemistry, and engineering and technology citations dropped from 43 to 15 percent.

Patent citations to academic articles rose faster than citations to industry or government authors, pushing the academic share of the total from 48 to 54 percent from 1987 to 1998. The academic sector's share of all article citations on patents increased particularly strongly in physics (from 29 to 41 percent), earth and space sciences (40 to 56 percent), and engineering and technology (26 to 46 percent)—fields with stagnating or declining industry article output. (See appendix tables 6-64 and 6-65.)

Figure 6-41.
Number of citations on U.S. patents to scientific and technical articles: 1987–98



NOTE: Changed U.S. Patent and Trademark Office procedures, greater ease of locating scientific and technical articles, and greater incentive to cite them may have contributed to some of these increases.

SOURCE: CHI Research, Inc. Science Indicators and Patent Citations databases; NSF, special tabulation.

See appendix table 6-64. *Science & Engineering Indicators – 2000*

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[79] 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, for example, 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.

[80] Some of the rise may reflect changed U.S. Patent and Trademark Office procedures, greater ease of locating the relevant prior art, and greater incentives to include all possible elements thereof. Nevertheless, the direction and strength of the trends reported here are congruent with those in academic patenting, discussed below. The number of citations reported here refer to articles published in a 12-year span, as follows: 1997 patent citations are to articles published in 1983 to 1994, and so forth.

Text table 6-10.
Number and distribution of citations on U.S. patents to the U.S. scientific and technical literature, by field

Citation year	Total	Physics	Chemistry	Earth & space	Mathematics	Clinical medicine	Biomedical research	Biology	Engineering & technology	All others
Number of citations										
1987	8,618	1,286	1,181	105	0	2,221	2,390	168	1,242	23
1988	9,498	1,595	1,212	81	2	2,423	2,749	220	1,209	5
1989	12,988	2,356	1,536	119	2	3,190	3,976	304	1,458	44
1990	12,936	2,169	1,673	76	3	3,415	3,818	306	1,443	31
1991	15,720	2,424	1,921	123	2	4,205	5,199	437	1,401	4
1992	19,425	2,667	2,451	94	18	5,293	6,945	436	1,492	26
1993	26,721	3,024	3,027	93	21	7,393	10,735	548	1,850	26
1994	27,437	3,589	3,114	122	14	7,215	10,332	677	2,346	25
1995	32,536	3,366	3,689	134	19	9,173	12,719	812	2,593	27
1996	47,142	3,506	4,535	195	25	13,637	20,646	1,349	3,207	36
1997	74,839	4,150	6,218	207	30	22,649	36,397	1,508	3,589	85
1998	108,335	4,719	6,900	285	35	33,437	55,891	2,426	4,452	189
Percent of citations										
1987	100	14.9	13.7	1.2	0.0	25.8	27.7	1.9	14.4	0.3
1988	100	16.8	12.8	0.9	0.0	25.5	28.9	2.3	12.7	0.1
1989	100	18.1	11.8	0.9	0.0	24.6	30.6	2.3	11.2	0.3
1990	100	16.8	12.9	0.6	0.0	26.4	29.5	2.4	11.2	0.2
1991	100	15.4	12.2	0.8	0.0	26.7	33.1	2.8	8.9	0.0
1992	100	13.7	12.6	0.5	0.1	27.2	35.8	2.2	7.7	0.1
1993	100	11.3	11.3	0.3	0.1	27.7	40.2	2.1	6.9	0.1
1994	100	13.1	11.3	0.4	0.1	26.3	37.7	2.5	8.6	0.1
1995	100	10.3	11.3	0.4	0.1	28.2	39.1	2.5	8.0	0.1
1996	100	7.4	9.6	0.4	0.1	28.9	43.8	2.9	6.8	0.1
1997	100	5.5	8.3	0.3	0.0	30.3	48.6	2.0	4.8	0.1
1998	100	4.4	6.4	0.3	0.0	30.9	51.6	2.2	4.1	0.2

NOTE: Count for 1987 patents is of citations to articles published in 1973-84; for 1988 patents to articles published in 1974-85; and so forth.

SOURCES: Institute for Scientific Information's Science Citation and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, special tabulation.

See appendix table 6-64. *Science & Engineering Indicators – 2000*

Examination of the sectoral patterns of patent citations reveals the prominent and growing role of biomedical research in the cited articles from every sector (ranging from 44 to 59 percent of all article citations), accompanied by strong or growing citation of papers in clinical medicine. (See appendix table 6-66.) The composition of citations to academic and industry articles, in particular, illustrates the key role of these areas of inquiry: Only 10 percent of citations to industry articles referred to physics, down from 29 percent a decade earlier. But 71 percent of patent citations to industry articles were to the life sciences, up from less than a quarter.

Further exploration of these trends was undertaken by Narin, Hamilton, and Olivastro.[81] Their study examined the citations on the front sheets of all 397,660 U.S. patents awarded in 1987–88 and 1993–94. While many citations were to other patents, about 430,000 referred to nonpatent materials; 242,000 were judged to be science references. In addition to the rapid increase in article citations on U.S. patents, the authors discovered a shortening interval between publication and citation and a large proportion of citations to publicly funded science (defined by the authors to include articles by academic, nonprofit, and government authors).[82] References tended to be to articles appearing in nationally and internationally recognized, peer-reviewed journals, including journals publishing basic research results, and to be field- and technology-specific.[83] The authors noted both national (U.S. patents citing U.S. authors with greater-than-expected frequency) and regional components in the patterns of citations.

Academic Patenting: Patent Awards, Licenses, Startups, and Revenue

Governments assign property rights to inventors in the form of patents to foster inventive activity that may have important economic benefits. The U.S. Patent and Trademark Office (PTO) grants such government-sanctioned property rights in the form of patents for inventions deemed to be new, useful, and non-obvious. This section discusses recent trends in academic patenting and income from these activities flowing to universities and colleges.[84]

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[81] Narin, Hamilton, and Olivastro (1997).

[82] This latter finding is broadly consistent with results obtained by Mansfield (1991), focusing on academic science only and using a very different study framework and approach.

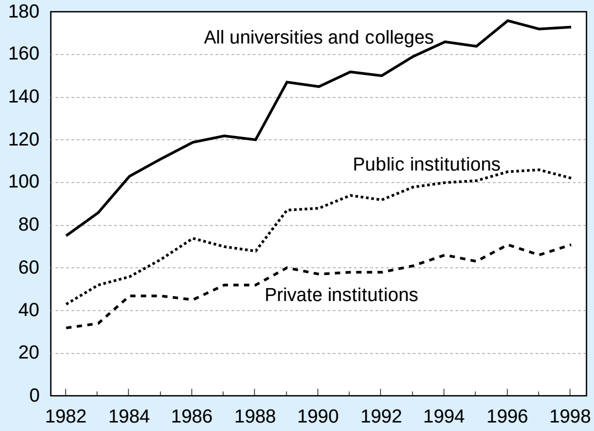
[83] See tables 2 and 3 in Narin, Hamilton, and Olivastro (1997).

Trends in academic patenting provide an indication of the importance of academic research to economic activity, which may well be growing even in the short term. The bulk of academic R&D is basic research, that 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 the U.S. PTO grants patents based on such basic work, especially in the life sciences.

A growing number of academic institutions are applying for, and receiving, protection for results of work conducted under their auspices. After slow growth in the 1970s, the number of academic institutions receiving patents increased rapidly in the 1980s from about 75 early in the decade to double that by 1989 and nearly 175 by 1997. This development, pronounced during the 1980s and more muted in this decade, reflected increases in the number of both public and private institutions receiving patents.[85] (See figure 6-42 and appendix table 6-67.)

Starting in the early 1980s, the number of institutions outside the ranks of the largest research universities (defined here as the top 100 in total R&D expenditures) with patent awards increased at a rapid pace. The Nation's largest research universities represented 64 percent of all academic institutions receiving patents in 1985; their number had fallen to half by 1996.[86] Much of the broadening of the base of patenting institutions occurred among public universities and colleges. (See appendix table 6-67.)

Figure 6-42.
Number of universities and colleges granted patents: 1982–98



NOTE: Numbers are lower-bound estimates because of some systemwide reporting.

See appendix table 6-67. *Science & Engineering Indicators – 2000*

Increasing university patenting and collaboration with industry have given rise to questions about possible unintended consequences—for universities and academic researchers—arising from these developments. Concerns have been expressed about potential distortions of the nature and direction of academic basic research, about contract clauses specifying delays or limitations in the publication of research results, and about the possibility of the suppression of research results for commercial gain. Unsettled questions also arise from faculty members' potentially conflicting economic and professional incentives in such arrangements. Universities as institutions may find themselves in a similarly ambiguous position as they acquire equity interests in commercial enterprises. In addition, scholars have asked whether patenting of government-sponsored research results may not in fact be detrimental to its intended goal of enhancing the transfer of new technologies.[87] These unsettled questions provide the backdrop for the rapidly rising numbers of academic patents.

The expansion of the number of institutions receiving patents coincided with rapid growth in the number of patent awards to academia, which rose from 589 in 1985 to 3,151 in 1998, accelerating rapidly since 1995. By the mid-1980s, the share of patents accounted for by the top 100 R&D-performing universities was about 77 percent of the total, as academic institutions started responding to provisions of the Bayh-Dole Act of 1980.[88] However, since the late 1980s, these large research universities have accounted for over 80 percent of all academic patents, a figure which increased to 89 percent by 1998. (See appendix table 6-67.)

The number of academic patents has risen tenfold, from about 250 annually in the early 1970s to more than 3,100 in 1998 (see figure 6-43), a far more rapid increase than for all annual U.S. patent awards. As a result, academic patents now approach 5 percent of all new U.S-origin patent awards, up from less than one-half of 1 percent two decades ago. The Bayh-Dole Act may have contributed to the strong rise in the 1980s, although university patenting was already on the rise before then. The creation of university technology transfer and patenting units, an increased focus on commercially relevant technologies, and closer ties between research and technological development may have contributed as well. A landmark Supreme Court ruling (Diamond v. Chakrabarty) allowing patentability of genetically-modified life forms may have been a

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[84] Chapter 7 presents a more comprehensive discussion of patented inventions in all U.S. sectors.

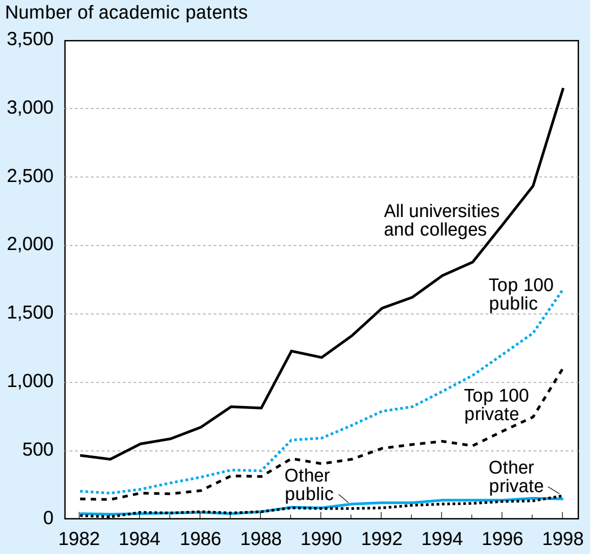
[85] Exact counts are difficult to obtain. Patent assignment depends on university practices which vary and can change with time. Patent assignment may be to boards of regents, individual campuses, subcampus organizations, or entities with or without affiliation with the university. The data presented here have been aggregated consistently by the U.S. Patent and Trademark Office starting in 1982. The institution count is conservative, since a number of university systems are included in the count and medical schools are often counted with their home institutions.

[86] These estimates are understated, since patent awards to some universities—for example, University of California, State University of New York—are generally recorded at the system level. But the trend reported here is calculated on a consistent basis.

[87] See Mazzoleni and Nelson (1998) and Ganz-Brown (1999).

[88] 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. Several empirical studies have recently examined effects of this law. See Henderson, Jaffe, and Trajtenberg (1998); and Mowery, Nelson, Sampart, and Ziedonis (in press)(2000).

Figure 6-43.
Number of academic patents granted: 1982–98



NOTE: The top 100 universities are defined as the institutions reporting the largest total R&D expenditures for 1997. Details do not add to total because of omission in detailed tally of academic patents held by unaffiliated agencies.

See appendix table 6-67. *Science & Engineering Indicators – 2000*

prime stimulus for the recent rapid increases, leading to greater PTO readiness to patent certain basic research outputs.

What is clear is that the vigorous increases in the number of academic patents largely reflect developments in the life sciences and biotechnology.[89] Two key trends in academic patenting are worth noting. First, a heavy concentration is evident in areas connected with the life sciences. Patents in a mere three technology areas or "utility classes"—all with presumed biomedical relevance[90]—accounted for 41 percent of the academic total, up from a mere 13 percent through 1980. (See figure 6-44.) Second, the growth in the number of academic patents was accompanied by a decrease in the number of utility classes in which they fall. In fact, academic patents are concentrated in far fewer application areas than are all U.S. patents. (See appendix table 6-68.)

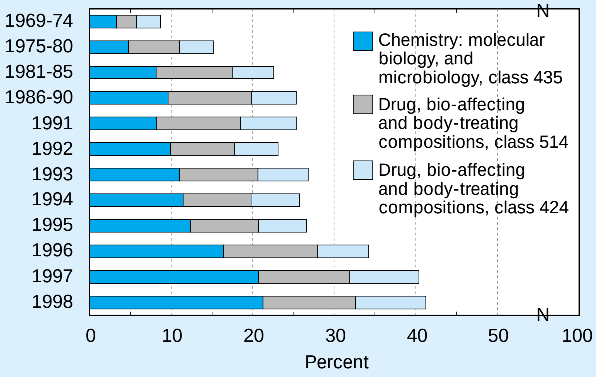
Valuation of patents—especially of science-based ones—is difficult, and there are no guarantees that patents will have any direct economic value. Nevertheless, the motivation behind academic patenting is to protect intellectual property that is deemed valuable by the university, and academic institutions are increasingly successful in negotiating royalty and licensing arrangements based on their patents. While total reported revenue flows from such licensing arrangements remain low, compared to R&D spending, a 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 readiness of entrepreneurs and companies to recognize and invest in the market potential of this research.

A 1992 survey by the U.S. General Accounting Office based on 35 universities found that they had substantially expanded their technology transfer programs during the 1980s. Typical licensees were small U.S. pharmaceutical, biotechnology, and medical businesses. During 1989–90, the reported income flows from these licenses were a mere $82 million. A more extensive survey has been conducted periodically since 1991 by the Association of University Technology Managers (AUTM).[91] The survey initially included only 98 universities, but has been augmented since 1993, with the additional institutions representing a coverage increase from 75 to 82 percent of academic R&D funds, from 85 to 90 percent of Federal academic R&D support, and from 80 to 91 percent of patents issued to academic institutions. (See text table 6-11.)

All indicators shown in this table point to an accelerating use of patenting by the Nation's universities and colleges. The number of new patents, license disclosures, applications filed, startup firms formed, and base of revenue-generating licenses and options are all growing at rapid rates, especially in the last two years shown. Key points are:

- ◆ University income from patenting and licenses is increasing steeply, reaching $483 million in 1997, although relative to academic research expenditures it remains low.
- ◆ About half of total royalties were classified by respondents as being related directly to the life sciences; about one-third was not classified by field; the remainder, labeled "physical sciences," appears to include engineering.

Figure 6-44.
Percentage of total academic patents in three largest academic utility classes: 1969–98, selected years



SOURCE: U.S. Department of Commerce, Patent and Trademark Office, Technology Assessment and Forecast Report, U.S. Universities and Colleges, 1969-98; NSF, special tabulation.

See appendix table 6-68. *Science & Engineering Indicators – 2000*

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[89] See Huttner (1999).

[90] Utility classes 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.

[91] Association of University Technology Managers, Inc. (1998).

Text table 6-11.
Academic patenting and licensing activities

	1991	1992	1993	1994	1995	1996	1997
Finances (millions of dollars)							
Gross royalties	$130.0	$172.4	$242.3	$265.9	$299.1	$365.2	$482.9
New research funding from licenses	NA	NA	NA	$106.3	$112.5	$155.7	$136.2
Royalties paid to others	NA	NA	$19.5	$20.8	$25.6	$28.6	$36.2
Unreimbursed legal fees expended	$19.3	$22.2	$27.8	$27.7	$34.4	$46.5	$55.5
Invention disclosures, patent applications, patents							
Invention disclosures received	4,880	5,700	6,598	6,697	7,427	8,119	9,051
New patent applications filed	1,335	1,608	1,993	2,015	2,373	2,734	3,644
Total new patents received	NA	NA	1,307	1,596	1,550	1,776	2,239
Licenses, options, startup companies							
Startup companies formed	NA	NA	NA	175	169	184	258
Number of revenue-generating licenses, options	2,210	2,809	3,413	3,560	4,272	4,958	5,659
New licenses and options executed	1,079	1,461	1,737	2,049	2,142	2,209	2,707
Equity licenses and options	NA	NA	NA	NA	99	113	203
Survey coverage							
Number of institutions responding	98	98	117	120	127	131	132
Percent of total academic R&D represented	65	68	75	76	78	81	82
Percent of federally funded academic R&D represented	79	82	85	85	85	89	90
Percent of academic patents represented	NA	NA	80	89	82	82	91

NA = not available

NOTE: New research funding from licenses is defined as research funds directly related to signing of a specific license agreement.

SOURCE: Association of University Technology Managers, Inc. (AUTM), *AUTM Licensing Survey, Fiscal Year 1991–Fiscal Year 1997* (Norwalk, CT: 1998).

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- The number of startups and of licenses and options granted increased strongly. Forty-one percent of new licenses and options went to large firms, 48 percent to small existing companies, and 11 percent to startups.

Conclusion

Over the past decade, the academic research and development enterprise has enjoyed strong growth. It continues to perform approximately half of U.S. basic research and is a major contributor to the nation's and the world's stock of scientific knowledge. Such knowledge appears to be increasingly tied to economic benefits. In turn, an increasingly technologically oriented economy is likely to place a premium on highly educated workers. Nevertheless, U.S. higher education is facing a number of challenges, some arising from within science and engineering, others from changes in the academic environment.

Higher education's overall financial environment has improved somewhat when compared to the recession years at the decade's turn, when many state governments combined flat or reduced appropriations with new accountability measures. Years of steep and unpopular increases in tuition and fees appear to lie in the past as well. Nevertheless, the Nation's universities and colleges continue to face cost pressures, even as nontraditional providers of teaching and training try to capture a growing share of traditional academic markets.

For many of the largest universities, a major uncertainty arises from the restructuring of the Nation's health care system. Some have responded by making structural changes in the relationships with their teaching hospitals, including one of turning them into for-profit ventures. Federal reimbursement changes are feared by many to have adverse effects on biomedical and clinical research and teaching.

For support of their R&D, academic institutions continue to rely heavily on the Federal Government, thus maintaining a certain dependence on implicit Federal priorities for the funding balance among fields. Universities' own resources are approaching one-fifth of their total R&D expenditures. However, in the face of financial pressures on all academic operations, this funding source cannot be expected to continue growing as a share of total academic R&D resources. Industry is often viewed as a potentially growing support source but has continued to supply less than 10 percent of the total funds, even as it has increasingly relied on academic R&D.

Demographic projections point to strong enrollment growth over the next decade and the continuation of several trends: more minority participation, growing numbers of older students, and greater proportions of non-traditional students. Issues of access, affordability, and fairness are likely to mix with considerations of institutional focus, mission, and strategy. Financial and other pressures will be part of the context in which they will unfold; undoubtedly, so will new service possibilities offered by technological developments, which carry their own costs and challenges.

These discussions will take place against the backdrop of increasing faculty retirements. As older faculty are leaving academia, hiring of young scientists and engineers can be expected to pick up further. However, the longer-term structure of this hiring is uncertain. Current trends suggest slower growth of the faculty segment than of other types of academic employment. Will universities and colleges shift the focus of their replacement hiring from tenure-track faculty positions into other, more flexible types of appointments?

The nature and goals of both undergraduate and graduate education are being debated. Are the current models appropriate, or should undergraduate education and graduate training allow for broader and more varied application of skills in the marketplace? Should graduate students be given more autonomy from their professors, perhaps by way of restructuring their modes of support? What is the appropriate role for the Federal Government in this support? Continued increases in the number of foreign students, vital for many graduate programs, cannot be taken for granted. Issues about the nature of graduate education join with questions of university missions and program organization.

The research universities are valued as a national resource: they educate and train large proportions of the Nation's scientists and engineers, embody the model of integrated graduate training and research, and conduct much of the nation's basic research. Yet questions abound. Is their graduate training developing a high-quality yet flexible workforce of scientists and engineers? Is it driven too much by research? Is their research enterprise too insular? Too driven by external demands from the Federal Government or industry? Does it cost too much? How can research be better connected to undergraduate education? With growing research involvement, smaller academic research performers face these same questions.

Answers to these and other questions will emerge gradually, as individual institutions respond to the challenges and opportunities they perceive. The Nation's universities and colleges have shown great ability to adapt to changed realities. In time, it will become possible to take stock of the changes and assess their extent. Many issues underlying these changes will persist, as higher education institutions try to find the appropriate balance among their many evolving functions.

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Chapter 7
Industry, Technology, and the Global Marketplace

Contents

Highlights

International Economic Comparisons

- **The U.S. economy continues to rank as the world's largest, and Americans continue to enjoy one of the world's higher standards of living.** Japan's economy was less than 18 percent of the U.S. economy in 1960 and trailed several European economies. By 1970, it had grown to be the world's second largest economy, and in 1989, Japan had a gross domestic product (GDP) twice that of Germany and equal to nearly 40 percent of U.S. GDP. The latest data (through 1996) show a strong U.S. economy outperforming other advanced industrial countries since 1991.
- **Comparisons of general levels of labor productivity, measured by GDP per employed person, show other parts of the world increasing labor productivity faster than the United States.** For more than 40 years, labor productivity growth in the United States generally trailed that in other countries. As of 1996, the gap had closed significantly, with labor productivity rates in many European nations nearly equal to that achieved in the United States. In 1960, U.S. GDP per employed person was twice that calculated for most European nations and four times that calculated for Japan.

U.S. Technology in the Marketplace

- **The United States continues to be the leading producer of high-technology products, and is responsible for about one-third of the world's production.** During the 1990s, U.S. high-technology industries regained some of the world market share lost during the previous decade. Its margin of leadership had narrowed during the 1980s when Japan rapidly enhanced its stature in high-technology fields.
- **The market competitiveness of individual U.S. high-technology industries varies, although each of the industries maintained strong—if not commanding—market positions over the 18-year period examined.** Three of the four science-based industries that form the high-technology group (computers, 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 1997.
- **U.S. trade in technology products accounts for a larger share of U.S. exports than U.S. imports; it therefore makes a positive contribution to the U.S. overall balance of trade.** After several years in which the surplus generated by trade in technology products declined, this trend was reversed 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 and electronics have outpaced imports leading to larger trade surpluses in 1996 and 1997 before narrowing in 1998.
- **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 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 were about $3.3 billion in 1997, down slightly from $3.5 billion in 1996. Japan is the largest consumer of U.S. technology sold as intellectual property, and South Korea is a distant second. Together, Japan and South Korea accounted for 56 percent of total receipts in 1997.

International Trends in Industrial R&D

- **Despite a two-decade decline in its international share of industrial research and development (R&D), the United States remains the world's leading performer of industrial R&D by a wide margin.** Data for 1995 and 1996 show a sharp increase in U.S. industrial R&D performance, outpacing growth in both Japan and the European Union. After 1990, the U.S. share stabilized at 46 percent of total industrial R&D performed by the Organisation for Economic Co-operation and Development (OECD) countries. By comparison, the European Union (EU) accounted for 30 percent of the total industrial R&D performed by OECD countries during 1990–94, and Japan accounted for about 20 percent.
- **Internationally comparable data on overall U.S. industrial R&D performance show the service sector's share rising from 4 percent in 1982 to 24 percent by 1992. During the period 1994–96, this sector's share of the total dropped to around 20 percent.** U.S. service sector industries, such as those developing computer software and providing communications services, have led the increase in R&D performance within the U.S. service sector. Service-sector R&D now accounts for a larger share of U.S. industrial R&D performance than either the electronics industry (13 percent of total) or the aerospace industry (11 percent of total)—the top two R&D-performing industries in the U.S. manufacturing sector in 1996.

Patented Inventions

- **In 1998, nearly 148,000 patents were issued in the United States.** The record number of new patented inventions capped off what had been years of increases. U.S. inventors received 54 percent of the patents granted in 1998. Although the 1998 share represents a drop of 1 percent from the previous year, the proportion of new patents granted to U.S. inventors has generally risen since the late 1980s.

♦ **Foreign patenting in the United States continues to be highly concentrated by country of origin. In 1998, two countries—Japan and Germany—accounted for nearly 60 percent of U.S. foreign-origin U.S. patents.** 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 1998, were awarded more U.S. patents than Canada—historically one of the top five foreign inventors patenting in the United States.

♦ **Recent patent emphases by foreign inventors in the United States show widespread international focus on several commercially important technologies.** Japanese inventors tend to concentrate their U.S. patenting in consumer electronics, photography, and—more recently—computer technologies. German inventors continue to develop new products and processes in technology areas associated with heavy manufacturing industries, such as motor vehicles, printing, advanced materials, and manufacturing technologies. Inventors from South Korea and Taiwan are earning an increasing number of U.S. patents in communications and computer technologies.

♦ **Americans successfully patent their inventions around the world.** U.S. inventors received more patents than other foreign inventors in both neighboring countries (Canada and Mexico); but also in distant and diverse markets, such as Japan, France, Italy, Brazil, India, Malaysia, and Thailand.

Venture Capital and High-Technology Enterprise

♦ **The pool of venture 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.** Both investor interest and venture capital disbursements continued to grow through 1998. In the early 1990s, however, the venture capital industry experienced a “recession” of sorts as investor interest waned and the amount of venture capital disbursed declined. This slowdown was short-lived, however, and investor interest picked up in 1992, and disbursements began to rise.

♦ **Software companies attracted more venture capital than any other technology area.** In 1998, venture capital firms disbursed a total of $16.8 billion, of which more than one-third went to firms developing computer software or providing software services. Telecommunications companies were second with 17 percent.

♦ **Very little venture capital actually goes to the entrepreneur as “seed” money.** During the past 10 years, money given to prove a concept or for early product development never accounted for more than 6 percent of total venture capital disbursements and most often represented 2–4 percent of the annual totals. In 1998, seed money accounted for about 4 percent of all venture capital disbursements, while money for company expansion was about 56 percent.

Following are some trends based on the various indicators of technology development and market competitiveness examined in this chapter:

♦ The United States continues to lead or be among the leaders in all major technology areas. Advancements in information technologies (computers and telecommunications products) continue to influence new technology development and to dominate technical exchanges between the United States and its trading partners.

♦ Asia’s status as both a consumer and developer of high-technology products has been enhanced by the technological development taking place in the newly industrialized Asian economies—in particular, South Korea and Taiwan—and in emerging and transitioning economies, such as China, Malaysia, and the Philippines. Despite its current economic problems, Asia’s influence in the marketplace seems likely to expand in the future as other technologically emerging Asian nations join Japan as both technology producers and consumers.

Beyond these challenges, the rapid technological development taking place around the world also offers new opportunities for the U.S. science and technology (S&T) enterprise:

♦ For U.S. business, rising exports of high-technology products and services to expanding economies in Asia, Europe, and Latin America are already apparent in the U.S. trade data and should grow in the years ahead.

♦ For research, the same conditions that create new business opportunities—the growing global technological capacity, the relaxation of restrictions on international business—can lead to new opportunities for the U.S. S&T research community. The many new, well-funded institutes and technology-oriented universities surfacing in many technologically emerging areas of the world will further scientific and technological knowledge and lead to new collaborations between U.S. and foreign researchers.

Introduction

Chapter Background

Science and engineering (S&E), and the technological developments that emerge from S&E activities, enable high-wage nations like the United States to compete alongside low-wage countries in today's increasingly global marketplace. Nearly a universally accepted wisdom today, the importance of S&E activities to the Nation's economic well-being was emphasized 50 years ago in *Science and Public Policy*, a report prepared for then-President Harry S Truman under the guidance of John Steelman (1947). (See chapter 1.) It stated, "Only through research and more research can we provide the basis for an expanding economy, and continued high employment levels." In the years following World War II, U.S. industry became an integral part of the research enterprise. Not just as a performer of R&D, U.S. industry became the main conduit for diffusing and commercializing investments in S&T made by industry, academia, and government. The *Science and Engineering Indicators 2000* continues to acknowledge the important role played by industry. Contained within this chapter are indicators or proxies that identify trends and provide measurements of industry's part in the S&T enterprise and, whenever possible, place U.S. activity and standing in the more science-based industries in a global context.

The highly competitive global marketplace facing the Nation today is yet another condition predicted 50 years ago in the Steelman report. Steelman (1947) warned of the reemergence of war-torn economies in Europe and Asia and the emergence of a new cadre of nation traders that would "...confront us with competition from other national economies of a sort we have not hitherto had to meet." If a nation's competitiveness is judged by its ability to produce goods that find demand in the international marketplace while simultaneously maintaining—if not improving—the standard of living of its citizens (OECD 1996), then the United States appears to have met the challenges outlined in the Steelman report. Now some 50 years after that report was written, the U.S. economy ranks as the world's largest, and Americans enjoy one of the world's higher standards of living—although many other parts of the world are closing the gap. (See figure 7-1 and appendix tables 7-1, 7-2, and 7-3.)

Chapter Organization

This chapter begins with a review of the market competitiveness of industries that rely heavily on R&D; these are often referred to as high-technology industries.[1] The importance of high-technology industries is linked to their high R&D spending and performance, which produce innovations that spill over into other economic sectors. Additionally, these industries help train new scientists, engineers, and other technical personnel. (See Nadiri 1993 and Tyson 1992.) The market competitiveness of a nation's technological advances, as embodied in new products and processes associated with these industries, can also serve as an indicator of the effectiveness of that country's S&T enterprise. The marketplace provides a relevant economic evaluation of a country's use of S&T.

U.S. high-technology industry competitiveness is assessed through an examination of market share trends worldwide, at home, and in various regions of the world. New 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.

The chapter explores several leading indicators of technology development (1) via an examination of changing emphases in industrial R&D among the major industrial countries and (2) through an extensive analysis of patenting trends. New information on international patenting trends of U.S. foreign inventors in several important technologies is presented.

The chapter concludes with a presentation of information on trends in venture capital disbursements. Venture capital is an important source of funds used in the formation and expansion of small high-technology companies. This section examines venture capital disbursements by stage of financing and by technology area in the United States.

U.S. Technology in the Marketplace

Most countries in the world acknowledge a symbiotic relationship between national investments in S&T and competitiveness in the marketplace: S&T support business competitiveness in international trade, and commercial success in the global marketplace provides the resources needed to support new S&T. Consequently, the health of the nation's economy becomes a performance measure for the national investment in R&D and in S&E.

This section discusses U.S. "competitiveness," broadly defined here as the ability of U.S. firms to sell products in the international marketplace. A great deal of attention is given to science-based industries producing products that embody above-average levels of R&D in their development (hereafter referred to as *high-technology industries*). OECD currently identifies four industries as high-technology based on their high R&D intensities: aerospace, computers and office machinery, electronics-communications, and pharmaceuticals.[2]

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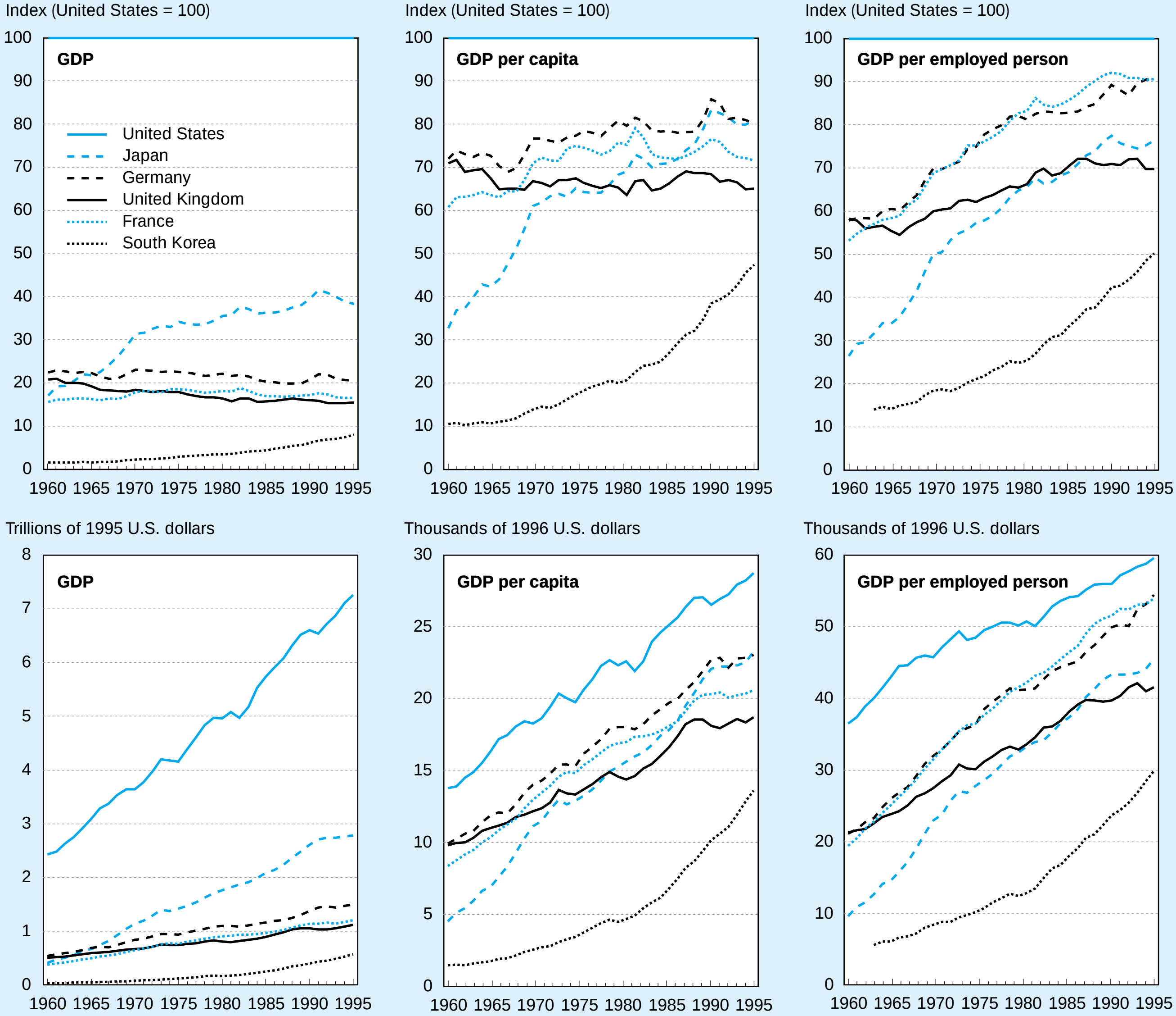
[1] In this chapter, high-technology industries are identified using R&D intensities calculated by the OECD. There is no single preferred methodology for identifying high-technology industries. The identification of those industries considered to be high-technology has generally relied on a calculation comparing R&D intensities. R&D intensity, in turn, has typically been determined by comparing industry R&D expenditures and/or numbers of technical people employed (such as scientists, engineers, and technicians) to industry value added or the total value of its shipments.

[2] In designating these high-technology industries, the 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

Figure 7-1.
International economic comparisons



NOTE: Country GDPs were determined with 1993 purchasing power parities using the Elteto-Köves-Szulc (EKS) aggregation method and 1996 U.S. dollars (1995 U.S. dollars for aggregate GDP).

See appendix tables 7-1, 7-2, and 7-3.

Science & Engineering Indicators – 2000

There are several reasons why high-technology industries are important to nations:

- High-technology firms are associated with innovation. Firms that innovate tend to gain market share, create new product markets, and/or use resources more productively (NRC, Hamburg Institute for Economic Research, and Kiel Institute for World Economics 1996; Tassey 1995).
- High-technology firms are associated with high value added production and success in foreign markets which helps to support higher compensation to the workers they employ (Tyson 1992).
- Industrial R&D performed by high-technology industries has other spillover effects. These effects benefit other com-

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on the basis of input-output matrices. The 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).

mercial sectors by generating new products and processes that can often lead to productivity gains, business expansions, and the creation of high-wage jobs (Nadiri 1993, Tyson 1992, and Mansfield 1991).

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 economic activity in high-technology industries is driving national economic growth around the world.[3] During the 18-year period examined (1980–97), high-technology production grew at an inflation-adjusted average annual rate of nearly 6.2 percent compared with a rate of 2.7 percent for other manufactured goods.[4] Global economic activity was especially strong at the end of the period (1994–97), when high-technology industry output grew at more than 11 percent per year—more than four times the rate of growth for all other manufacturing industries. (See appendix table 7-4.) Output by the four high-technology industries—those identified as being the most research intensive—represented 7.1 percent of global production of all manufactured goods in 1980; by 1997, this output represented 11.9 percent.

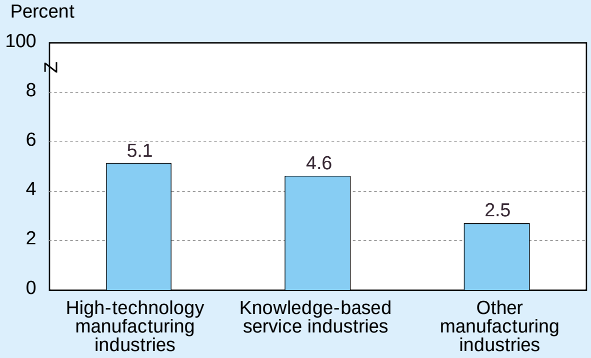
During the 1980s, the United States and other high-wage countries increasingly moved resources toward the manufacture of higher-value, technology-intensive goods often referred to as high-technology manufactures. In 1989, U.S. high-technology manufactures represented nearly 11 percent of total U.S. production of manufactured output, up from 9.6 percent in 1980. High-technology manufactures also accounted for growing shares of total production for European nations, although to a lesser degree than that seen in the United States. The one exception was the United Kingdom where the transition to high technology during the 1980s was similar to that in the United States. High-technology manufactures represented just 9 percent of the United Kingdom's total manufacturing output in 1980 and nearly 11 percent by 1989. The Japanese economy led all other major industrial countries in its concentration on high-technology industries during the 1980s. In 1980, high-technology manufactures accounted for about 8 percent of total Japanese production, approached 11 percent in 1984, and then increased to 11.6 percent in 1989. (See the sidebar, "International Activity in High-Technology Service Industries.")

Data for the 1990s show an increased emphasis on high-technology manufactures among the major industrial countries. (See figure 7-4.) In 1997, high-technology manufactures were estimated to represent 15.7 percent of manufacturing output in Japan, 14.7 percent in the United States, 11.7 percent in the United Kingdom, and 8.3 percent each in France and Germany. Two other Asian countries, China and South Korea, typify how important R&D-intensive industries have become to the newly industrialized economies. In 1980, high-technology manufactures accounted for less than 7 percent of China's total manufacturing output; this proportion jumped

International Activity in High-Technology Service Industries

For several decades, revenues generated by U.S. service sector industries have grown faster than revenues generated by the Nation's manufacturing industries. Data collected by the U.S. Department of Commerce show that the U.S. service sector's share of the U.S. GDP grew from 49 percent in 1959 to 64 percent in 1997 (See appendix table 9-4.) Service sector growth has in large part been fueled by industries often described as "knowledge-based" industries—those incorporating science, engineering, and technology in the services being provided or in the delivery of those services. Prominent examples of these "knowledge-based" industries include communication services, financial services, business services (including computer software–related services), educational services, and health services. These industries have been growing nearly as fast as the high-technology manufacturing sector discussed earlier. (See figure 7-2.)

Figure 7-2.
Average annual rates of growth in three U.S. economic sectors: 1980–97



See appendix tables 7-4 and 7-5.

Science & Engineering Indicators – 2000

New data provided by the WEFA Group tracks overall revenues earned by these industries in 64 countries.[*] Similar to the value of production or data on total shipments previously discussed for high-technology manu-

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[*] Unlike that for manufacturing industries, national data tracking activity in many of the hot new service sectors are limited in the level of industry disaggregation that is available and the types of activity for which national data are collected.

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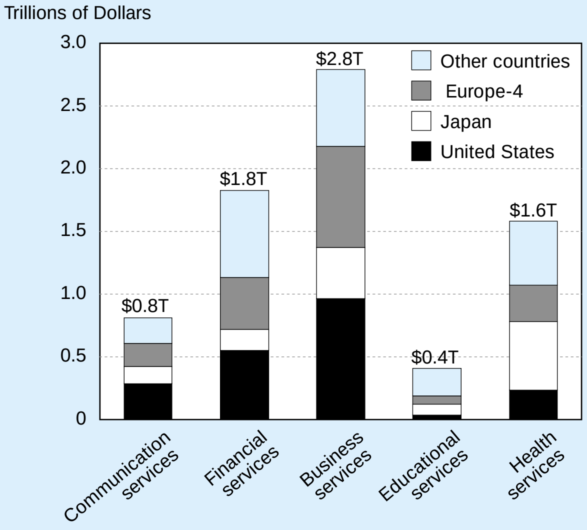
[3] This section is based on data reported by the WEFA Group in its Global Industry Model database. This database provides production data for 68 countries and accounts for more than 97 percent of global economic activity.

[4] Knowledge-based service sector industries grew at an average annual inflation-adjusted rate of 4.6 percent during this period.

facturing industries, these data permit an examination of the global U.S. position in each of the service sector industries. (See figure 7-3 and appendix table 7-5.)

Combined worldwide sales in these five service sector industries exceeded $7.4 trillion in 1997, up from $5.8 trillion in 1990 and $3.4 trillion in 1980 (1997 dollars). The United States was the leading national provider of high-technology services, responsible for more than 28–30 percent of total world service revenues during the 1980s and for about 27 percent of revenues during the 1990–97 period.

Figure 7-3.
Global activity in five knowledge-based service industries in 1997



NOTE: Europe-4 refers to the four largest European economies: France, Germany, Italy, and the United Kingdom.

See appendix table 7-5. *Science & Engineering Indicators – 2000*

Business services, which include computer and data processing services, research and engineering services, and other business services, is the largest of the five-industry service sector and accounted for nearly 38 percent of revenues in 1997. The U.S. business service industry is the largest in the world with 34.4 percent of industry revenues in 1997. Japan was second at 14.7 percent, followed by Germany with 10.0 percent and France at 9.8 percent. Unfortunately, data on individual business services by country are not available.

Services provided by financial institutions represent the second largest of the five service industries examined, and accounted for nearly 25 percent of revenues in 1997. Among the three largest advanced nations, the U.S. financial services industry is the largest with 30.0 percent of world industry revenues in 1997. Japan was again second at 9.3 percent followed by Germany at 6.6 percent.

Communications services, which include telecommunications and broadcast services, represent the third largest of the five service industries examined and accounted for 10.9 percent of revenues in 1997. In what many consider the most technology-driving of the service industries, the U.S. industry has the most dominant position. In 1997, U.S. communications firms generated revenues that accounted for 35.2 percent of world revenues, more than twice the share held by Japanese firms, and nearly five times that held by German firms.

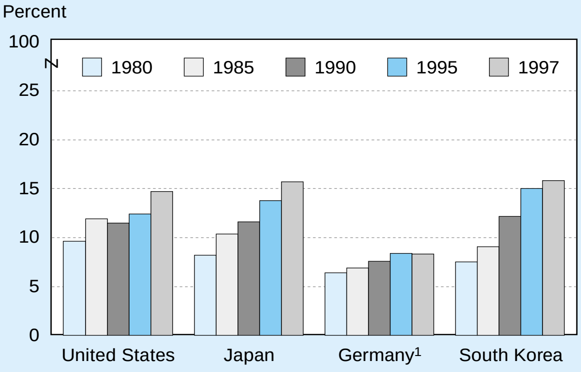
More than the first three, the remaining two knowledge-based service industries—health services and educational services—operate on the edge of government services. Health services industry data examined here track services provided by private hospitals, doctors, and miscellaneous medical services. Educational services include commercial education and library services. In both health and education services, Japan's industries are the largest in the world and lead the next largest national industry—that in the United States—by large margins. Japan's share of world revenues in the health services industry was 34.6 percent in 1997—more than twice the share for the U.S. health services industry. Of the four largest European economies, Italy had the largest health service industry. In educational services, Japan's leading share of the world revenues was lower than that in health services—21.7 percent versus 34.6 percent—but this leading share was two and a half times greater than the second largest national industry in the United States. Italy once again had the next largest share, 4.8 percent, although the other large European economies had educational services nearly as big. Educational services represented the smallest of the five knowledge-based service industries with about one-seventh of the revenues generated by the business services industry worldwide.

to 11.6 percent in 1989 and reached 14.8 percent in 1997—about the same as in the United States. In 1997, high-technology manufacturing in South Korea accounted for about the same percentage of total output as in Japan (15.8 percent) and almost twice the percentage of total manufacturing output in France and Germany.

Share of World Markets

Throughout the 1980s, the United States was the leading producer of high-technology products, and was responsible for more than one-third of total world production from 1980 to 1987, and for about 30 percent of world production for the rest of the decade. U.S. world market share held fairly steady

Figure 7-4.
High-technology industries' share of total manufacturing output



See appendix table 7-4. *Science & Engineering Indicators – 2000*

¹German data are for West Germany only.

during much of the 1990s and moved up slightly in both 1996 and 1997. (See figure 7-5.) In 1997, production by U.S. high-technology industry accounted for nearly 32 percent of world high-technology production.

While U.S. high-technology industry struggled to maintain market share during the 1980s, the Asian global market share in high-technology industries 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 since 1980. Japan continued to gain market share through 1991. Since then, however, Japan's market share has dropped steadily, falling to under 22 percent of world production in 1997 after accounting for nearly 26 percent in 1991.

By comparison, many European nations' share of world high-technology production is much lower. Germany produced about 8 percent of world high-technology production in 1980, about 7 percent in 1989, and less than 6 percent in 1997. Shares for the United Kingdom declined in a similar fashion. In 1980, United Kingdom's high-technology industry produced about 7 percent of world output, it dropped to about 6 percent in 1989, and to 4.4 percent by 1997. French high-technology industry never accounted for more than 4.5 percent of world high-technology output during the period examined, and its shares trended downward to about 3 percent by 1997. Italy's shares were the lowest among the four large European economies, ranging from a high of about 2.5 percent of world high-technology production in 1980 to a low of about 1 percent in 1997.

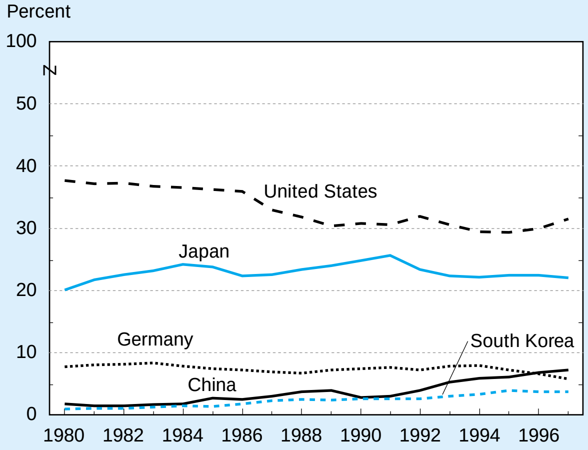
Developing Asian nations made the most dramatic gains since 1980. China's market share doubled during the 1980s, moving from 1.8 percent in 1980 to 3.9 in 1989, and is on track to double again during the 1990s with its latest share reaching 7.2 in 1997. Production by China's high-technology industries in 1997 was larger than any European nation. Like China, high-technology industries in South Korea quickly gained market during the 1980s and expanded that market share in the 1990s. Starting with less than 1 percent in 1980, output by high-technology industries in South Korea accounted for 2.4 percent of world output in 1989 and 3.7 percent by 1997. Compared with high-technology production in the four largest European countries, South Korea's share of world production in 1997 was smaller than that in either Germany or United Kingdom, but larger than that produced by high-technology industries in both France and Italy.

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 during the 18-year period examined. Yet 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: aerospace and communications equipment. Since then, both of these industries—in particular, communications equipment—reversed their downward trends and gained market share in the mid- to late 1990s. (See figure 7-6.)

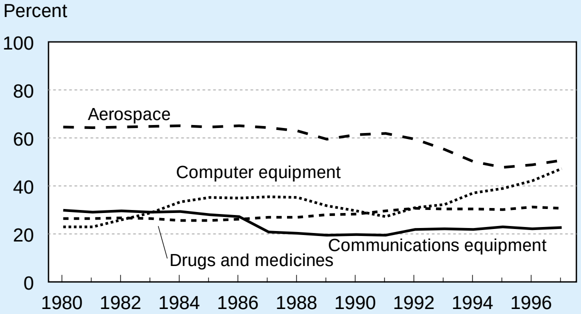
The U.S. aerospace industry, the Nation's strongest high-technology industry in terms of world market share, was the one high-technology industry to lose market share in the 1980s and again in the 1990s. For much of the 1980s, the U.S. aerospace industry supplied about two-thirds of world demand. By the late 1980s, the U.S. share of the world aerospace market began an erratic decline and dropped to under 60 percent by 1989. The U.S. aerospace industry maintained this market share up until 1993 when market share, once again, began to slip, falling to its lowest level for the period (under 48 percent) in 1995. The U.S. share recovered somewhat during the following two years reaching 51 percent of the world market in 1997. While European aerospace industries made some gains during this time, China's industry recorded large gains in global market share beginning in 1992. In 1980, China

Figure 7-5.
Country share of global high-technology output



See appendix table 7-4. *Science & Engineering Indicators – 2000*

Figure 7-6.
U.S. global output share, by high-technology industry



See appendix table 7-4. *Science & Engineering Indicators – 2000*

supplied about 2.9 percent of world aircraft shipments; by 1997, its share had increased to nearly 16 percent. (See figure 7-7.)[5]

As previously noted, two U.S. high-technology industries lost market share during the late 1980s and then reversed that trend during the 1990s. By 1997, the United States was the number one supplier of computer equipment in the world and the second leading supplier of communications equipment behind Japan.

Of the four high-technology industries, only the U.S. aerospace and U.S. pharmaceutical industries managed to retain their number one rankings throughout the 18-year period. Of these two, only the U.S. pharmaceutical industry had a larger share of the global market in 1997 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 foreign-made technologies pressures U.S. producers to be inventive and to move toward more rapid innovation to maintain domestic market share.

This discussion of world market shares shows that U.S. producers are leading suppliers of high-technology products to the global market. That evaluation incorporates U.S. sales to domestic, as well as to foreign customers. In the next sections, these two markets are examined separately.

Exports by High-Technology Industries

While U.S. producers reaped many benefits from having the world's largest home market (as measured by GDP), mounting trade deficits highlight the need to also serve demand in foreign markets. U.S. high-technology industries have traditionally been more successful exporters than other U.S. industries. Consequently, high-technology industries have attracted considerable attention from policymakers as they seek ways to return the United States to a more balanced trade position.

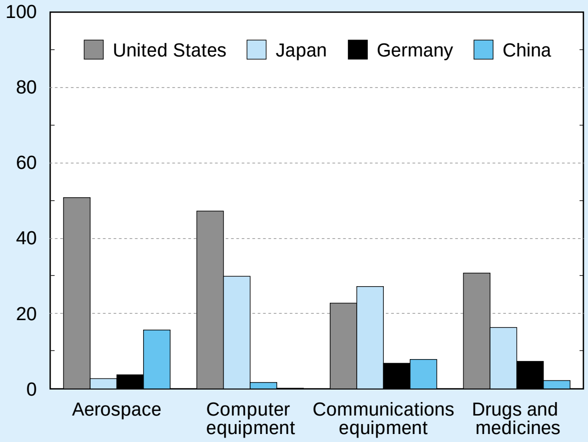
Foreign Markets

Despite its domestic focus, the United States has been an important supplier of manufactured products in foreign markets throughout the 1980–97 period. From 1994 to 1997, the United States was the leading nation exporter of manufactured goods and accounted for about 12 percent of world exports.

U.S. high-technology industries have contributed to this strong export performance of the nation's manufacturing industries. (See figure 7-8.) During the same 18-year period, U.S. high-technology industries accounted for between 17 and 25 percent of world high-technology exports—which is at times twice the level achieved by all U.S. manufacturing industries. In 1997, the latest year for which data are available, exports by U.S. high-technology industries accounted for 18.1 percent of world high-technology exports. Japan was second, accounting for 9.1 percent, followed by the United Kingdom with 8.3 percent.

The drop in U.S. share over the 18-year period is in part the result of the emergence of high-technology industries in newly industrialized economies, especially within Asia. Singapore and South Korea are two examples. In 1980, high-technology industries in Singapore and South Korea accounted for about 2.6 percent and 1.5 percent of world high-technology exports, respectively. Both nations' market shares doubled by the late 1980s. The latest data for 1997 show Singapore's share reaching 8.0 percent and South Korea's share reaching 5.4 percent.

Figure 7-7.
Global output share, by selected country and high-technology industry: 1997



See appendix table 7-4. *Science & Engineering Indicators – 2000*

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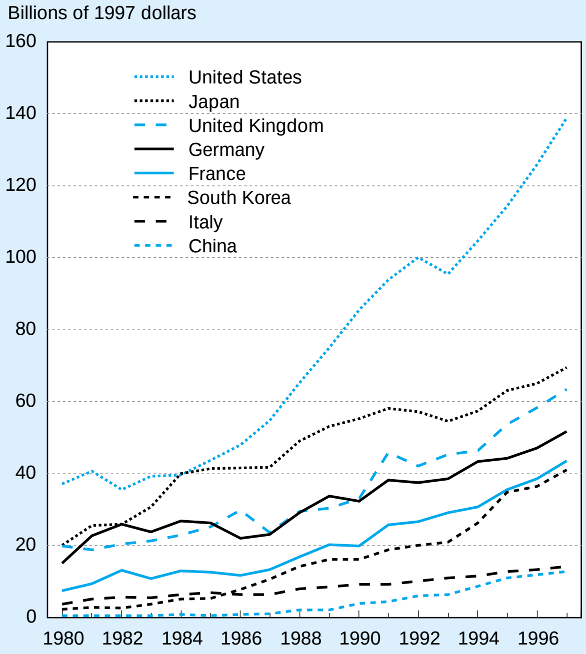
[5] Industry experts in the United States contacted to confirm such a large China presence in the market for aerospace products suggest that China's production may be more heavily concentrated in satellite launch equipment and noncommercial production than in commercial aircraft.

Figure 7-8.
High-technology exports



See appendix table 7-4. *Science & Engineering Indicators – 2000*

Industry Comparisons

Throughout the 18-year period, individual U.S. high-technology industries either led in exports or were second to the leader in each of the four industries included in the high-technology grouping. The most current data (1997) show the United States as the export leader in three industries and third in just one—drugs and medicines. (See figure 7-9.)

U.S. industries producing aerospace, computers, and drugs and medicines all accounted for smaller export shares in 1997 than in 1980. The communications equipment industry was the sole U.S. high-technology industry to improve its share of world exports during the period. By comparison, the share of world exports held by Japan's communications equipment industry dropped steadily after 1985—eventually falling to 12.3 percent by 1997 from a high of 33.6 percent just 12 years earlier. Once again the newly industrialized economies of Asia demonstrated an ability to produce high-technology goods to world-class standards and were rewarded with great success in selling to foreign markets. In 1997, South Korea supplied 7.8 percent of world communications product exports, up from just 2.9 percent in 1980. Singapore supplied 9.9 percent of world computer equipment exports in 1997, up from 4.8 percent in 1980. Other Asian newly industrialized economies have demonstrated strong capabilities in those two high-technology industries.

Competition in the Home Market

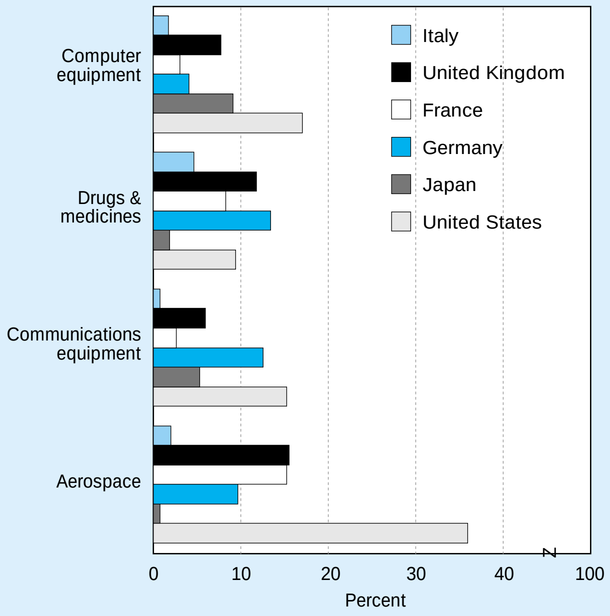
A country's home market is often thought of as the natural destination for the goods and services produced by domestic firms. For obvious reasons—including proximity to the customer and common language, customs, and currency—marketing at home is easier than marketing abroad.

With trade barriers falling and the number of foreign firms able to produce goods to world standards rising, however, product origin may be only one factor among many influencing the consumer's choice between competing products. Price, quality, and product performance often become equally or more important determinants guiding product selection. Thus, in the absence of trade barriers, the intensity of competition faced by domestic producers in their home market can approach—and, in some markets, may even exceed—the level of competition faced in foreign markets. Explanations for U.S. competitiveness in foreign markets may be found in the two dynamics of the U.S. market: the existence of tremendous domestic demand for the latest advanced technology products and the degree of world-class competition that continually pressures U.S. industry toward innovation and discovery.

National Demand for High-Technology Products

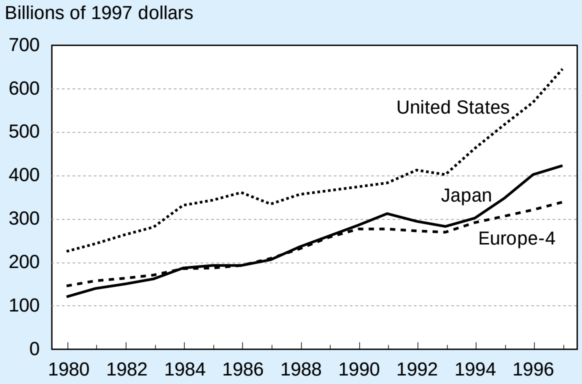
Demand for high-technology products in the United States far exceeds that in any other single country and is larger than the combined markets of the four largest European nations: Germany, the United Kingdom, France, and Italy. (See figure 7-10.) This was consistently the case for the entire 1980–97 period. Japan was the second largest market for high-tech-

Figure 7-9.
Export market share in high-technology industries: 1997



See appendix table 7-4. *Science & Engineering Indicators – 2000*

Figure 7-10.
National consumption of high-technology products



NOTE: Europe-4 refers to the four largest European economies: Germany, France, the United Kingdom, and Italy.

See appendix table 7-4. *Science & Engineering Indicators – 2000*

nology products in the world, although its share of world consumption has generally declined since 1991. China again stands out. In 1980, China consumed less than 2 percent of world high-technology output—its demand doubled by the end of the decade and doubled again by 1997. The latest annual data (1997) show China's economy as the world's second largest consumer of aerospace products, trailing only the United States, and the fourth largest consuming nation of communications equipment, trailing the United States, Japan, and Germany.

National Producers Supplying the Home Market

Throughout the 1980–97 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 7-11.) In 1997, U.S. producers supplied about 81.5 percent of the home market for high-technology products (aerospace, computers, communications equipment, and pharmaceuticals). In 1980, however, U.S. producers' share was much higher, about 92.5 percent.

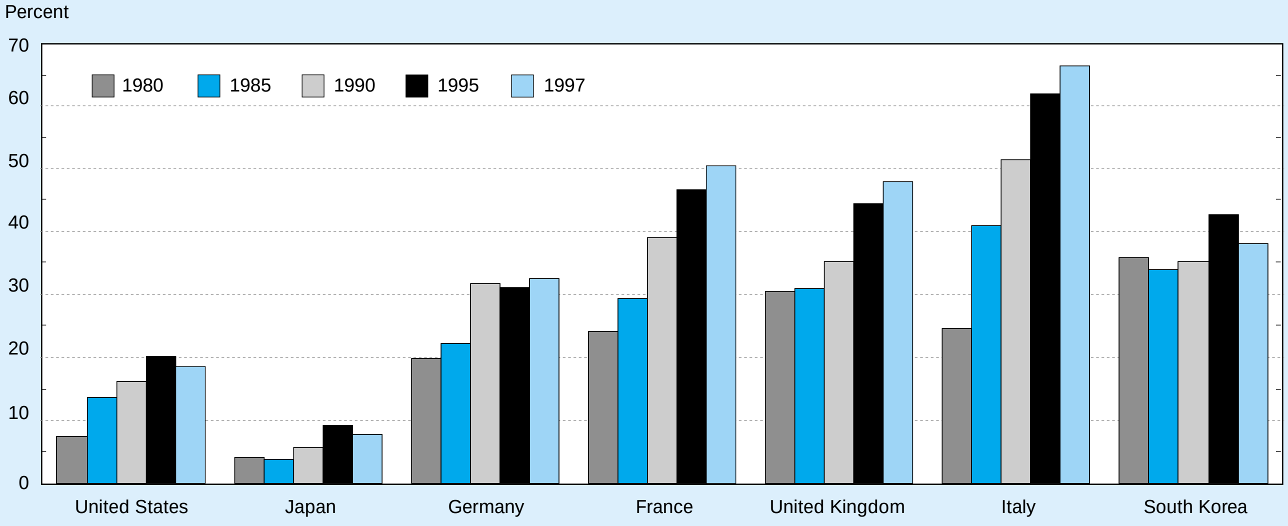
Other countries have experienced similar increased foreign competition in their domestic markets. This is especially true in Europe. A more economically unified European market has had the effect of making Europe an even more attractive market to the rest of the world. Rapidly rising import penetration ratios in the four large European nations 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 when compared with product markets for less technology-intensive manufactures.

The Japanese home market, the second largest national market for high-technology products and historically the most self-reliant of the major industrial countries, also increased its purchases of foreign technologies during the 18-year period, albeit slowly. In 1980, imports of high-technology manufactures supplied about 4 percent of Japanese domestic consumption, rising to 5.3 percent in 1989, and then to 7.8 percent by 1997.

U.S. Trade Balance

The U.S. Bureau of the Census has developed a classification system for exports and imports of products that embody new or leading-edge technologies. This classification system allows trade to be examined in 10 major technology areas

Figure 7-11.
Import share of domestic high-technology markets



See appendix table 7-4. *Science & Engineering Indicators – 2000*

that have led to many leading-edge products. These 10 advanced technology areas are as follows:

- *Biotechnology*—The medical and industrial application of advanced genetic research toward the creation of new drugs, hormones, and other therapeutic items for both agricultural and human uses.
- *Life science technologies*—The application of scientific advances (other than biological) to medical science. For example, medical technology advances, such as nuclear resonance imaging, echocardiography, and novel chemistry, coupled with new production techniques for the manufacture of drugs, have led to new products that allow for the control or eradication of disease.
- *Opto-electronics*—The development of electronic products and components that involve emission or detection of light, including optical scanners, optical disk players, solar cells, photosensitive semiconductors, and laser printers.
- *Computers and telecommunications*—The development of products that process increasing volumes of information in shorter periods, including fax machines, telephone switching apparatus, radar apparatus, communications satellites, central processing units, computers, and peripheral units, such as disk drives, control units, modems, and computer software.
- *Electronics*—The development of electronic components (except 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.
- *Computer-integrated manufacturing*—The development of products for industrial automation, including robots, numerically controlled machine tools, and automated guided vehicles that allow for greater flexibility in the manufacturing process and reduce the amount of human intervention.
- *Material design*—The development of materials, including semiconductor materials, optical fiber cable, and videodisks, that enhance the application of other advanced technologies.
- *Aerospace*—The development of technologies, such as most new military and civil airplanes, helicopters, spacecraft (with the exception of communications 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 science 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. Since the characteristics of products the United States exports are likely to be different from the products the nation imports, experts evaluated exports and imports separately.

There is no single preferred methodology for identifying high-technology industries. Generally, this identification has relied on some calculation comparing R&D intensities. R&D intensity, in turn, has typically been determined by comparing industry R&D expenditures and/or numbers of technical people employed (such as scientists, engineers, and technicians) with industry value added or the total value of its shipments. These classification systems suffer from a degree of subjectivity introduced by the assignment of establishments and products to specific industries. The information produced by these R&D-intensity–based classification systems is often distorted by the inclusion of all products produced by the selected high-technology industries, regardless of the level of technology embodied in the product. In contrast, the advanced technology product system of trade data 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 subsequently reviewed by other experts.

The Importance of Advanced Technology Product Trade to Overall U.S. Trade

U.S. trade in advanced technology products accounted for an increasingly larger share of all U.S. trade (exports plus imports) in merchandise between 1990 and 1998. (See text table 7-1.) Total U.S. trade in merchandise exceeded $1.6 trillion in 1998; $343 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 (28 percent versus 17 percent in 1998) 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, that changed in 1996. In 1996 and again in 1997, exports of U.S. advanced technology products outpaced imports producing larger surpluses both years. In 1998, the slowdown in Asian economies led to a decline in exports to this region and a reduction in the surplus generated from U.S. trade in advanced technology products. (See figure 7-12 and text table 7-1.)

Technologies Generating a Trade Surplus

During the 1990s, U.S. exports of advanced technology products generally exceeded imports in 8 of 10 technology

Text table 7-1.
U.S. International trade in merchandise
(Billions of U.S. Dollars)

	1990	1991	1992	1993	1994	1994	1996	1997	1998
Total exports (billions of U.S. dollars)	393.0	421.9	447.5	464.8	512.4	575.9	611.5	679.3	670.6
Technology products (percent)	24.1	24.1	23.9	23.3	23.6	24.0	25.3	26.4	27.8
Other merchandise (percent)	75.9	75.9	76.1	76.7	76.4	76.0	74.7	73.6	72.2
Total imports (billions of U.S. dollars)	495.3	488.1	532.4	580.5	663.8	749.4	799.3	877.3	918.8
Technology products (percent)	12.0	13.0	13.5	14.0	14.8	16.7	16.3	16.8	17.1
Other merchandise (percent)	88.0	87.0	86.5	86.0	85.2	83.3	83.7	83.2	82.9
Total trade (billions of U.S. dollars)	888.3	910.0	979.9	1,045.3	1,176.2	1,325.3	1,410.8	1,556.6	1,589.4
Technology products (percent)	17.3	18.1	18.3	18.1	18.6	19.9	20.2	21.0	21.6
Other merchandise (percent)	82.7	81.9	81.7	81.9	81.4	80.1	79.8	79.0	78.4

NOTE: Total trade is the sum of total exports and total imports.

SOURCE: U.S. Bureau of the Census, Foreign Trade Division <<http://www.fedstats.gov>>1999.

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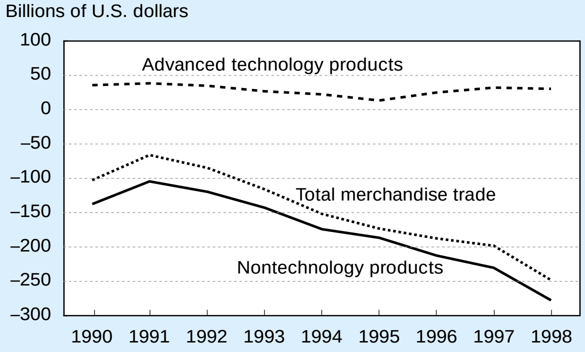
areas.[6] Trade in aerospace technologies consistently produced the largest surpluses for the United States during the 1990s. Those surpluses narrowed in the mid-1990s as competition from Europe's Airbus Industrie challenged U.S. companies' preeminence both at home and in foreign markets. Aerospace technologies generated a net inflow of $25 billion in 1990, and almost $29 billion in 1991 and 1992. Trade balances then declined 13 percent in 1993, 9 percent in 1994, and 14 percent in 1995. Since then, annual trade balances in aerospace technologies have grown each year. In 1998, the U.S. trade in aerospace technologies produced a net inflow of $39 billion, the largest surplus recorded during the 1990–98 period.

In five other the technology areas, trade is fairly balanced, with only a slight edge to U.S. exports over imports. U.S. trade in biotechnologies, computer integrated manufacturing technologies, material design, weapons, and nuclear technologies each showed surpluses of less than $2 billion in 1998.

Electronics, a technology area where U.S. imports typically exceeded exports, showed a trade surplus in both 1997 and 1998. The annual trade deficit in this technology area grew annually from 1990 to 1994 and then began to narrow. In 1998, U.S. exports of electronics exceeded imports by $4.2 billion. Economic problems in Asia and a stronger U.S. dollar may have lowered the level of electronics products imported from Asia.

Figure 7-12.
U.S. merchandise trade balance



Calculated from text table 7-1.

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Technologies Generating a Trade Deficit

In 1998, trade deficits were recorded in three technology areas—computers and telecommunications, 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 nine years examined. U.S. trade in life science technologies had consistently generated annual trade surpluses up until 1998. In 1998, life science exports to Asia fell by 18 percent, and imports from Europe rose sharply, especially from Germany and Ireland. Interestingly, in a technology area where the United States is considered at the forefront—computers and telecommunications—annual U.S. imports have exceeded exports consistently since 1992. Nearly three-quarters of all U.S. imports in this technology area are produced in Asia.[7]

Top Nation Customers, by Technology Area

Japan and Canada are U.S. industry's largest nation customers for U.S. technology products. Each country is the destination for about 11 percent of total U.S. technology exports.

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[6] U.S. trade in software products is not a separate ATP category but is included in the ATP category covering computers and telecommunications products. In order to better examine this important technology area, U.S. trade in software products was broken out from the computers and telecommunications category creating an eleventh category.

[7] The Bureau of the Census is not able to identify the degree to which this trade is between affiliated companies.

European countries are also important consumers of U.S. technology products. New markets have developed in several newly industrialized and developing economies, especially in Asia. Technology purchases by these economies now approach levels sold to many of the advanced European countries.

Japan and Canada are among the top three customers across a broad range of U.S. technology products. Japan ranks among the top 3 in 10 of 11 technology areas—Canada in 8. (See figure 7-13.) The United Kingdom is a leading consumer of U.S. products in five areas: opto-electronics, computers and telecommunications, aerospace, weapons and computer software. Although several other advanced nations are also important customers for particular U.S. technologies, notably Germany (life science technologies and nuclear technologies) and Belgium (biotechnology), several of the newly industrialized and emerging Asian economies now rank among the largest consumers for U.S. technology products.

Top Nation Suppliers, by Technology Area

The United States is not only an important exporter of technologies to the world, but it is also a consumer of foreign-made technologies. Imported technologies enhance productivity of U.S. firms and workers, improve health care for U.S. residents, and offer U.S. consumers more choices.

The leading economies in Asia and Europe are important suppliers to the U.S. market in each of the 11 technology areas. (See figure 7-14.) Japan is a major supplier in five advanced technology categories, Germany in four. France, Canada, and the United Kingdom also supply a wide variety of technology products to the United States and are among the top three in several advanced technology areas.

A large volume of technology products comes from newly developed and developing Asian economies, in particular Malaysia, South Korea, Taiwan, and China. Growing technology product imports from these Asian economies and from other regions into one of the most demanding markets in the world indicate a further widening of technological capabilities globally.

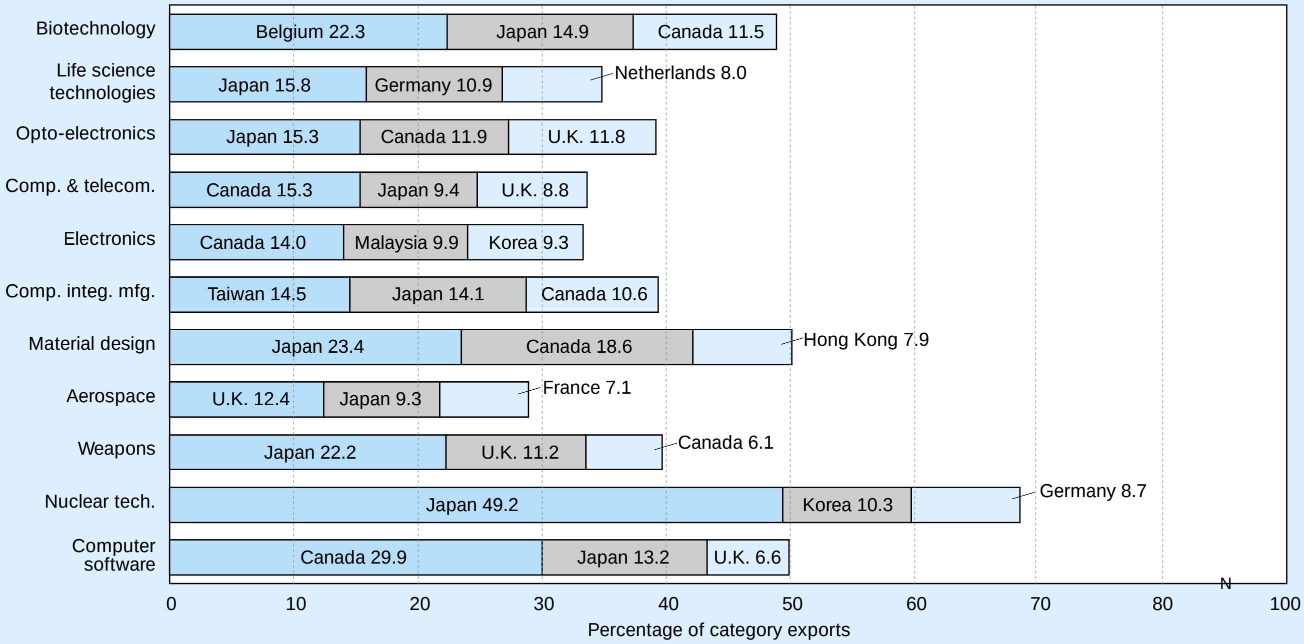
U.S. Royalties and Fees Generated from Trade in Intellectual Property

The United States has traditionally maintained a large surplus in international trade of 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 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 reached $33.7 billion in 1997. This level extended a decade of steady increases that has resulted in a doubling of U.S. receipts since 1990. During the 1987–96 period, U.S. receipts were generally four to five times as large as U.S. payments to foreign firms for transactions involving intellectual property. The gap narrowed in 1997 as U.S. payments increased by 20

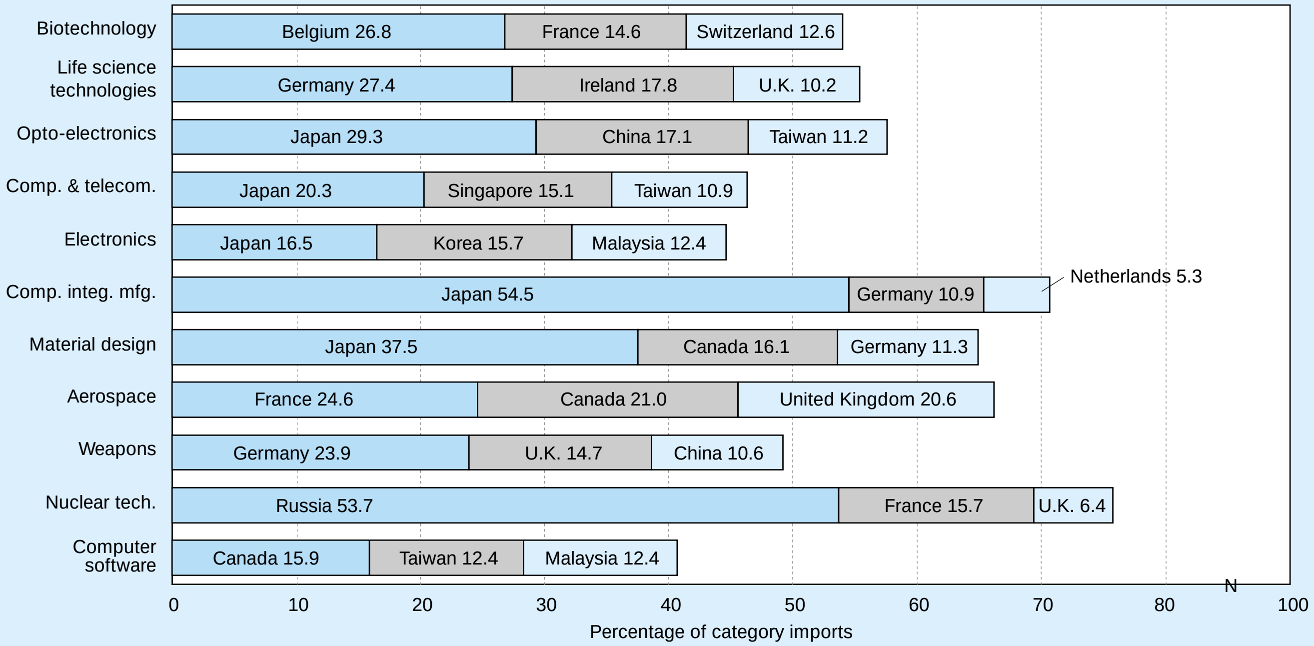
Figure 7-13.
Three largest export markets for U.S. technology products: 1998



See appendix table 7-6.

Science & Engineering Indicators – 2000

Figure 7-14.
Top three foreign suppliers of technology products to the United States: 1998



See appendix table 7-6. *Science & Engineering Indicators – 2000*

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 three and one-half times greater than payments. U.S. trade in intellectual property produced a surplus of $24.3 billion in 1997, down slightly from the nearly $25 billion surplus recorded a year earlier. Most (about 75 percent) of the transactions involved exchanges of intellectual property between U.S. firms and their foreign affiliates. (See figure 7-15.)[8]

Exchanges of intellectual property among affiliates have grown at about the same pace as those among unaffiliated firms. These trends suggest both a growing internationalization of U.S. business and a desire by U.S. firms to retain a high level of control on any intellectual property leased 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 reflect better the exchange of technical know-how and its market value at a given point in 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 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. During the past decade, royalties and fees received from foreign firms have been, on average, three times those paid out by U.S. firms to foreigners for access to their technology. U.S. receipts from such technology sales were about $3.3 billion in 1997, down slightly from $3.5 billion in 1996, but still nearly double that reported for 1987. (See figure 7-16 and appendix table 7-8.)

Japan is the largest consumer of U.S. technology sold as intellectual property. In 1997, Japan accounted for about 44 percent of all such receipts. The EU countries together represented about 22 percent. Another Asian country, South Korea, is the second largest consumer of U.S. technology sold as intellectual property, accounting for nearly 12 percent of U.S. receipts in 1997. South Korea has been a large 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.

To a large extent, the U.S. surplus in the exchange of intellectual property is driven by trade with Asia. In 1997, U.S. receipts (exports) from technology licensing transactions were

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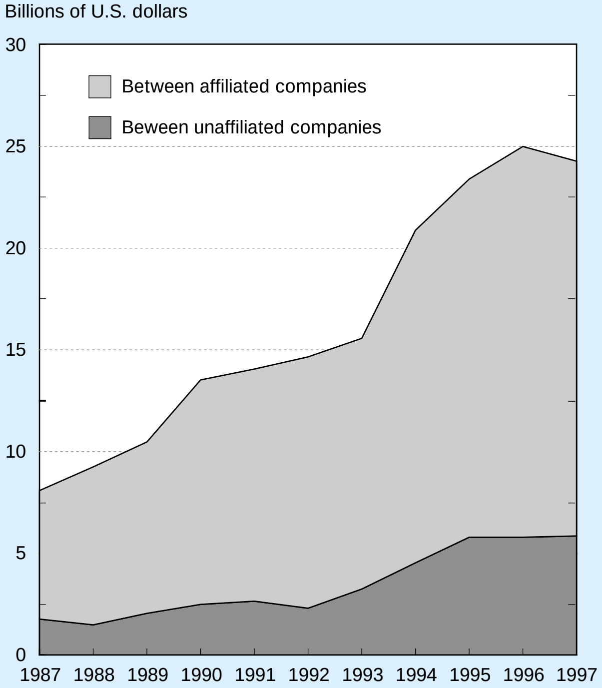
[8] An affiliate refers to a business enterprise located in one country that is directly or indirectly owned or controlled by an entity of another country to the extent of 10 percent or more of its voting stock for an incorporated business or an equivalent interest for an unincorporated business.

Figure 7-15.
U.S. trade balance in intellectual property



See appendix table 7-7. *Science & Engineering Indicators – 2000*

nearly six times U.S. firm payments (imports) to Asia. As previously noted, Japan and South Korea were the biggest customers for U.S. technology sold as intellectual property. Together these countries accounted for more than 55 percent of total receipts in 1997.

The U.S. experience with Europe has been very different from that with Asia. Over the years, the balance of U.S. trade with Europe in intellectual property has bounced back and forth, showing either a small surplus or deficit until 1995. In 1995, United States–Europe trade produced a considerably larger surplus for the United States compared with earlier years, the result of a sharp decline in U.S. purchases of technical know-how from the smaller European countries that year. The following year also showed a large surplus, but this time it was driven by a jump in receipts from the larger European countries. The latest data (1997) show receipts from the larger European countries dropping back to pre-1996 levels, which caused a considerably smaller surplus from U.S. trade with Europe in intellectual property in 1997.

Foreign sources for U.S. firm purchases of technical know-how have changed somewhat over the years, with increasing amounts of coming from Japan. About one-fourth of 1997 U.S. payments for technology sold as intellectual property were made to Japanese firms. Europe still accounts for slightly more than 60 percent of the foreign technical know-how purchased by U.S. firms with France, Germany, and the United Kingdom being the principal European suppliers. Since 1992, however, Japan has been the single largest foreign supplier of technical know-how to U.S. firms.

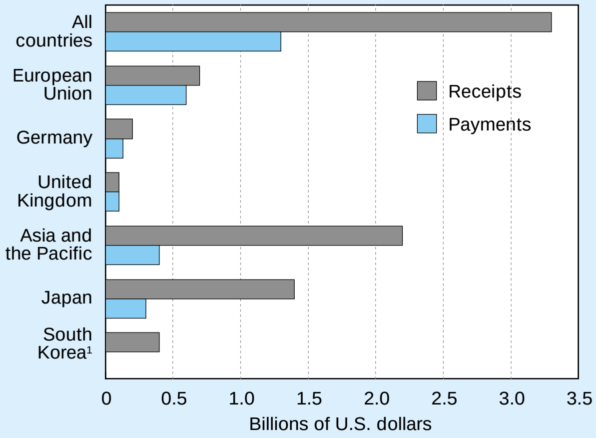
International Trends in Industrial R&D

In high-wage countries like the United States, industries stay competitive in a global marketplace through innovation (Council on Competitiveness 1999). Innovation can lead to better production processes and better-performing products (for example, those that are more durable or more energy efficient). It can thereby provide the competitive advantage high-wage countries require when competing with low-wage countries.

R&D activities serve as an incubator for the new ideas that can lead to new products, processes, and industries. Though they are not the only source of new innovations, R&D activities conducted in industry-run laboratories and facilities are associated with many of the important new ideas that have helped shape modern technology.

U.S. industries that traditionally conduct large amounts of R&D have met with greater success in foreign markets than less R&D-intensive industries and have been more supportive of higher wages for their employees.[9] Moreover, trends in industrial R&D performance serve as leading indicators of future technological performance. This section examines these R&D trends, focusing particularly on growth in industrial R&D activity in the top R&D-performing industries of the United States, Japan, and the European Union.[10]

Figure 7-16.
U.S. royalties and fees generated from the exchange of industrial processes between unaffiliated companies: 1997



[1]Data withheld to avoid disclosing operations of individual companies.
See appendix table 7-8. *Science & Engineering Indicators – 2000*

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[9] See the section, "U.S. Technology in the Marketplace," earlier in this chapter for a presentation of recent trends in U.S. competitiveness in foreign and domestic product markets.

[10] This section uses data from the OECD's Analytical Business Enterprise R&D database (Paris, April 1999) to examine trends in national industrial R&D performance. This database tracks all R&D expenditures (both defense- and nondefense-related) carried out in the industrial sector, regardless of funding source. For an examination of U.S. industrial R&D by funding source and type of research performed, see chapter 2 in this volume, "U.S. and International Research and Development: Funds and Alliances."

Overall Trends

The United States has long led the industrial world in the performance of industrial R&D. During the past two decades, as technology has become more closely associated with firm success in the global marketplace, other advanced economies have put more of their resources into R&D and have increased their industrial R&D performance at an annual growth rate that exceeds that in the United States. (See the sidebar, "Economists Estimate Rates of Return to Private R&D Investment.")

Consequently, the U.S. share of total industrial R&D performed by all OECD member countries fell between 1973 and 1990. (See figure 7-17.) Despite this decline, the United States remained the leading performer of industrial R&D by a wide margin, even surpassing the combined R&D of the 15-nation European Union. For its part, Japan—in keeping with its belief in the economic benefits of investments in R&D—rapidly increased R&D spending in the 1970s and 1980s that led to a large increase in its share of total OECD R&D by 1990. Data for 1996 show U.S. industrial R&D performance accounting for 45.3 percent of total R&D performed in OECD countries, EU performance for 26.4 percent, and Japanese performance for 18.8 percent.

R&D Performance by Industry

The United States, the European Union, and Japan represent the three largest economies in the industrial world and compete head to head in the international marketplace. An analysis of R&D data provides some explanation for past successes in certain product markets, provides insights into future product development, and signals shifts in national technology priorities.[11]

United States

R&D performance by U.S. industry followed a pattern of rapid growth during the 1970s, which accelerated during the early 1980s. That growth pattern stalled during the latter part of the decade and into the 1990s. When adjusted for inflation, U.S. industrial R&D performance shows a period of annual declines, beginning in 1992, that continued through 1994. Since then, U.S. industry has ratcheted up its performance R&D with the latest data showing annual increases of about 7 percent above inflation in both 1995 and 1996. (See figure 7-18 for the top five categories of R&D performance.)

Throughout the 1970s and 1980s, the U.S. aerospace industry was consistently the largest performer of R&D, accounting for 20–25 percent of total R&D performed by U.S. industry. The industry manufacturing electronics equipment and components was the next largest performer during this period, accounting for 11–16 percent. During the 1990s, the Nation's R&D emphasis shifted in several ways. The aerospace industry's share declined while the share for the industry manufacturing communications equipment increased. In 1996, the communications equipment industry became the top R&D performer in the United States. In many ways the more important change to emerge in the 1990s was the rise in R&D performance by U.S. service sector industries. The service sector's share of U.S. industrial R&D performance jumped from 14 percent in 1989 to 19 percent in 1990, and then rose to 24 percent in 1991 and 1992. Since 1992, the pace of R&D performance in the U.S. service sector has slowed somewhat, and R&D performance in the manufacturing sector has picked up. In 1996, manufacturing industries performed nearly 81 percent of total U.S. industrial R&D, while the share attributed to service sector industries dropped to about 19 percent.

Japan

During the 1970s, R&D performance in Japanese industries grew at a higher rate than in the United States. Japanese industry continued to expand its R&D spending rapidly through 1985, more than doubling the annualized growth of the previous decade. Japanese industrial R&D spending slowed somewhat during the second half of the 1980s, but the country still led all other industrial nations in terms of average annual growth in industrial R&D. Unlike the generally declining trend observed for manufacturing industries in the United States, Japanese manufacturing industries consistently accounted for about 95 percent of all R&D performed by Japanese industry. R&D in Japanese service sector industries appears to have accelerated during the early 1990s, but that trend did not continue in 1995 and 1996. The country's industrial R&D continues to be dominated by the manufacturing sector. (See figure 7-19.)

An examination of growth trends for the top five R&D-performing industries in Japan reflects that country's long-standing emphasis on communications technology (including consumer electronics and all types of audiovisual equipment). This industry was the leading performer of R&D throughout the period reviewed. Japan's motor vehicle industry was the third leading R&D performer in 1973, but rose to number two in 1980 and has retained that position nearly every year through 1996. Japanese auto makers earned a reputation for high quality and value during these years, which earned them increasingly larger shares of the global car market.

Electrical machinery producers are also among the largest R&D performers in Japan, and they have maintained high R&D growth throughout the period examined. In 1994, this industry had moved past the motor vehicle industry to become Japan's second leading R&D-performing industry before falling back to its traditional third position in 1995 and 1996. In comparison, the U.S. electrical machinery industry's ranking among the top R&D performers in the United States has dropped steadily since 1973.

The European Union

Like Japan and the United States, manufacturing industries perform the bulk of industrial R&D in the 15-nation European Union. The European Union's industrial R&D appears to be somewhat less concentrated in the mid 1990s than in the United States, but more so than in Japan. Manufactur-

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[11] Industry-level data are occasionally estimated here in order to provide a complete time series for the 1973–96 period.

Economists Estimate Rates of Return to Private R&D Investment

The study of economic returns to R&D investment has developed over the past 30 years. Although estimates of the rates of return differ, the leading researchers in the field agree that R&D has a significant and important positive effect on economic growth and the overall standard of living.

It should be noted, however, that the precise magnitude of these returns cannot be measured without the use of simplifying assumptions in the analysis. A recent survey article by Nadiri (1993) examined 63 studies in this area published by prominent economists, mostly in reference to the United States, but also in reference to Japan, Canada, France, and Germany. Looking at the results of these studies, he concluded that R&D activity renders, on average, a 20- to 30-percent annual return on private (industrial) investments. (See text table 7-2.) This is not to say that every research project has a high, or even a positive, rate of return. Rather, portfolios of scientific research projects selected for analysis have the rates of return cited above. Since they reflect average returns to a selected group of projects, these returns cannot be applied to aggregate R&D expenditures. It should also be pointed out that the more basic the research, the harder it is to evaluate the returns to R&D.

Returns to society overall are estimated to be even higher. Society often gains more from successful scientific advancements than does the organization conducting the research. Therefore, there are two rates of return: the private rate of return, which is based on the expenses incurred and profits made by the company conducting the research, and the social rate of return, which is based on the overall effects on society, including the firm conducting the research.

Recent academic research has also played a key role in enabling technological advances in the private sector. Studies show that approximately 10 percent of the new products and processes developed by firms depend on recent academic research and that the association between academic and industrial research has been strongest in medicine and electronics. (See text table 7-3.) Still, association should not be construed as causation. These studies do not rigorously establish a causal relationship between university research and industrial patents. In fact, that relationship may be reversed, to some extent, by feedback mechanisms, in which industrial patents encourage further research by local universities.

Note: This information was first presented in chapter 8 of *Science and Engineering Indicators 1996*.

Text table 7-2.
Estimated annual rates of return to R&D expenditures in the United States according to various economic studies

Author(s) and year of study	Rate of return[a]
Firm-level studies	
Link (1983)	3
Bernstein-Nadiri (1989b)	7
Schankerman-Nadiri (1986)	13
Lichtenberg-Siegel (1991)	13
Bernstein-Nadiri (1989a)	15
Clark-Griliches (1984)	19
Griliches-Mairesse (1983)	19
Jaffe (1986)	25
Griliches (1980)	27
Mansfield (1980)	28
Griliches-Mairesse (1984)	30
Griliches-Mairesse (1986)	33
Griliches (1986)	36
Schankerman (1981)	49
Minasian (1969)	54
Industry-level studies	
Terleckyj (1980)	0[b]
Griliches-Lichtenberg (1984a)	4
Patel-Soete (1988)[c]	6
Mohnen-Nadiri-Prucha (1986)	11
Terleckyj (1974)	15
Wolff-Nadiri (1987)	15
Sveikauskas (1981)	16
Bernstein-Nadiri (1988)	19
Link (1978)	19
Griliches (1980)	21
Bernstein-Nadiri (1991)	22
Scherer (1982, 1984)	36

[a] For studies for which Nadiri (1993) reports a range of possible returns, the midpoint of that range is provided in this table.

[b] Not significantly different from zero in a statistical sense. This result, however, may be a reflection of limitations in the quantity of data used in the study.

[c] Economy-level study (all industries grouped together).

SOURCE: M.J. Nadiri, "Innovations and Technological Spillovers," Working Paper No. 4423 (Cambridge, MA: National Bureau of Economic Research, 1993).

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Text table 7-3.
Percentage of new products and processes that were dependent on academic research, for selected industries in the United States: 1975–85

	Percent dependent, at least partially, on recent academic research for their timely development		Percent developed with "very substantial aid" from recent academic research	
Industry	Products	Processes	Products	Processes
Information processing	11	11	17	16
Electronics	6	3	3	4
Chemical	4	2	4	4
Instruments	16	2	5	1
Pharmaceuticals	27	29	17	8
Metals	13	12	9	9
Petroleum	1	1	1	1
Average	11	9	8	6

SOURCES: E. Mansfield, "Academic Research and Industrial Innovations," Research Policy 1991, 20:1–12; and E. Mansfield, "Academic Research Underlying Industrial Innovations: Sources, Characteristics, and Financing," *The Review of Economics and Statistics* 77(1): 55–65, 1995.

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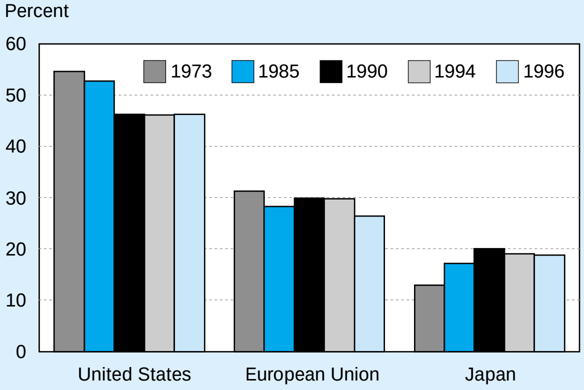
Figure 7-17.
Shares of total industrial R&D in OECD countries

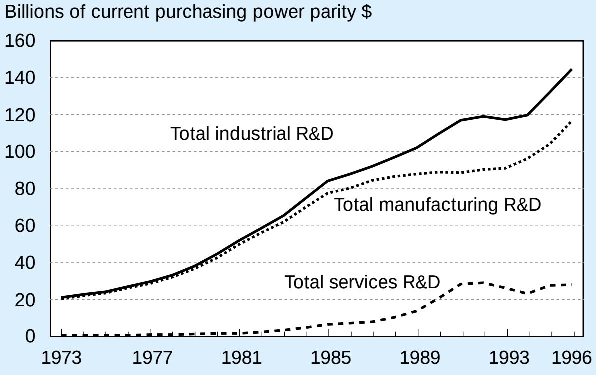


SOURCE: The Organisation for Economic Co-operation and Development, Analytical Business Enterprise R&D database (Paris: 1997). *Science & Engineering Indicators – 2000*

ers of electronics equipment and components, motor vehicles, and industrial chemicals have consistently been among the top five performers of industrial R&D in the European Union. (See figure 7-20.) In 1995, Germany led the European Union in the performance of motor vehicle and industrial chemical R&D, while France led in industrial R&D performed by communications equipment (consumer electronics and all types of audiovisual equipment) manufacturers, and the United Kingdom in pharmaceuticals.

R&D performed by the European Union's service sector has doubled since the mid-1980s, accounting for about 11 percent of total industrial R&D performed by 1995. 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 1995), Italy (15.3 percent), and France (10.0 percent).

Figure 7-18.
U.S. industrial R&D performance: 1973–1996

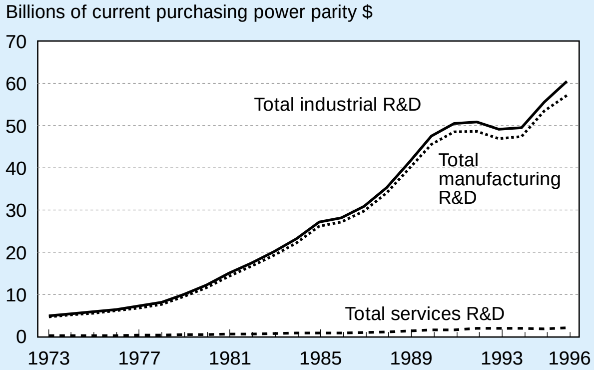


Top industrial R&D performers and their share of total industrial R&D

1976		1986		1996	
Aerospace	23.5%	Aerospace	24.0%	Services (total)	19.5%
Elec. equip. & components	12.1%	Elec. equip. & components	15.6%	Elec. equip. & components	13.2%
Motor vehicles	10.3%	Office machinery & computers	11.2%	Aerospace	11.2%
Office machinery & computers	8.9%	Motor vehicles	11.1%	Motor vehicles	11.1%
Elec. machinery	8.8%	Services (total)	8.5%	Office machinery & computers	8.8%

See appendix table 7-9. *Science & Engineering Indicators – 2000*

Figure 7-19.
Japanese industrial R&D performance: 1973–1996

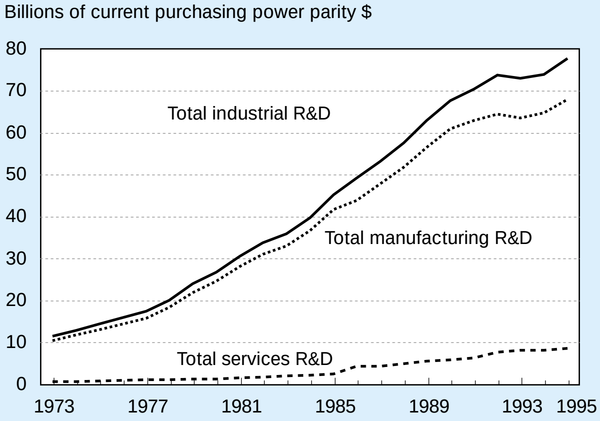


Top industrial R&D performers and their share of total industrial R&D

1976		1986		1996	
Elec. equip. & components	14.9%	Elec. equip. & components	18.1%	Elec. equip. & components	16.1%
Industrial chemicals	12.9%	Motor vehicles	13.1%	Motor vehicles	12.8%
Motor vehicles	11.5%	Industrial chemicals	10.5%	Electrical machinery	10.9%
Elec. machinery	11.0%	Electrical machinery	10.1%	Industrial chemicals	9.2%
Nonelectrical machinery	10.0%	Nonelectrical machinery	8.3%	Nonelectrical machinery	8.7%

See appendix table 7-10. *Science & Engineering Indicators – 2000*

Figure 7-20.
EU 15 industrial R&D performance: 1973–1995



Top industrial R&D performers and their share of total industrial R&D

1976		1986		1995	
Elec. equip. & components	15.6%	Elec. equip. & components	17.0%	Motor vehicles	14.4%
Industrial chemicals	13.3%	Industrial chemicals	11.3%	Elec. equip. & components	14.0%
Aerospace	12.5%	Motor vehicles	11.1%	Services (total)	11.2%
Motor vehicles	10.0%	Aerospace	10.8%	Pharmaceuticals	10.0%
Electrical machinery	8.1%	Electrical machinery	8.0%	Industrial chemicals	9.6%

NOTE: 1996 data are unavailable.

See appendix table 7-11. *Science & Engineering Indicators – 2000*

Patented Inventions

New technical inventions have important economic benefits to a nation, because they can often lead to innovations in new or improved products or more efficient manufacturing processes—or even to new industries. To foster inventive activity, 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 nonobvious.

Patent data provide useful indicators of technical change and serve as a means of measuring inventive output over time.[12] Further, U.S. patenting by foreign inventors enables measurement of the levels of invention in those foreign countries (Pavitt 1985) and can serve as a leading indicator of new technological competition (Faust 1984). Patenting trends can therefore serve as an indicator—albeit one with certain limitations—of national inventive activities.[13]

This section describes broad trends in inventive activity in the United States over time by national origin of owner, patent office class, patent activity, and commerce activity.

U.S. Patenting

In 1998, nearly 148,000 patents were issued in the United States. This record number of new inventions resulting in new patents capped off what had been years of increases since 1990. In 1995, U.S. patents granted fell short of the previous year's mark, but not by much. The upward trend resumed with small increases in U.S. patents granted in 1996 and 1997 before a 32 percent jump in 1998. (See appendix table 7-15.)[14]

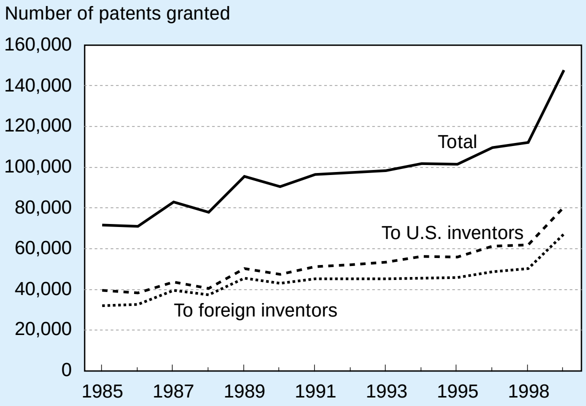
Patents Granted to U.S. Inventors

During the 1980s, the number of U.S. patents awarded to U.S. inventors began to decline just as the number awarded to foreign inventors began to rise. This of course raised questions about U.S. inventive activity and whether these numbers were yet another indicator of U.S. competitiveness on the decline. By the end of the decade, however, U.S. inventor patenting picked up and continued to increase and outpace foreign inventor patenting in the United States. This trend has continued during the 1990s. Rising nearly every year since 1990, U.S. inventors were awarded more than 61,000 new patents in 1996 and more than 80,000 patents in 1998. (See figure 7-21.)

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. Examining patent data by owner's sector of employment can therefore provide a good indication of the sector in which the inventive work was done. In 1998, 79 percent of U.S. owned patents were owned by corporations. (See the sidebar, "Top Patenting Corporations.")[15] This percentage has increased gradually over the years.[16]

After business entities, individuals are the next largest group of U.S. patent owners. Prior to 1985, individuals owned, on average, 24 percent of all U.S. owned patents.[17] Their share has fluctuated downward since then. In 1998, the share accounted for by individuals dropped to its lowest point—20 percent. The Federal share of patents averaged 3.3 percent of the total during the period 1963–84. Thereafter, U.S. Government-owned patents as a share of total U.S. origin patents declined.[18] U.S. Government-owned patents were encouraged

Figure 7-21.
U.S. patents granted, by nationality of inventor



See appendix table 7-12. *Science & Engineering Indicators – 2000*

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[12] See Griliches (1990) for a survey of literature related to this point.

[13] Although the U.S. Patent and Trademark Office 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 and, consequently, it is not advisable to compare patenting rates among different industries or fields (Scherer 1992).
- ♦ *Inconsistency in quality*—the importance of patented inventions can vary considerably.

Despite these and other limitations, patents provide a unique source of information on inventive activities.

[14] Although patent applications have been rising, the U.S. Patent and Trademark Office attributes most of the increase in 1998 to greater administrative efficiency and the hiring of additional patent examiners.

[15] About 5 percent of U.S. patents granted to U.S. inventors in 1998 were owned by U.S. universities and colleges. The U.S. Patent and Trademark Office counts these as being owned by corporations. For further discussion of academic patenting, see chapter 6, "Academic Research and Development: Financial and Personnel Resources, Support for Graduate Education, and Outputs."

[16] From 1985 to 1995, corporate-owned patents accounted for between 73 and 76 percent of total United States–owned patents. Since then, corporations increased their share each year and represented 79 percent of total United States–owned patents in 1998.

[17] Prior to 1985, data are provided as a total for the period 1963–84.

[18] Federal inventors frequently obtain a statutory invention registration (SIR) rather than a patent. An SIR is not ordinarily subject to examination, and it costs less to obtain than a patent. Also, an SIR gives the holder the right to use the invention, but does not prevent others from selling or using it as well.

Top Patenting Corporations

An examination of the top patenting corporations in the United States over the past 25 years illustrates the rapid technological transformation achieved by Japan during a relatively short period. In 1973, no Japanese companies were among the top 10 patenting corporations in the United States. In 1983, three Japanese companies were among the top 10. By 1993, Japanese companies outnumbered U.S. companies, and data for 1996 show 7 Japanese companies among the top 10. The most recent data (1998) now show 1 South Korean company among the top 10—3 U.S. companies, and 6 Japanese companies. (See text table 7-4.) Similar to Japan's, Korea's U.S. patenting now emphasizes computer technologies, television and communications technologies, and power generation technologies. Despite their economic problems, Korea's and Japan's continued success patenting inventions in the United States indicates a growing capacity for innovation in important technologies.

Text table 7-4.
Top patenting corporations

Company	Number of patents
In 1998	
International Business Machines Corp.	2,657
Canon Kabushiki Kaisha	1,928
NEC Corporation	1,627
Motorola Inc.	1,406
Sony Corporation	1,316
Samsung Electronics Co., Ltd	1,304
Fujitsu Limited	1,189
Toshiba Corporation	1,170
Eastman Kodak Company	1,124
Hitachi, Ltd	1,094
From 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, Office of Information Systems, TAF Program.

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by legislation enacted during the 1980s which called for U.S. agencies to establish new programs and increase incentives to their scientists, engineers, and technicians that would facilitate the transfer of technology developed in the course of government activities.[19]

Patents Granted to Foreign Inventors

Foreign-origin patents represent nearly half (46 percent in 1998) of all patents granted in the United States.[20] Their share rose throughout most of the 1980s before edging downward in 1989. At their peak in 1988, foreign-origin patents accounted for 48 percent of total U.S. patents. The following year and up until 1996, U.S. inventor patenting increased at a faster pace than that by foreign inventors, dropping the foreign share to 44 percent. Both U.S. and foreign patenting picked up in 1997 and 1998.

Foreign patenting in the United States is highly concentrated by country of origin. In 1998, two countries—Japan and Germany—accounted for nearly 60 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 7-22.)

While patenting by inventors from the leading industrial countries has leveled off and has even begun to decline in some instances other economies, particularly Asian economies outside Japan, have stepped up their patenting activity in the United States and are showing themselves to be strong inventors of new technologies.[21] This is especially true for Taiwan and South Korea. Before 1985 (data are available starting in 1963), Taiwan was awarded just 568 U.S. patents. Between 1985 and 1995, Taiwan was awarded nearly 9,000 U.S. patents. During the next three years, Taiwan was awarded another 7,000 U.S. patents. U.S. patenting activity by inventors from South Korea shows a similar growth pattern. Before 1985, South Korea was awarded just 172 U.S. patents. Since then, more than 11,000 new patents have been awarded. In 1998, South Korea was awarded more patents than Taiwan, and both countries surpassed Canada to become the fifth and sixth most active foreigner inventors in the United States. Sweden and the Netherlands are two other countries awarded more than 1,000 patents and showing large increases in U.S. patenting in 1998.

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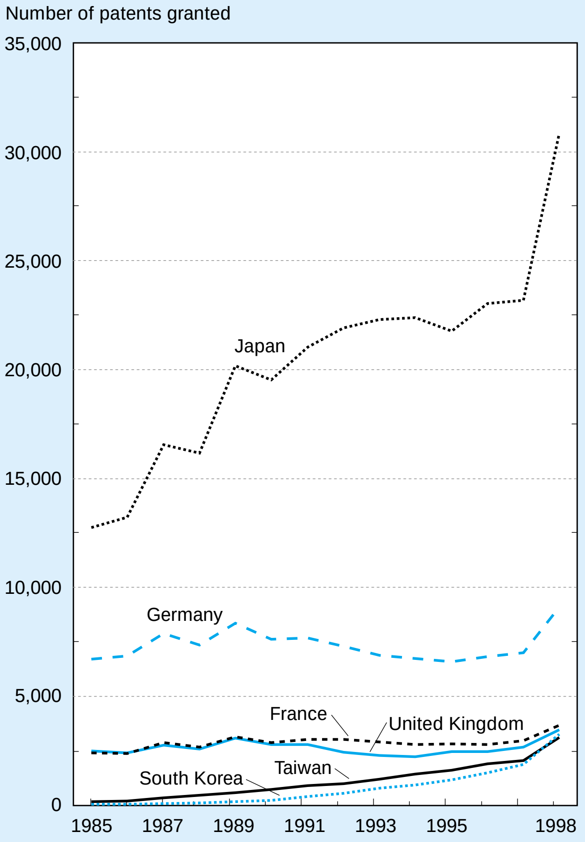
[19] The Stevenson-Wydler Technology Innovation Act of 1980 made the transfer of federally owned or originated technology to state and local governments and to the private sector a national policy and the duty of government laboratories. The act was amended by the Federal Technology Transfer Act of 1986 to provide additional incentives for the transfer and commercialization of federally developed technologies. Later, Executive Order 12591 of April 1987 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.

[20] Corporations account for about 90 percent of all foreign-owned U.S. patents in 1998.

[21] Some of the decline in U.S. patenting by inventors from the leading industrial nations may be attributed to the move toward European unification, which has encouraged wider patenting within Europe.

Figure 7-22.
U.S. patents granted to foreign inventors, by nationality of inventor



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

See appendix table 7-12. *Science & Engineering Indicators – 2000*

Technical Fields Favored by Foreign Inventors

A country's distribution of patents by technical area has proved to be a reliable indicator of a nation's technological strengths, as well as an indicator of direction in product development. This section compares and discusses the various key technical fields favored by inventors in the world's three leading economies—the United States, Japan, and Germany—and in two newly industrialized economies—Taiwan and South Korea.[22]

Fields Favored by U.S., Japanese, and German Inventors

While U.S. patent activity spans a wide spectrum of technology and new product areas, the patenting of U.S. corporations shows a particular emphasis on several of the technology areas that are expected to play an important role in future economic growth. (See U.S. OSTP 1997, pp. 5–9.) In 1997, corporate patent activity reflected U.S. technological strengths in developing new medical and surgical devices, electronics, telecommunications, advanced materials, and biotechnology. (See text table 7-5.)

The 1997 patent data continue to show Japanese inventors emphasizing technology classes associated with photography, office machines, and consumer electronics industries. What is also evident in 1997 is the broader range of U.S. patents awarded to Japanese inventors 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 the processing, storage, and transmission of information.

German inventors continue to develop new products and processes in technology areas associated with heavy manufacturing industries in which that country has traditionally maintained a strong presence. The 1997 U.S. patent activity index shows a German emphasis on motor vehicles, printing, new chemistry and advanced materials, and material handling equipment-related patent classes.

Fields Favored by Two Newly Industrialized Economies

Patent activity in the United States by inventors from foreign countries can be used to identify a country's technological strengths and is also seen as a leading indicator of U.S. product markets likely to see increased competition.

As recently as 1980, Taiwan's U.S. patent activity was primarily in the area of toys and other amusement devices. By the 1990s, Taiwan was active in such areas as communications technology, semiconductor manufacturing processes, and internal combustion engines. The latest available data (1997) show that inventors from Taiwan have continued to patent heavily in processes used in the manufacture of semiconductor devices. They also show heavy activity in computer storage and display devices, advanced materials, and transistors. (See text table 7-6.) Ten years earlier, inventors from Taiwan received only 1 patent in any of these technology classes.

U.S. patenting by South Korean inventors has also shown rapid technological development. The 1997 data show that 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 7-6.)

Both South Korea and Taiwan are already major suppliers of computers and peripherals to the United States. The recent patenting data show that their scientists and engineers are

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[22] Information in this section is based on the U.S. Patent and Trademark Office'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 developing 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.

continuing to develop the new technologies and improve existing technologies. It is likely that these new inventions will enhance their competitiveness in the United States and global markets.

Patenting Outside the United States

In most parts of the world, foreign inventors account for a much larger share of total patent activity than is the case in the United States. When foreign patent activity in the United States is compared with that in 11 other important countries in 1985, 1990, and again in 1996, only Russia and Japan had less foreign patent activity. (See figure 7-23 and appendix table 7-13.)

What is often obscured by the rising numbers in foreign-origin patents in the United States is the success and widespread activity of U.S. inventors in patenting their inventions around the world. In 1996, U.S. inventors led all other foreign inventors not just in countries neighboring the United States, but also in distant and diverse markets, such as Japan, France, Italy, Brazil, India, Malaysia, and Thailand. (See figure 7-24.) Japanese inventors edge out Americans in Germany and dominate foreign patenting in South Korea. German inventors lead all foreign inventors in Russia; they are also quite active in many of the other countries examined.

Venture Capital and High-Technology Enterprise

One of the most serious challenges to new entrepreneurs in the innovation process 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 may include hands-on involvement by the venture capitalist in the firm. Venture capital thus can aid the growth of promising small companies and facilitate the introduction of new products and technologies, and is an important source of funds used in 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 pool of capital managed by venture capital firms grew dramatically during the 1980s as venture capital emerged as a truly important source of financing for small innovative firms. (See text table 7-7.) By 1989, the capital managed by venture capital firms totaled $33.5 billion, up from an estimated $4.1 billion in 1980. The number of venture capital firms also grew during the 1980s—from around 448 in 1983 to 670 in 1989.

In the early 1990s, the venture capital industry experienced

Text table 7-5.
Top 15 most emphasized U.S. patent classes for corporations from the United States, Japan, and Germany: 1997

United States	Japan	Germany
1. Surgical Instruments	Photography	Printing
2. Biology of multicellular organisms	Information storage and retrieval	Plant protecting and regulating compositions
3. Surgery: light, thermal, and electrical applications	Electrophotography	Clutches and power-stop control
4. Surgery: application, storage, and collection	Liquid crystal cells	X-ray or gamma ray devices
5. Prothesis	Facsimile	Organic compounds (includes classes 532–570)
6. Computers and digital processing	Typewriting machines	Fabrication of plastics and earthenware
7. Data processing	Television signal processing	Machine element or mechanism
8. Special receptacle or package	Printing of symbolic information	Winding, tensioning, or guiding devices
9. Telephone communications	Optics: systems and element	Metal deforming
10. Communications: Directive radio wave systems	Active solid-state devices	Internal combustion engines
11. Chemistry: Molecular biology and microbiology	Radiation imagery chemistry	Coating or plastic fabrication
12. Chemistry: Natural resins or derivatives	Storage or retrieval of magnetic information	Paper making
13. Information processing system organization	Internal-combustion engines	Power-driven conveyors
14. Cryptography	Television	Sheet feeding or delivering
15. Chemistry: analytical and immunological testing	Electrical generator or motors	Synthetic resins or natural rubbers

NOTE: Ranking is based on patenting activity of nongovernment U.S. or foreign organizations, which are predominantly corporations. Patenting by individuals and governments is excluded.

SOURCE: U.S. Patent and Trademark Office, Office of Information Systems, TAF Program.

Science & Engineering Indicators – 2000

Text table 7-6.
Top 15 most emphasized U.S. patent classes for corporations from South Korea and Taiwan: 1997

South Korea	Taiwan
1. Television signal processing for recording	Semiconductor device manufacturing process
2. Television	Etching substrate processes
3. Static information storage and retrieval	Solid state devices
4. Semiconductor manufacturing process	Metal treatment
5. Electric lamp and discharge devices	Coded data generation or conversion
6. Dynamic information storage or retrieval	Electrical nonlinear devices
7. Dynamic magnetic information storage or retrieval	Illumination
8. Coded data generation or conversion	Electrical connectors
9. Electric heating	Supports
10. Refrigeration	Fluid sprinkling, spraying, and diffusing
11. Electric lamp and discharge devices	Receptacles
12. Miscellaneous active electrical nonlinear devices	Audio processing systems and devices
13. Liquid crystal cells, elements and systems	Computer graphics processing
14. Winding, tensioning, or guiding	Static information storage and retrieval
15. Electrical power supply or regulation systems	Electronic digital logic circuitry

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 Systems, TAF Program. Science & Engineering Indicators – 2000

a recession of sorts, as investor interest waned and the amount of venture capital disbursed to companies declined—especially compared to the extensive venture capital activity of the late 1980s. The number of firms managing venture capital also declined during the early 1990s, but the slowdown was short-lived. Investor interest picked up during 1992, and disbursements began to rise. Both investor interest and venture capital disbursements have continued to grow through 1998. The latest data show that total venture capital under management rose to $84.2 billion in 1998, more than double the amount managed just three years earlier.

California, New York, and Massachusetts together account for about 65 percent of venture capital resources. It appears that 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.[23]

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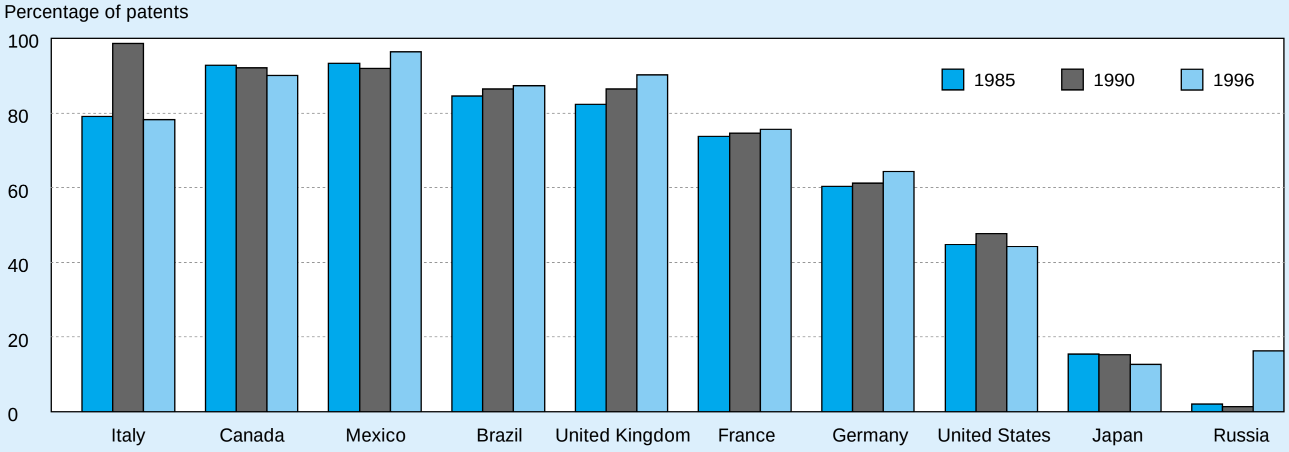
[23] Discussion on the location of venture capital firms is derived from data presented in Venture Economics Information Services (1999). Data on U.S. R&D performance by state are presented in chapter 4, “Higher Education in Science and Engineering.”

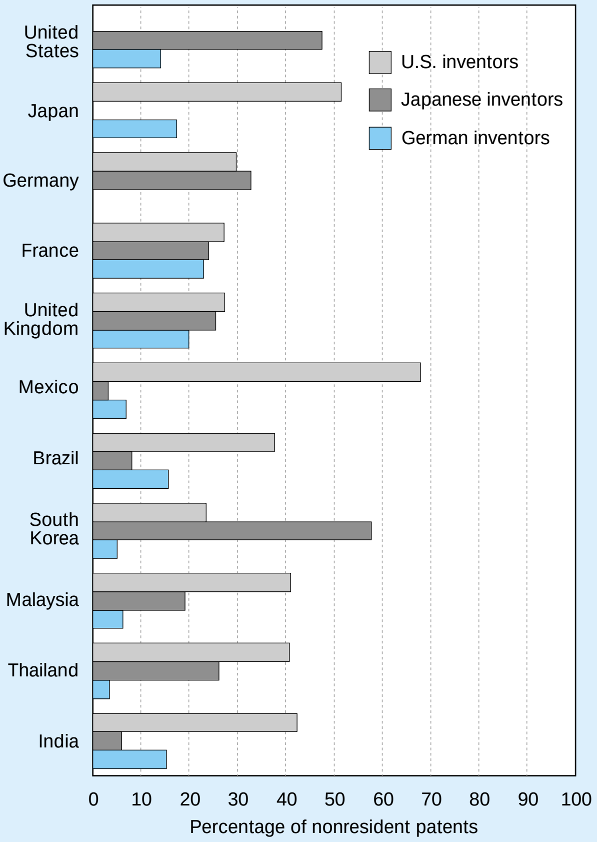
Figure 7-23.
Share of total patents awarded to nonresident inventors



See appendix tables 7-12 and 7-13.

Science & Engineering Indicators – 2000

Figure 7-24.
Patents granted to nonresident inventors: 1996



NOTE: Data for Malaysia and Thailand taken directly from source documents.

See appendix table 7-13. *Science & Engineering Indicators – 2000*

Venture Capital Commitments and Disbursements

Several years of very high returns on venture capital investments have stimulated increased investor interest. This interest soared from 1995 to 1998, with new commitments reaching $25.3 billion in 1998, up from $15.2 billion in 1997, and $10.5 billion in 1996. Pension funds remain the single largest supplier of new funds, supplying nearly 60 percent of committed capital in 1998. Corporations are the next largest source, supplying 12 percent of committed capital, followed closely by individuals at 11 percent.[24]

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 and larger, creating surplus funds available for investments in new or expanding innovative firms. Since 1990, firms producing computer software or providing computer-related services generally received the largest share of new disbursements. (See figure 7-25 and appendix table 7-14.) In 1990, software companies received 17 percent of all new venture capital disbursements, twice the share going to computer hardware companies and biotechnology companies. That share rose to 27 percent in 1993, and again in 1997. The latest data show software companies receiving more than one-third of all venture capital disbursements in 1998. Telecommunications companies also attracted

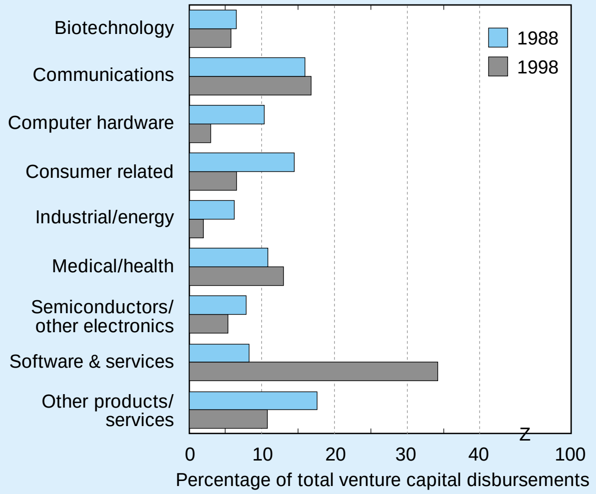
Text table 7-7.
Venture capital under management in the United States: 1980–98
(Millions of U.S. dollars)

	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

SOURCE: 1999 National Venture Capital Association Yearbook, Venture Economics Information Services (1999).

Science & Engineering Indicators – 2000

Figure 7-25.
U.S. venture capital disbursements, by industry category: 1988 and 1998



See appendix table 7-14. *Science & Engineering Indicators – 2000*

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[24] Based on information contained in Venture Economics Information Services (1999).

large amounts of venture capital during the 1990s, and edged out software companies for the lead in 1992 and 1994. Medical and health-care related companies received a large share of venture capital throughout the 1990s, reaching a high of 18 percent in 1994 before dropping to 14 percent in 1998. Computer hardware companies, an industry highly favored by the venture capitalists during the 1980s, received just 3 percent of total venture capital disbursements in the most recent period.

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:[24]

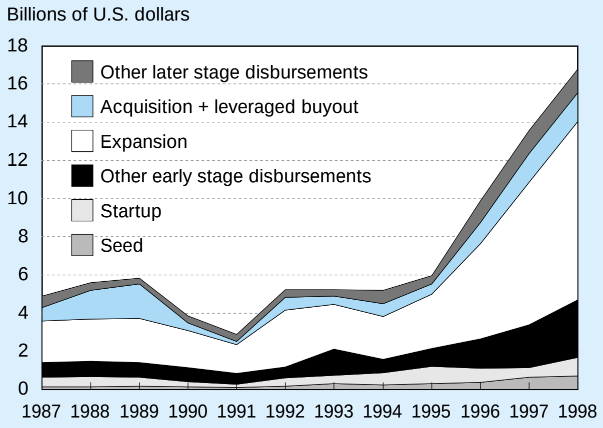
- *Seed financing*—usually involves a small amount of capital provided to an inventor or entrepreneur to prove a concept. It may support product development, but rarely is used for marketing.
- *Startup financing*—provides funds to companies for use in product development and initial marketing. This type of financing usually is provided to companies that are just getting organized or to those that have been in business just a short time, but have not yet sold their products in the marketplace. Generally, such firms have already assembled key management, prepared a business plan, and made market studies.
- *First-stage financing*—provides funds to companies that have exhausted their initial capital and that need funds to initiate commercial manufacturing and sales.
- *Expansion financing*—includes working capital for the initial expansion of a company, funds for either major growth expansion (involving plant expansion, marketing, or development of an improved product development), 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.[25]
- *Management and leveraged buyout*— includes funds to enable operating management to acquire a product line or business from either a public or private company. Often these companies are closely held or family owned.[26]

For this report, the first three are referred to as early-stage financing and the remaining three as later-stage financing.

An examination of venture capital disbursements by financing stage clearly shows that most of the funds are directed to later-stage investments. Since 1982, later-stage investments captured between 59 and 75 percent of venture capital disbursements, with the high and low points both reached in the 1990s. In 1998, later-stage investments represented 72 percent of total disbursements. (See figure 7-26 and appendix table 7-15.) Capital for company expansions attracted by far the most investor interest with this financing stage alone attracting more than half of all venture capital disbursed since 1995.

Contrary to how venture capital is often viewed, only a relatively small amount of venture capital goes to the struggling inventor or entrepreneur trying to prove a concept or to help with product development. Over the 19-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. Seed financing represented about 5 percent of all venture capital in four of the last five years. Consistent with observations made when all venture capital investments are examined, firms developing computer software, telecommunications technologies, and those classified as medical and health-related are the largest recipients of venture capital seed-type financing in the late 1990s. (See appendix table 7-16.) Computer software is the leading technology area receiving seed-type financing, although its share is slightly lower than that seen in the examination of total venture capital investments (34 percent overall versus 32 percent as seed money). Recently, telecommunications firms gained favor with forward-looking venture capitalists and attracted 21 percent of venture capital seed-stage investments in 1998, up from 15 percent in 1997, and 7 percent in 1996. Medical and health-related firms received about 20 percent in each of the last two years examined.

Figure 7-26.
U.S. venture capital disbursements, by stage of financing: 1987–98



See appendix table 7-15. *Science & Engineering Indicators – 2000*

Summary: Assessment of U.S. Technological Competitiveness

This chapter brings together a collection of indicators that contrast and compare national technological competitiveness across a broad range of important technological areas. Based on the various indicators of technology development and market competitiveness examined, the United States continues to lead or be among the leaders in all major technology areas. Advancements in information technologies (computers and telecommunications products) continue to influence new technology development and to dominate technical exchanges between the United States and its trading partners.

Asia's status as both a consumer and developer of high-technology products has been enhanced by the technological development taking place in the newly industrialized Asian economies—in particular, South Korea and Taiwan—and in emerging and transitioning economies, such as China, Malaysia, and the Philippines. Based on the trends presented in this chapter in patenting, in high-technology production, and purchases of technological know-how, Asia's influence in the marketplace seems likely to expand in the future as other technologically emerging Asian nations join Japan as both technology producers and consumers.

The current strong position of the United States as the world's leading producer of high-technology products reflects its success both in supplying a large home-based market, as well as in serving foreign markets. In addition to the Nation's long commitment to investments in S&T, this success in the international marketplace may in part be a function of scale effects derived from serving this large, demanding domestic market. It may be further aided by 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. business, rising exports of high-technology products and services to expanding economies in Asia, Europe, and Latin America are already apparent in the U.S. trade data and should grow in the years ahead. For research, the same conditions that create new business opportunities—the growing global technological capacity and the relaxation of restrictions on international business—can lead to new opportunities for the U.S. S&T research community. The many new, well-funded institutes and technology-oriented universities surfacing in many technologically emerging areas of the world will further scientific and technological knowledge and lead to new collaborations between U.S. and foreign researchers.

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Chapter 8

Science and Technology: Public Attitudes and Public Understanding

Contents

Highlights

Interest in—and Knowledge about—Science and Technology

- **In National Science Foundation (NSF) surveys conducted during the past two decades, about 9 out of every 10 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.
- **The number of people who feel either well informed or moderately well informed about science and technology is fairly low.** In 1999, only 17 percent of those surveyed described themselves as well informed about new scientific discoveries and the use of new inventions and technologies; approximately 30 percent thought they were poorly informed.
- **Most Americans know a little, but not a lot, about science and technology.** Between 1997 and 1999, however, public understanding of basic science concepts and terms increased slightly.
- **Although there was little change in the late 1990s in the percentage of correct responses to most of the survey questions pertaining to knowledge of basic science concepts and terms, the percentage of correct responses to three items did increase.** More people are able to define a molecule, the Internet, and DNA. The growing awareness of DNA is probably attributable to heavy media coverage of the use of DNA in crime-solving and in advancements in the field of medicine.
- **About three-quarters of Americans lack a clear understanding of the nature of scientific inquiry.** Although more than one-half have some understanding of probability, only one-third were familiar with how an experiment is conducted and less than one-quarter could adequately explain what it means to study something scientifically.

Public Attitudes Toward Science and Technology

- **There seems to have been a small, upward trend in positive attitudes toward science and technology.** Overall, data from the NSF survey show increasing percentages of Americans *agreeing* that “science and technology are making our lives healthier, easier, and more comfortable” and *disagreeing* that “we depend too much on science and not enough on faith.”
- **Although no detectable change occurred in overall public attitudes toward genetic engineering in the late 1990s, there was an increase in the number of individuals expressing reservations among (1) college graduates and (2) that portion of the public classified as attentive to new medical discoveries.** Among the former, the percentage who agreed that the harms of genetic engineering are greater than the benefits increased from 20 percent in 1995 to 29 percent in 1999. Among the latter group, the percentage rose from 30 percent in 1997 to 36 percent in 1999.

International Comparisons

- **North Americans and Europeans appear to have more favorable attitudes toward science and technology than the Japanese.** In addition, U.S. residents seem to harbor fewer reservations about science and technology than their counterparts in Europe, Canada, and Japan.
- **In North America, Europe, and Japan, university-educated citizens have the most positive attitudes toward science and technology, and the least reservations, whereas those who did not complete high school have the least favorable attitudes and the most reservations.** The inverse relationship between education and reservations about science and technology seems to be strongest in the United States, compared with three other sociopolitical systems.

Use of Computers and Computer Technology in the United States

- **In 1999, for the first time ever, a majority (54 percent) of American adults had at least one computer in their homes.** The percentage has been rising steadily since 1983, when only 8 percent had computers in their homes.
- **Approximately one-third of Americans subscribed to an online service and had home e-mail addresses in 1999.** Among those with access to the Internet, the amount of time spent using e-mail and visiting Web sites increased from an average of 80 hours per year in 1995 to approximately 270 hours in 1999.
- **The number of people without access to a computer either at home or at work fell substantially between 1983 and 1999—from 70 percent down to 34 percent.** However, more than 70 percent of those without high school diplomas did not have access to a computer either at home or at work in 1999.

The Relationship Between Science and the Media: Communicating with the Public

- **The science community and the news media are missing opportunities to communicate with each other and the public.** A recent study identified several problems including (1) scientists’ distrust of the media, (2) a perceived lack of public interest in science, (3) communication barriers, and (4) the need for a better informed and educated public. Both scientists and the media could do a better job of communicating with the public so that taxpayers gain a better understanding of what they are getting from their investment in research and development (R&D).
- **Belief in paranormal phenomena, including astrology, extrasensory perception, and alien abductions, is fairly widespread.** Such beliefs may reflect a lack of scientific literacy or indicate a dearth of critical thinking skills needed not only to understand what is going on in the world, but also to make well-informed choices at the ballot box and in other day-to-day living activities. Depictions of paranormal activities in the entertainment media probably exacerbate the problem.

Introduction

Chapter Overview

Most Americans have highly positive attitudes toward science and technology. There is strong support for government investment in basic research, and Americans also appreciate technological advancements, especially rapidly expanding communication capabilities such as the Internet, which have permeated—and are having a pervasive impact on—an ever expanding number of daily living activities.

The news about science literacy is less positive. Americans do not seem to know much about science, especially the scientific process. Moreover, the prevalence of scientific illiteracy, or a dearth of critical thinking skills, may mean that many Americans are not adept at making, or adequately prepared to make, well-informed choices at the ballot box or in their personal lives.

Most Americans rely on television and newspapers as their major sources of information. Although the media can be commended for providing more access to more information than ever before, there is some concern that the press—with more cooperation from the science and engineering community—could do a better job of informing the public about science and technology and their contribution to economic prosperity, national security, and the health and well-being of society. In addition, the increase in information has led to "information pollution" or the presentation of fiction as fact in a growing number of television shows. The fact that many Americans are having trouble distinguishing between the two has caught the attention of the science—and science policy—community, where concern about the state of scientific literacy has never been higher. A technological society, one that is increasingly dependent on the intellectual capacity of its citizens, cannot afford to ignore ignorance.

Chapter Organization

This chapter begins with a discussion of the public's interest in, and knowledge about, science and technology. The level of interest in science and technology is an indicator of both the visibility of the science and engineering community's work and the relative importance accorded science and technology by society. The first section also contains data on the level of public understanding of basic science concepts and the nature of scientific inquiry and information on the level of interest and understanding in other countries.

In the second section, public attitudes toward science and technology 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, nuclear power, genetic engineering, space exploration, and the use of animals in scientific research.

The third section is devoted to a discussion of computer usage, which is a relatively new way for the public to have access to information about science and technology. The fourth section covers findings from a recent study on science and the media. Finally, concerns about belief in paranormal phenomena are examined in the last section of this chapter.

Interest in~~an~~d Knowledge about—Science and Technology

Americans are quick to say they are interested in news about science and technology. In NSF surveys[1] conducted during the past two decades, about 9 of every 10 adults report being very or moderately interested in new scientific discoveries and the use of new inventions and technologies. However, the number who feel well—or moderately well—informed about these subjects is considerably smaller, and evidence shows their lack of confidence in their knowledge is justified. That is, most Americans know a little, but not a lot, about science and technology.[2]

In this section, four topics will be covered:

- public interest in science and technology and other issues,
- the public's self-assessed level of knowledge about science and technology and other issues,

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[1] Thirteen of the 14 *Indicators* volumes published since 1972 have included a chapter on public attitudes toward and understanding of science and technology. 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. The 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 results can be found in past volumes of *Indicators* (NSB biennial series).

In general, the response rate for each of the NSF surveys has been at 70 percent or higher. However, for the 1999 survey, the response rate was 66 percent. For more information on the 1999 survey methodology, see Miller, Kimmel, and Hess 2000.

[2] It is often suggested that people tend to respond to surveys by supplying what they think are "correct" or "expected" answers. For example, expressing interest in news stories about science and technology could be deemed a correct response. Although surveys (in addition to NSF's) have consistently shown high levels of interest in science and technology (Gannett 1996, Pew Research Center 1997), evidence that the average news consumer actually pays attention to reports covering these topics is lacking (Hartz and Chappell 1997). Research sponsored by the Pew Center for the People and the Press provides further insight leading to the conclusion that people may not be entirely truthful when responding to survey questions about their interests in various types of news subject. The study revealed that, although relatively few people claim to have interest in news stories about celebrities and scandal, their actual level of knowledge about these subjects is higher than that for any other news category (Parker and Deane 1997).

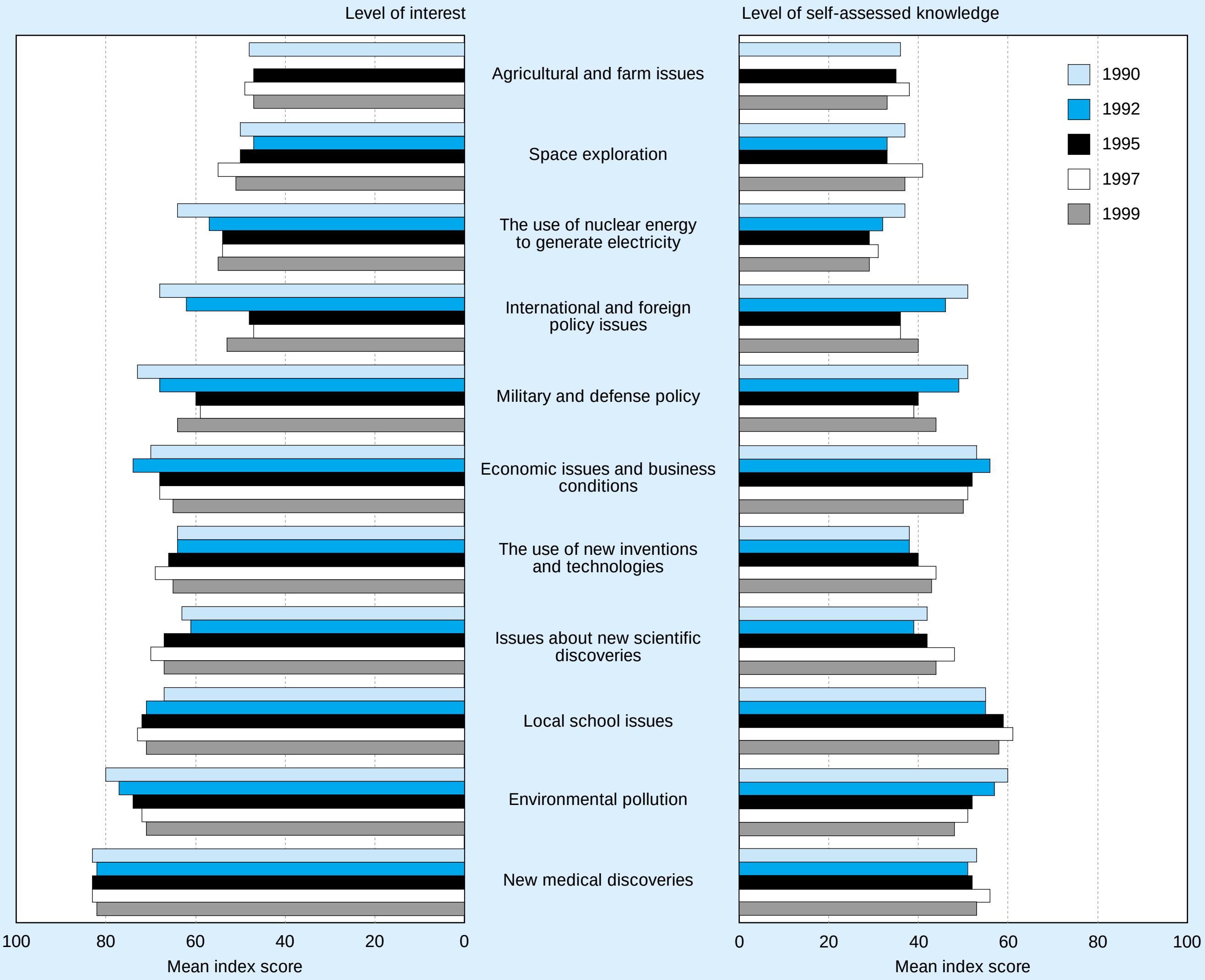
- the "attentive" public for science and technology policy, and
- public understanding of science and technology.

Public Interest in Science and Technology and Other Issues

U.S. residents say they are quite interested in science and technology. More than 40 percent of those who participated in NSF's 1999 Survey of Public Attitudes Toward and Understanding of Science and Technology said they were very interested in new scientific discoveries and in the use of new inventions and technologies; another 40 to 50 percent said they were moderately interested in these subjects; and about 10 percent reported no interest. (See appendix table 8-1.) Among the 11 topics included in the survey, only the level of interest in new medical discoveries, environmental pollution, and local school issues appears higher. (See figure 8-1.)

Approximately two-thirds of the respondents said they were very interested in new medical discoveries. None of the other policy issues received anywhere near such a high percentage of "very interested" responses.[3] Local school issues was a

Figure 8-1.
Indices of public interest in and self-assessed knowledge about scientific and technological issues: 1990–99



See appendix tables 8-2 and 8-5.

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[3] Surveys sponsored by Research!America show overwhelming public support for medical research. It is not a coincidence that the high level of support—coupled with the high level of interest in new medical discoveries—coincides with historically strong Federal financial support of research sponsored by the National Institutes of Health (NIH) (Hartz and Chappell 1997). (See chapter 2, " U.S. and International Research and Development: Funds and Alliances.") Interestingly, NIH has relatively little name recognition; less than 5 percent of the public can name the government agency that funds most of the medical research paid for by taxpayers. In contrast, 57 percent can name the National Aeronautics and Space Administration (NASA), and 70 percent can name the Food and Drug Administration (Research!America 1999).

distant second, with 54 percent of the respondents saying they were very interested in this topic, followed by environmental pollution at 51 percent. (See appendix table 8-1.)

Issues receiving between 40 and 50 percent "very interested" responses were new scientific discoveries (45 percent), military and defense policy (42 percent), economic issues and business conditions (42 percent), and the use of new inventions and technologies (41 percent). Percentages for the other four issues ranged from 30 percent for international and foreign policy to 22 percent for agricultural and farm issues. Interest in space exploration is relatively low; it ranked next to last among the 11 issues.[4] (See appendix table 8-1.)

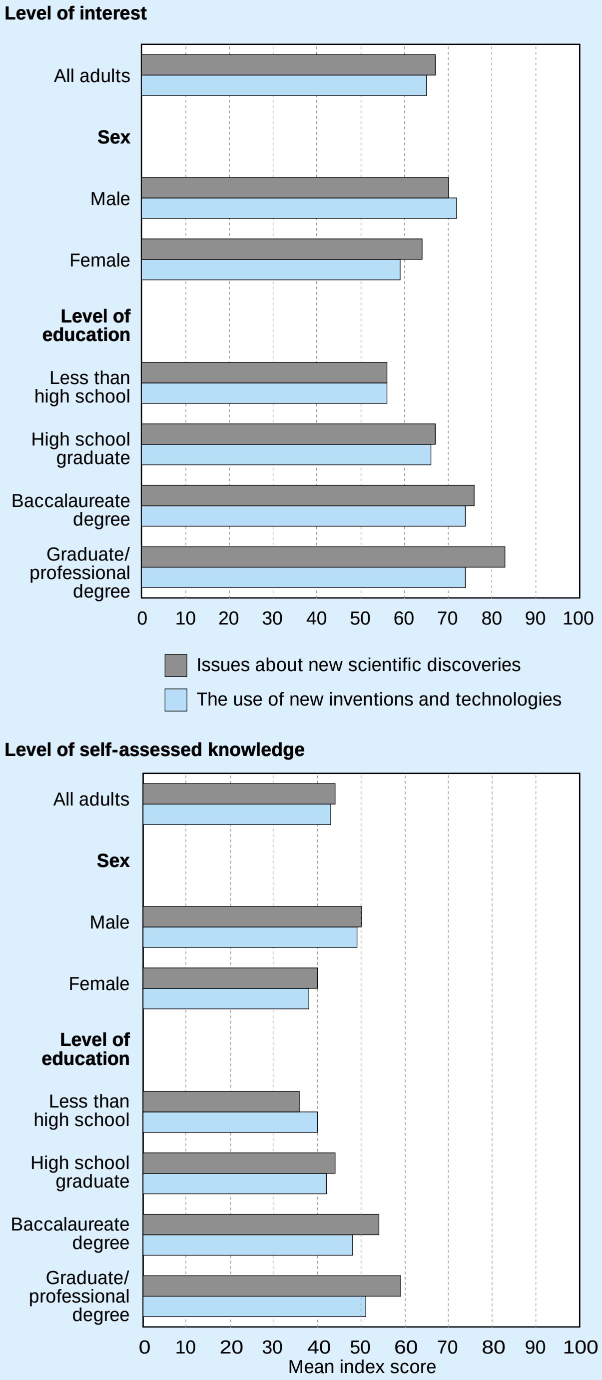
Interest in science and technology may be at its highest level ever. Using a 0–100 index,[5] the average level of public interest in new scientific discoveries ranged between 67 and 70 in the late 1990s; only in one other year (1983) did it reach that level, although it has always been at 60 or higher. Interest in new inventions and technologies tracks quite closely with that of new scientific discoveries; in 1999, the index levels for the two issues were 65 and 67, respectively. (See figure 8-2 and appendix table 8-2.)

New medical discoveries is the only issue that has consistently had index scores in the 80s; those for environmental pollution and local school issues have generally been in the 70s. Interest in environmental pollution seems to have subsided slightly in the 1990s. (See appendix table 8-2.)

Among the other survey findings:

- Interest in economic issues and business conditions has dipped somewhat since 1992, when it ranked third among the 11 issues in the survey. The decline in interest may be attributable to the health of the U.S. economy in the mid- and late 1990s.
- Interest in military and defense policy and in international and foreign policy reached a peak in 1990 (coinciding with the pending Gulf War at the time the survey was conducted). Interest in international and foreign policy took an upward swing between 1997 and 1999, from 47 to 53, which may reflect heightened interest stemming from the war in the Balkans.
- Interest in the use of nuclear energy to generate electricity fell from 64 in 1990 to 54 in 1995; little change in the level of interest occurred in the late 1990s. (See appendix table 8-2.)

Figure 8-2.
Indices of public interest in and self-assessed knowledge about scientific and technological issues, by sex and level of education: 1999



See appendix tables 8-3 and 8-6.

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Comparing Interest by Sex and Level of Education

Men express more interest than women in new scientific discoveries and in the use of new inventions and technologies. (See figure 8-2.) The gap is particularly large for the latter. Only space exploration has a larger disparity. Men also

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[4] An earlier survey produced results mirroring those of NSF's: 43 percent of that survey's respondents said they were very interested in learning more about science discoveries in general, and 45 percent said they were very interested in learning more about new inventions. In addition, 67 percent reported being very interested in learning more about advances in medicine. In contrast, only 32 percent had this level of interest in learning more about space exploration (Roper 1996).

[5] Responses were converted to a 0–100 scale 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. Indices were obtained by adding all the values for each issue and taking the average.

express more interest than women in economic and business conditions, military and defense policy, international and foreign policy, and nuclear energy. Women are more interested in new medical discoveries, environmental pollution, and local school issues. (See appendix table 8-3.)

Level of formal education and number of mathematics and science courses taken are strongly associated with interest in new scientific discoveries. (See figure 8-2 and appendix table 8-3.) The relationship between education and level of interest is also strong for space exploration, economic issues and business conditions, and for international and foreign policy—and somewhat less strong for the use of new inventions and technologies and new medical discoveries. Local school issues, the use of nuclear energy to generate electricity, and environmental pollution do not seem to show a relationship between level of interest and level of education. Finally, those with relatively low levels of formal education are more likely than others to express high interest in agricultural and farm issues. (See appendix table 8-3.)

International Comparisons

In general, a substantial amount of similarity exists between U.S. residents and those in three other “sociopolitical systems,”[6] in terms of interest in particular public policy issues.[7] For example, for all four—the United States, the European Union, Japan, and Canada—the Index of Issue Interest in environmental issues is in the low to middle 70s. However, survey respondents in the United States and Canada seem to have higher levels of interest in health and medical issues than their counterparts in Europe and Japan. (See text table 8-1.)

Americans are somewhat more interested than Europeans in new scientific discoveries and in new inventions and technologies, whereas Europeans are slightly more interested than Americans in environmental issues.

The Japanese appear to be less interested than Europeans or North Americans in science and technology. In general, Japanese adults express relatively more interest in economic matters and local issues—for example, land use—than in new scientific discoveries and the use of new inventions and technologies. A significantly higher percentage of college-educated respondents in Japan (compared with the percentage of those with less formal education) reported substantial interest in scientific and technological issues, which is also the case in Europe and in North America (Miller, Pardo, and Niwa 1997).

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[6] The term “sociopolitical systems” is used because data for Europe were collected with one survey, the 1992 Eurobarometer. Residents of 11 countries participated in this survey. Those countries are Belgium, Denmark, England, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal, and Spain.

[7] The international information in this chapter comes from a comparative analysis of data from the following sources: the 1992 Eurobarometer, the 1995 NSF Survey of Public Understanding of and Attitudes Toward Science and Technology, the 1991 Japan National Study, and the 1989 Canadian National Study (Miller, Pardo, and Niwa 1997).

Text table 8-1.
Issue interest index scores for the European Union, the United States, Japan, and Canada

Issue	Mean scores European Union (1992)	United States (1995)	Japan (1991)	Canada (1989)
New scientific discoveries	61	67	50	63
New inventions and technologies	59	66	53	58
New medical discoveries	68	83	65	77
Environmental issues	75	74	71	74
Space exploration	–	50	45	48
Energy/nuclear power	–	54	59	–
Computers and related technologies	–	–	–	43
Economic policy	–	68	65	52
Education/local schools	–	72	62	–
Agricultural issues	–	47	56	–
Military/defense issues	–	60	56	–
Foreign & international policy	–	48	55	–
Politics	55	–	–	50
Sports news	48	–	–	42
Taxes	–	–	71	–
Land use issues	–	–	65	–
Senior citizen issues	–	–	74	–

– = Issue not included in the survey

SOURCE: J.D. Miller, R. Pardo, and F. Niwa, *Public Perceptions of Science and Technology: A Comparative Study of the European Union, the United States, Japan, and Canada* (Chicago: Chicago Academy of Sciences,1997).

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The Public's Self-Assessed Level of Knowledge about Science and Technology and Other Issues

In general, Americans do not believe they are well informed about issues pertaining to science and technology. In fact, for all issues included in the NSF survey, the level of self-assessed knowledge appears considerably lower than the level of expressed interest. This is especially true for complex subjects, like science and technology, where a lack of confidence in understanding what goes on in laboratories or within the policymaking process is understandable. For example, in 1999, at least 40 percent of respondents in NSF's public attitudes survey said they were very interested in science and technology. Yet only 17 percent described themselves as well informed about new scientific discoveries and the use of new inventions and technologies; approximately 30 percent thought they were poorly informed. (See appendix table 8-4.)

Thus, index scores for the responses to the questions having to do with how well informed people think they are about various issues were lower than those for the level of interest in those same issues. (See figure 8-1.) In 1999, three had index scores in the 50s (local school issues, new medical discoveries, and economic issues and business conditions); five, in the 40s (environmental pollution, new scientific discoveries, military and defense policy, the use of new inventions and technologies, and international and foreign policy); and three, in the 20s or 30s (space exploration, agricultural and farm issues, and the use of nuclear energy to generate electricity). (See appendix table 8-5.)

In the 1990s, for most issues, there were no discernible trends in the level of self-assessed knowledge. However, there seems to have been a decline in perceived knowledge about environmental pollution and the use of nuclear energy to generate electricity. (See appendix table 8-5.)

Level of Self-Assessed Knowledge, by Sex and Level of Education

For 8 of the 11 issues in the 1999 survey, male respondents reported higher self-assessment of their knowledge than female respondents. For five of these issues—economic issues and business conditions, military and defense policy, the use of new inventions and technologies, international and foreign policy, and space exploration—the gender gap is more than 10 index points. (See appendix table 8-6.)

In contrast, women have higher index scores than men on two issues—local school issues and new medical discoveries—but the disparity in scores between the two sexes is relatively small. For environmental pollution, the index scores were identical in 1999.

As expected, generally, the more education one has—and the more mathematics and science courses one has taken—the better informed one thinks he or she is. The relationship between education and self-assessed knowledge is particularly strong for new scientific discoveries, the use of new inventions and technologies, and space exploration. It is also strong for economic issues and business conditions and for international and foreign policy issues, but weak or nonexistent for the other issues in the survey. (See appendix table 8-6.)

The "Attentive" Public for Science and Technology Policy

No one has the time or the inclination to keep up with every issue on the public policy agenda. Moreover, not many people are interested in many issues. A recent study contained the following conclusion:

> An analysis of public attentiveness to more than 500 news stories over the last 10 years confirm[ed] that the American public pays relatively little attention to many of the serious news stories of the day. The major exceptions to this rule are stories dealing with natural and man-made disasters and U.S. military actions[8] (Parker and Deane 1997).

Also, different people will be interested in, and will be well informed about, different issues. Some are interested in particular issues that affect their daily lives. For example, parents of school-age children are more likely than others to show interest in issues having to do with the quality of schools in their communities. Chances are these parents are not only interested in, but well-informed about, local school issues. Others are just interested in particular issues, and because of their interest, they have taken the time to become knowledgeable about them; they probably also follow public policy developments in their areas of interest.

It may not be easy to pinpoint exactly who is the audience for issues pertaining to science and technology policy. It is probably safe to say that members of the science and engineering workforce, especially those in the academic community, are probably interested in, and well informed about, various science and technology policy issues, but the number of members in this community is relatively small. (See chapter 3, "Science & Engineering Workforce," and chapter 6, "Academic Research and Development: Financial and Personnel Resources, Support for Graduate Education, and Outputs.") In addition, other members of the public follow news reports about new scientific discoveries and new inventions and technologies. It is interesting to single out the audience for science and technology policy so that their attitudes and knowledge can be compared with those of everyone else.

Therefore, it is useful to classify the public into three groups:

- ♦ The attentive public: Those who (1) express a 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

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[8] The most closely followed news stories from 1986 through the middle of 1999 were identified by the Pew Research Center for People and the Press. In all, there were 689 such stories. Only 39 can be considered to have anything to do with science or technology, a small proportion (less than 6 percent) of the total. Most of those have to do with weather and earthquake coverage, lending credence to the truism that stories about natural and made disasters are more likely than others to grab the public's attention. It should be noted that a science-related story is at the top of the list: the most closely watched story of the period was the explosion of the Space Shuttle Challenger in 1986. (See sidebar, "The Most Closely Followed Science-Related News Stories: 1986–99.")

The Most Closely Followed Science-Related News Stories: 1986–99

For nearly 15 years, the Pew Research Center for the People and the Press (1999b) has been tracking the most closely followed news stories in the United States. Out of 689 stories identified by the Center during the period, 39 have at least some relevance to science and medicine. Those stories, and the month and year the public was surveyed (which is a good indication of when the event occurred), are listed below. Next to each entry is the percentage of those surveyed who said they were following the story “very closely” (the other choices given to respondents were “fairly closely,” “not too closely,” or “not at all closely”).

Weather is the subject of 12 of the stories on the list; they are clustered toward the top. Ten stories involve coverage of space exploration, including the lead story of the period studied, the explosion of the Space Shuttle Challenger. Four news stories are about earthquakes and the damage they cause. Two are about problems at nuclear reactor plants. Health is the subject of six stories, and three are about efforts to clone animals and people.

80%	Explosion of the Space Shuttle Challenger (July 1986)
73%	Destruction caused by the San Francisco earthquake (November 1989)
66%	Hurricane Andrew (September 1992)
65%	The floods in the Midwest (August 1993)
63%	Earthquake in Southern California (January 1994)
51%	News about cold weather in the Northeast and Midwest (January 1994)
50%	Flight of the Space Shuttle (October 1988)
49%	Drought and its effects on American farmers (August 1988)
48%	The blizzard on the East Coast (January 1996)
46%	Nuclear accident at Chernobyl in the Soviet Union (July 1986)
42%	Hot weather this summer and the greenhouse effect (August 1988)
39%	Unseasonable weather patterns (December 1998)
38%	The heat wave and its impact throughout the country (July 1998)
37%	The floods in California (March 1995)
36%	Hurricane Mitch and the rain and mudslides in Central America (November 1998)
34%	John Glenn’s flight on the Space Shuttle Discovery (November 1998)
34%	Floods in the Pacific Northwest (January 1997)
34%	Reports about flooding in Texas and other southwestern states (June 1990)
28%	Problems at nuclear reactor plants (October 1988)
25%	The earthquake in Japan (February 1995)
24%	The breast implant controversy (February 1992)
24%	Deployment of the Hubble Space Telescope (May 1990)
23%	The controversy over whether women in their forties should have regular mammograms (February 1997)
22%	The exploration of the Planet Mars by the Pathfinder Spacecraft (August 1997)
22%	Discoveries made by the spacecraft Voyager 2 (September 1989)
21%	Plans by a Chicago scientist to open a clinic for cloning people (January 1998)
20%	Earthquake in Iran (July 1990)
19%	The outbreak of an Asian flu spread by birds or chickens (January 1998)
17%	The cloning of a sheep by a Scottish biologist (April 1997)
15%	The new drug Viagra designed to help men overcome impotence (June 1998)
15%	The problems aboard the Russian Space Station Mir (September 1997)
14%	The problems aboard the Russian Space Station Mir (August 1997)
11%	The return of Space Shuttle astronaut Shannon Lucid to Earth (October 1996)
11%	The outbreak of plague in India (October 1994)
9%	The debate over U.S. policy concerning global warming (November 1997)
9%	Discovery of scientific evidence of the beginnings of the universe (May 1992)
9%	AIDS conference in San Francisco (July 1990)
8%	NASA’s discovery of possible life on Mars (September 1996)
6%	The cloning of mice by scientists in Hawaii (July 1998)

a weekly or monthly news magazine, or read a magazine relevant to the issue.[9]

- The interested public: Those who claim to have a high level of interest in a particular issue, but do not feel well informed about it.
- The residual public: Those who are neither interested in, nor feel well-informed about, a particular issue.

There is an attentive public for every policy issue; these groups differ in size and composition.

Data for 1999 show that, for most issues covered by the NSF survey, less than 10 percent of the public can be considered attentive. New medical discoveries has the largest audience: 16 percent of all survey respondents in 1999 were classified as attentive to that subject. (See appendix table 8-7.)

Those likely to be attentive to science and technology policy issues are identified by combining the attentive public for new scientific discoveries with the attentive public for new inventions and technologies. In 1999, 12 percent of the population qualified for that distinction, down from 14 percent in 1997. Forty-four percent of the population can be classified as the "interested public" for science and technology issues with the "residual" population also at 44 percent of the total. (See appendix table 8-7.)

The Attentive Public for Science and Technology Policy, by Sex and Level of Education

A direct correlation exists between attentiveness to science and technology policy issues, years of formal education, and the number of science and mathematics courses taken during high school and college. In 1999, only 9 percent of people without high school diplomas were classified as attentive to science and technology policy issues, compared with 23 percent of those with graduate and/or professional degrees. Similarly, 9 percent of those with limited coursework in science and mathematics were attentive to science and technology policy issues, compared with 19 percent of those who had taken nine or more high school and college science or math courses. Men were more likely than women to be attentive to science and technology policy issues. (See figure 8-3 and appendix table 8-8.)

International Comparisons

In the United States, Europe, and Canada, approximately 1 in 10 adults can be classified as attentive to science and technology policy; the proportion is smaller—about 7 percent—in Japan. The percentage classified as the "interested" public (for science and technology policy) is higher in the United States than it is in the other three sociopolitical systems. In 1995, it was 47 percent, compared with 33 percent in Europe (for 1992), 40 percent in Canada (1989), and 12 percent in Japan (1991). For all countries, there is a positive relationship between level of education and level of attentiveness (Miller, Pardo, and Niwa 1997). (See text table 8-2.)

Public Understanding of Science and Technology

Science literacy in the United States (and in other countries) is fairly low. That is, the majority of the general public knows a little, but not a lot, about science and technology. For example, most Americans know that the Earth goes around the Sun and that light travels faster than sound. However, not many can successfully define a molecule, and few have a good understanding of what the Internet is despite the fact that the Information Superhighway has occupied front page headlines throughout the late 1990s—and usage has skyrocketed. (See the section "Use of Computers and Computer Technology in the United States" and chapter 9, "Significance of Information Technologies.") In addition, most Americans have little comprehension of the nature of scientific inquiry.

It is important to have some knowledge of basic scientific facts, concepts, and vocabulary. Those who possess such knowledge have an easier time following news reports and participating in public discourse on various issues pertaining to science and technology. It may be even more important to have an appreciation for the scientific process. Understanding how ideas are investigated and analyzed is a sure sign of scientific literacy. This knowledge is valuable not only in keeping up with important issues and participating in the political process, but also in evaluating and assessing the validity of various other types of information.

In NSF's Survey of Public Attitudes Toward and Understanding of Science and Technology, respondents are asked a series of questions designed to assess their knowledge and understanding of basic science concepts and terms. There are 20 such questions, 13 of which are true/false, 3 are multiple choice, and 4 are open-ended; that is, respondents are asked to define in their own words DNA, a molecule, the Internet, and radiation. In addition, respondents are asked questions designed to test their understanding of the scientific process, including their knowledge of what it means to study something scientifically, how experiments are conducted, and probability.

Understanding Terms and Concepts

The percentage of correct responses to most of the questions pertaining to respondents' knowledge of basic science concepts and terms was fairly constant in the late 1990s. For example, more than 70 percent of those interviewed knew that:

- Oxygen comes from plants.
- The continents have been moving for millions of years and will continue to move in the future.
- Light travels faster than sound.
- The Earth goes around the Sun (and not vice versa).
- All radioactivity is not man-made. (See appendix table 8-9.)

In contrast, about one-half or fewer of the respondents knew that:

- The earliest humans did not live at the same time as dinosaurs.

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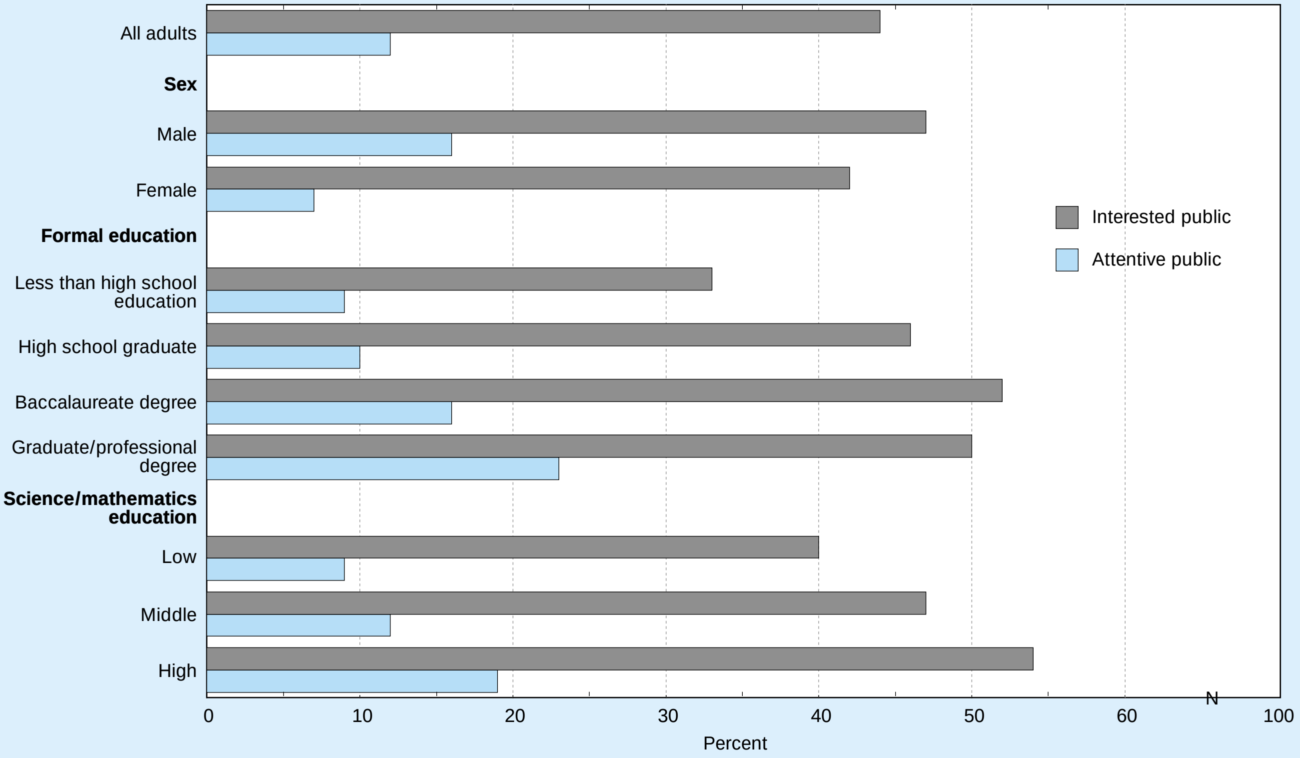
[9] For a general discussion of the concept of issue attentiveness, see Miller, Pardo, and Niwa (1997).

Figure 8-3.
Public attentiveness to science and technology: 1999



NOTES: The "attentive" public are people who (1) express a 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. The "interested" public are people who express a high level of interest in a particular issue but don't 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 as "low" if they took five or fewer.

See appendix table 8-8.

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Text table 8-2.
Percentage of adults attentive to, or interested in, science and technology

	European Union (1992)		United States (1995)		Japan (1991)		Canada (1989)	
Variable	AP	IP	AP	IP	AP	IP	AP	IP
All adults	10	33	10	47	7	12	11	40
Education								
Less than high school	5	25	4	37	1	8	9	37
High school graduate	9	33	8	48	7	13	11	45
Baccalaureate degree	18	40	21	53	14	15	19	46
Sex								
Male	13	36	12	49	12	15	14	44
Female	7	30	8	45	2	10	7	47
Civic scientific literacy								
Well informed	18	45	29	55	40	26	26	42
Moderately well informed	14	39	14	51	12	21	16	44
Not well informed	7	27	7	45	4	9	8	40
Number of cases	1,226	3,971	195	946	101	177	209	809

AP = attentive public; IP = interested public

SOURCE: J.D. Miller, R. Pardo, and F. Niwa, *Public Perceptions of Science and Technology: A Comparative Study of the European Union, the United States, Japan, and Canada* (Chicago: Chicago Academy of Sciences,1997).

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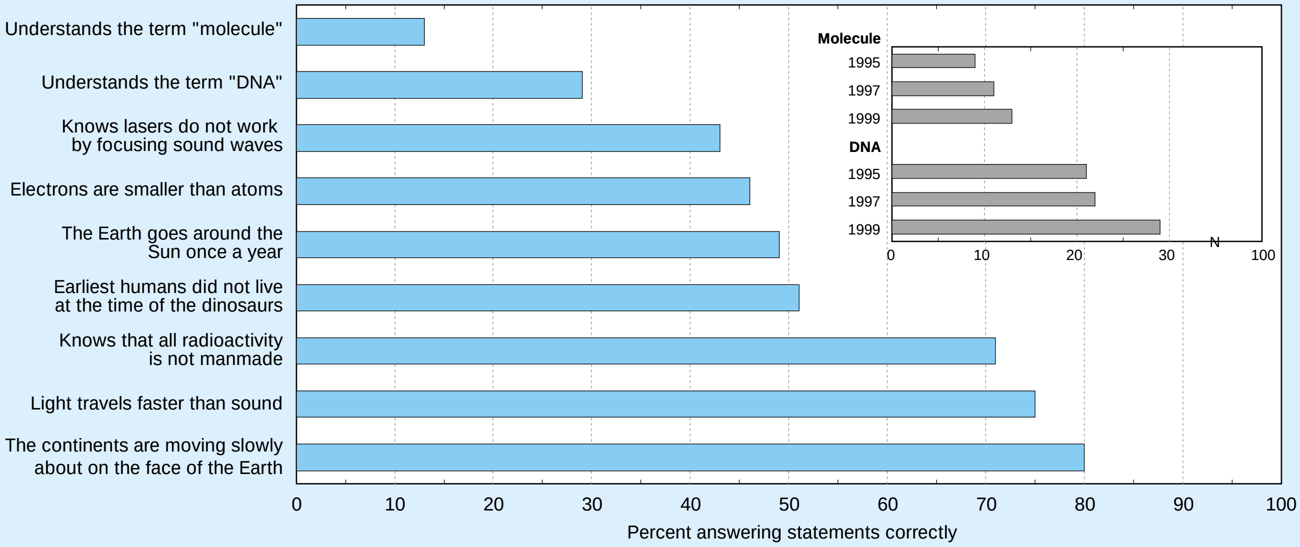
- It takes the Earth one year to go around the Sun.
- Electrons are smaller than atoms.
- Antibiotics do not kill viruses.[10]
- Lasers do not work by focusing sound waves. (See appendix table 8-9.)

In addition, few respondents (11 percent) were able to define radiation, the Internet (16 percent), a molecule (13 percent), and DNA (29 percent). Although the percentage of correct responses to these questions is considerably lower than that for the short-answer questions, it is noteworthy that the percentage of correct responses to three of these questions increased in the late 1990s:

- In 1995, only 9 percent of respondents could successfully define a molecule. That percentage rose to 11 percent in 1997 and to 13 percent in 1999.
- In 1999, 29 percent of the respondents could define DNA, up from 21 percent in 1995 and 22 percent in 1997. Undoubtedly, this growing awareness of DNA is attributable to heavy media coverage of the use of DNA in crime-solving and in advancements in the field of medicine. (See figure 8-4.)
- The percentage of those able to define the Internet increased from 13 percent in 1997 to 16 percent in 1999.

These survey questions have been used to develop an Index of Scientific Construct Understanding, making it possible to track the level of knowledge in the United States over time and to compare that level with the level in other countries.[11] Nine of the survey items are included in this index; they are listed in figure 8-4.[12] The mean score for American adults on the Index of Scientific Construct Understanding was 58. The comparable scores for 1995 and 1997 were 55 for both years. Understanding of basic science concepts and terms is strongly related to both the level of formal education and the number of high school and college science and mathematics courses taken. The mean scores for college graduates and those with graduate or professional degrees were 74 and 80, respectively, compared with 44 for individuals who did

Figure 8-4.
Public understanding of scientific terms and concepts: 1999



See appendix table 8-9.

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[10] The growing resistance of bacteria to antibiotics has received widespread media coverage in the past few years. In identifying the main cause of the problem—the over-prescribing of antibiotics—it is mentioned that antibiotics are ineffective in killing viruses. Despite the media coverage, more than half of those surveyed answered "true" to the statement "Antibiotics kill viruses as well as bacteria." Although the percentage of those answering false went up slightly—from 40 percent in 1995 to 45 percent in 1999—the lack of correct responses indicates a lack of communication with the public on this health-related issue.

[11] Although comparable data for other countries have not been updated since the early 1990s, the most recent information available indicates similar scores for the United States, Denmark, the Netherlands, and Great Britain. All have slightly higher scores than France and Germany. For a complete discussion of these data, see chapter 7 in *Science & Engineering Indicators – 1998* (NSB 1998).

[12] The items included in the Index of Scientific Construct Understanding were first identified by confirmatory factor analysis. So that these items could be placed on a common metric applicable to studies in the United States and to studies conducted in other countries, a set of item-response theory (IRT) values was computed for each item, which takes into account the relative difficulty of each item and the number of items used in each study. This technique has been used by the Educational Testing Service and other national testing organizations in tests such as the Test of English as a Foreign Language, the computer-based versions of the Graduate Record Examination, and the National Assessment of Educational Progress. The original IRT score for each respondent is computed with a mean of 0 and a standard deviation of 1, which means that half the respondents would have a negative score. So that more understandable terms could be used, the original IRT score was converted to a 0–100 scale.

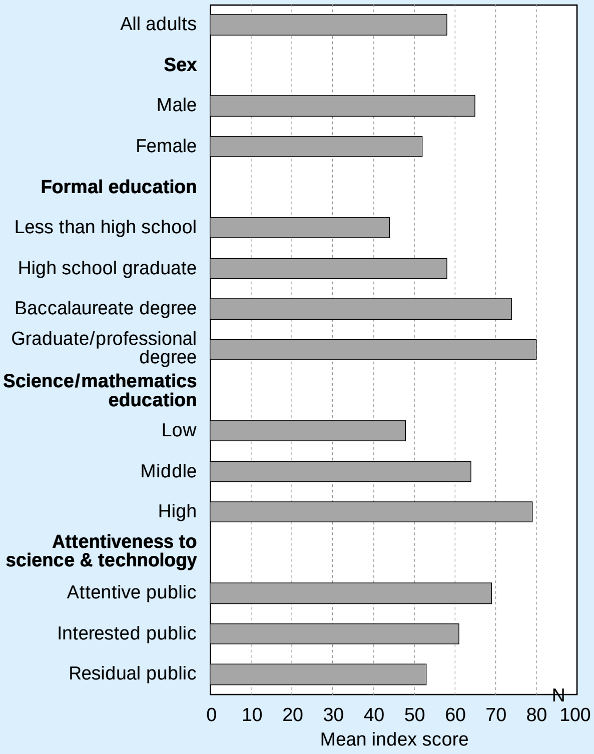
not complete high school. Those who completed nine or more high school and college science or math courses had a mean score of 79, compared with 48 for adults who had taken five or fewer courses. Men scored significantly higher than women, with a mean score of 65 compared with 52 for women. (See figure 8-5 and appendix table 8-10.)

Two of the true/false survey questions (not included in the Index of Scientific Construct Understanding) have relatively low percentages of correct responses:

- About one-third of the respondents answered “true” to the statement, “The universe began with a huge explosion.”
- Forty-five percent answered “true” to the statement, “Human beings, as we know them today, developed from earlier species of animals.” (See appendix table 8-9.)

Responses to these two questions may reflect religious beliefs rather than actual knowledge about science. For the last three-quarters of the century, probably the most controversial topic in science teaching has to do with how evolution is taught—or not taught—in U.S. classrooms. In late 1999, states taking opposite sides of the issue received a considerable amount of publicity in the news media. In Kansas and Kentucky, the teaching of evolution was dropped as a required part of the curriculum.[13] (The National Science Board issued a statement in August 1999 on the Kansas action; see NSB 1999.) In contrast, New Mexico’s board of education adopted an “evolution only” policy. For a more comprehensive discussion of curriculum content at the precollege level, see chapter 5, “Elementary and Secondary Education.”

Figure 8-5.
Mean score on Index of Scientific Construct Understanding, by sex, level of education, and attentiveness to science and technology: 1999



See appendix table 8-10. *Science & Engineering Indicators – 2000*

Understanding of Scientific Inquiry

To find out how well the public understands the nature of scientific inquiry, NSF asked survey respondents a series of questions. First, they were asked to explain what it means to study something scientifically.[14] In addition, respondents were asked questions pertaining to the experimental evaluation of a drug[15] and to determine their understanding of probability.[16]

In the 1999 survey, 21 percent of the respondents provided good explanations of what it means to study something scientifically.[17] About one-third answered the experiment questions correctly, including being able to say why it was better to use a control group. More than half (55 percent) of the respondents answered the four probability questions correctly. (See appendix table 8-11.)

The level of understanding of the nature of scientific inquiry is estimated using a combination of each survey participant’s responses to the questions. To be classified as understanding the nature of scientific inquiry, a respondent had to 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 about the ex-

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[13] In an October 1999 poll, sponsored by the *Kansas City Star* and the *Wichita Eagle*, 52 percent of the respondents disagreed with the state board of education’s decision; 57 percent agreed with the statement that “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.”

[14] 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?”

[15] The question 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?”

[16] 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] A correct understanding of scientific study includes responses describing scientific study as theory testing, experimentation, or rigorous, systematic comparison.

periment, i.e., explain why it was better to test a drug using a control group. In 1999, 26 percent of the survey respondents gave responses that met these criteria. (See figure 8-6 and appendix table 8-11.) In 1995 and 1997, the comparable percentages were 21 percent and 27 percent, respectively.

Public Attitudes Toward Science and Technology

In general, Americans express highly favorable attitudes toward science and technology. In the 1999 NSF public attitudes survey, overwhelming majorities agreed—and few disagreed—with the following statements:

- Science and technology are making our lives healthier, easier, and more comfortable (90 percent agreed and 9 percent disagreed).
- Most scientists want to work on things that will make life better for the average person (83 percent agreed and 15 percent disagreed).
- With the application of science and technology, work will become more interesting (73 percent agreed and 23 percent disagreed).
- Because of science and technology, there will be more opportunities for the next generation (84 percent agreed and 14 percent disagreed). (See appendix table 8-12.)

In a 1996 survey,

- Nearly half the respondents said that the terminology that best describes their reaction to science and technology was "satisfaction or hope"; 36 percent chose "excitement or wonder"; and only 6 percent answered "fear or alarm."
- More than half the respondents said that new developments in science and technology will have a positive impact on the overall standard of living in the United States; one-fifth thought the impact would be negative.
- Approximately four out of five respondents agreed that encouraging the brightest young people to go into scientific careers should be a top national priority (Roper 1996).

Despite these indicators, a sizeable portion—although not a majority—of the public has some reservations concerning science and (especially) technology. See sidebar, "Attitudes of Scientists, Legislators, and the Public Toward Science and Technology." For example, in the 1999 NSF survey, half of those queried agreed with the statement: "We depend too much on science and not enough on faith" (45 percent disagreed). And, about 40 percent agreed that "science makes our way of life change too fast" (57 percent disagreed). (See appendix table 8-12.)

Overall, however, there seems to have been a small, upward trend in positive attitudes toward science and technology. In general, data from the NSF survey show increasing percentages of Americans

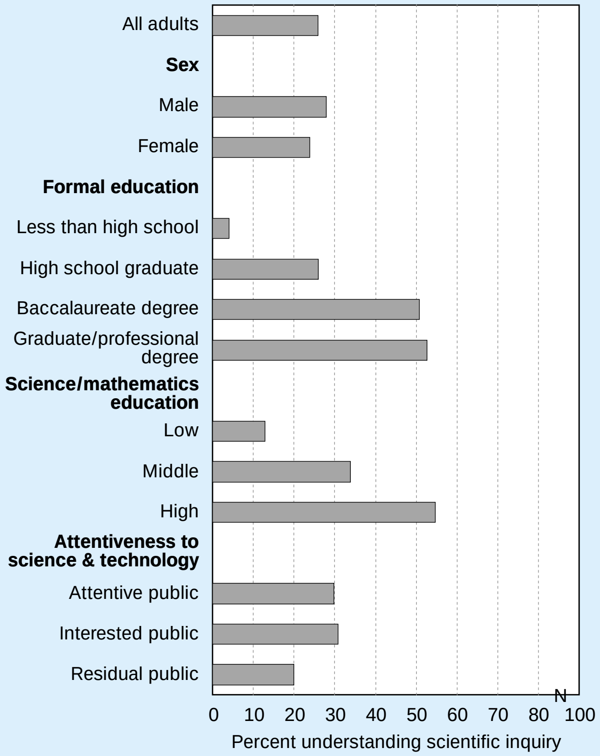
- *agreeing* that "science and technology are making our lives healthier, easier, and more comfortable" and
- *disagreeing* that "we depend too much on science and not enough on faith." (See appendix table 8-13.)

In addition, the survey results indicate that an increasing number of people believe that the benefits of scientific research outweigh any harmful results. (See the section "Perceptions of Scientific Research.")

The concern that does exist appears to be related to the impact of technology on society. For example, NSF survey respondents were fairly evenly split about whether "computers and factory automation will create more jobs than they will eliminate." (See appendix table 8-14.) And, a sizeable minority—46 percent—agreed with the statement that "people would do better by living a simpler life without so much technology." (See appendix table 8-15.) Also, about 3 out of every 10 people surveyed agreed that "technological discoveries will eventually destroy the Earth" and that "technological development creates an artificial and inhumane way of living." (See appendix tables 8-16 and 8-17.)

In a 1999 survey, more than half the respondents (55 percent) agreed with the statement, "Our growing reliance on technology is generally good because it makes life more convenient and easier." However, 39 percent of the respondents

Figure 8-6.
Public understanding of the nature of scientific inquiry: 1999



See appendix table 8-11. *Science & Engineering Indicators – 2000*

Attitudes of Scientists, Legislators, and the Public Toward Science and Technology

In a 1998 survey, researchers at the University of New Mexico Institute for Public Policy queried randomly selected individuals representing three groups—working scientists, members of state legislatures, and the general public—to find out their perspectives on nuclear security.* Included in the survey were several questions having to do with attitudes toward science and technology. Not unexpectedly, the scientists held more positive attitudes than members of the other two groups. For example, 83 percent of the scientists agreed that "science is the best source of reliable knowledge about the world"; about two-thirds of the legislators and members of the public also agreed with that statement. Responses to a question related to technology, however, showed a real difference of opinion. Forty percent of the respondents representing the general public agreed with the statement that "technology has become dangerous and unmanageable," compared with only 13 percent of the scientists and 15 percent of the legislators. (See figure 8-7.)

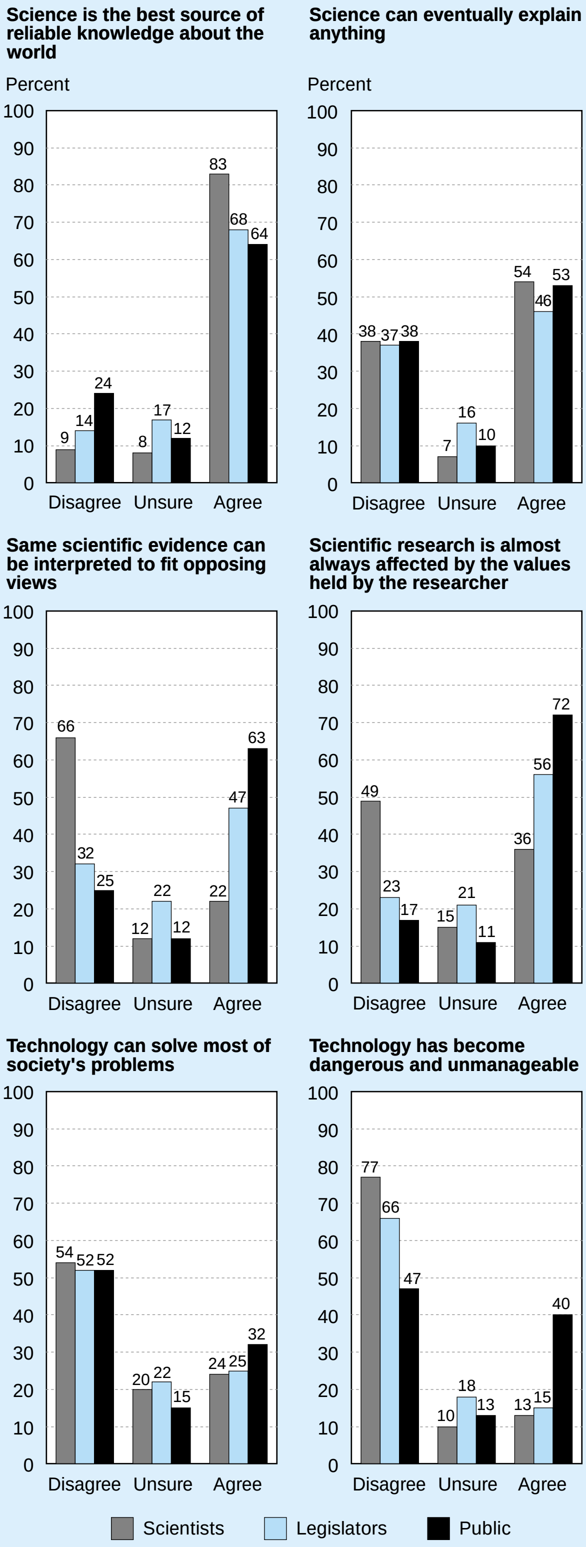
Responses to other questions revealed a general consensus among members of the three groups: slightly more than half the scientists and members of the public agreed that "science can eventually explain anything"; just under 50 percent of the legislators chose that response. Also, slightly more than half of each group disagreed with the statement "technology can solve most of society's problems."

Two questions exposed very different attitudes toward the process of scientific inquiry: A majority of the public and approximately half the legislators agreed with the following statements:

- The same scientific evidence can almost always be interpreted to fit opposing points of view.
- The results of scientific research will almost always be significantly affected by the values held by the researcher.

In contrast, only 22 percent of the scientists agreed with the first statement, and 36 percent with the second.

Figure 8-7.
Attitudes of scientists, legislators, and the public toward science and technology: 1997



SOURCE: K.G. Hebron and H.C. Jenkins-Smith, *Public Perspectives on Nuclear Security* (Albuquerque, New Mexico: The University of New Mexico Institute for Public Policy, 1998), pp. 210–11, 213.

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*The response rates for the general public, the scientists, and the legislators were 54.8 percent, 53.8 percent, and 21.7 percent, respectively. Because the response rate for the legislators was less than half that of the other two groups, extensive nonresponse analysis was conducted. A comparison of views between legislator respondents and nonrespondents showed a significant difference on three survey questions. Data from those questions are not included in this sidebar. For more information on the nonresponse analysis, see Herron and Jenkins-Smith (1998).

agreed with the other choice, "Our growing reliance on technology is generally bad because we will become too dependent on it and life will get too complicated." Those with higher incomes are more likely to have positive attitudes toward technology: 73 percent of the respondents reporting at least $75,000 in annual income chose the first statement, compared with only 46 percent of those reporting less than $20,000 (The Pew Research Center 1999a).

In another survey, more than half the respondents agreed that "science and technology [have] caused some of the problems we face as a society" (13 percent answered "most" of the problems). Responses to another question in the same survey were more positive: when asked to describe their "reaction when [they acquire] a new technical gadget, like a VCR," nearly three out of five chose the response, "excitement at discovering what it can do"; another quarter of those surveyed picked "hope it will let you do things more easily." Only 6 percent feared they would not be able to use the new device, and 9 percent chose "indifference or lack of interest" (Roper 1996).

The Promise of Science—and Reservations

To track trends in public attitudes toward science and technology and to compare attitudes in the United States with those in other countries, an Index of Scientific Promise and an Index of Scientific Reservations were developed. In addition, the ratio of the Promise Index to the Reservations Index is a useful indicator of current and changing attitudes toward science and technology.[18]

Although a strong positive relationship exists between a person's level of education and favorable attitudes toward science and technology, both the Index of Scientific Promise and the Index of Scientific Reservations have remained fairly stable since 1992. However, it is noteworthy that the overall ratio of Promise to Reservations rose from 1.74 in 1995 to 1.89 in 1997. In 1999, the ratio was 1.87. (See appendix table 8-18.)

International Comparisons

North Americans and Europeans appear to have more favorable attitudes toward science and technology than the Japanese. At 55, Japan's mean score on the Index of Scientific Promise was considerably lower than that for the United States, the European Union, and Canada, all of which have scores close to 70. In all four sociopolitical systems, university-educated citizens have the most positive attitudes toward science and technology, whereas those who did not complete high school have less favorable attitudes. (See text table 8-3.)

U.S. residents seem to harbor fewer reservations about science and technology than their counterparts in the other three sociopolitical systems. The European Union, Japan, and Canada have similar Index of Scientific Reservations mean scores—all in the upper 50s—whereas the U.S. score was in the upper 30s.

In all four sociopolitical systems, individuals with the lowest levels of formal education expressed the highest levels of reservation about science and technology. The inverse relationship between education and reservations about science seems to be strongest in the United States. In addition, those who scored highest on measures of science literacy reported significantly lower levels of reservation about science and technology than those with less knowledge of science.

In all four societies, women were slightly more likely than men to hold reservations about science and technology. The disparities were small and may be attributable to differences in educational achievement.

Public Attitudes Toward the Funding of Scientific Research by the Federal Government

All indicators point to widespread support for government funding of basic research. In the 1999 NSF survey, 82 percent of those queried 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.

Moreover, the level of agreement has been rising—and the level of disagreement falling—since 1992. (See appendix table 8-19.) During the mid-1990s, a gender gap in support for federally funded basic research seemed to be closing. In 1999, 84 percent of the men in the survey agreed with the statement cited above, compared with 80 percent of the women. (See appendix table 8-19.)

Support for federally funded basic research is closely tied to education level. In other words, the level of support rises with the level of formal education. In 1999, 72 percent of those surveyed who had not completed high school agreed with the statement; that percentage rose to 84 percent for high school graduates, to 87 percent for those with college degrees, and to 91 percent for those with graduate or professional degrees. (See appendix table 8-19.)

In addition, those with more positive overall attitudes toward science and technology were more likely to express support for government funding of basic research. In 1999, 90 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 61 per-

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[18] The Index of Scientific Promise and the Index of Scientific Reservations are factor scores converted to a 0–100 scale. For each of the four countries or regions, a separate confirmatory factor analysis verified the existence of a two factor structure, and factor scores were computed for each dimension for each country or region. Within each country or region, the lowest possible factor score (strong disagreement with all of the items) was set to zero, 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 metric accordingly.

A core of items was identical in all countries and regions, and there was some minor variation in wording for some items from country to country. The strength of this factor analytic approach is that it allows the calibration of complete disagreement and complete agreement as end points on a 0–100 scale and creates a metric that is comparable across countries and regions. The questions used in the United States are described in the notes for appendix table 8-18; the questions used in Canada, Europe, and Japan are described in Miller, Pardo, and Niwa (1997).

cent of those with relatively low index scores. (See figure 8-8 and appendix table 8-20.)

Other studies have revealed similar favorable attitudes toward the government's role in supporting science and technology. In one survey, more than 80 percent of the respondents agreed that "the Federal Government has an important role to play in encouraging new developments in science and technology" and that "it is important that the United States be the world leader in technological progress" (Roper 1996). (See sidebar, "Americans Give High Marks to Government Investment in R&D.")

Only 14 percent of those who participated in the NSF survey thought the government was spending too much on scientific research; 37 percent thought the government was not spending enough. 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 reducing pollution, improving health care, improving educa-

Text table 8-3.

Index of Scientific Promise and Index of Scientific Reservations for the European Union, the United States, Japan, and Canada

	Mean scores			
Variable	European Union (1992)	United States (1995)	Japan (1991)	Canada (1989)
Scientific Promise				
All adults	69	68	55	72
Level of formal education				
Less than high school	68	63	54	68
High school graduate	69	68	55	75
Baccalaureate degree	71	71	56	84
Sex				
Male	70	69	55	76
Female	68	67	54	68
Civic scientific literacy				
Well informed	70	72	64	84
Moderately well informed	69	69	58	80
Not well informed	79	67	54	69
Attentiveness to science and technology policy				
Attentive public	74	74	56	79
Interested public	72	69	59	74
Residual public	67	65	54	69
Number of cases	6,122	2,006	1,457	2,000
Scientific Reservations				
All adults	58	39	56	56
Level of formal education				
Less than high school	64	51	62	60
High school graduate	57	39	55	52
Baccalaureate degree	53	27	50	40
Sex				
Male	57	38	55	53
Female	60	40	57	58
Civic scientific literacy				
Well informed	46	24	45	39
Moderately well informed	55	30	55	45
Not well informed	62	42	56	59
Attentiveness to science and technology policy				
Attentive public	57	30	54	45
Interested public	57	38	52	54
Residual public	60	42	57	59
Number of cases	6,122	2,006	1,457	2,000

SOURCE: J.D. Miller, R. Pardo, and F. Niwa, *Public Perceptions of Science and Technology: A Comparative Study of the European Union, the United States, Japan, and Canada* (Chicago: Chicago Academy of Sciences,1997).

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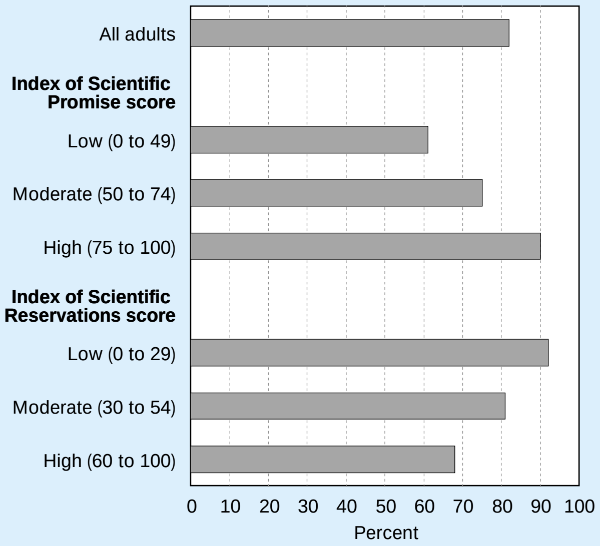
Figure 8-8.
Support for government funding of basic scientific research, by level of general support for or reservations about science and technology: 1999



See appendix table 8-20. *Science & Engineering Indicators – 2000*

tion, and helping older people. In the survey, only exploring space and improving national defense had less support for increased spending than scientific research.[19] In fact, 46 percent of the respondents thought spending on space exploration was excessive, a higher percentage than that for any other item in the survey. (See appendix tables 8-21 and 8-22 and the section "Perceptions of Space Exploration.") It should be noted that few respondents really know what the government spends on various programs.[20]

International Comparisons

Government support for basic scientific research is at least as popular in Europe, Japan, and Canada as it is in the United States. In all four sociopolitical systems, the level of support has been about 80 percent or higher; the highest levels seem to be in Canada and Japan. (See text table 8-4.) In all four societies,

- The level of formal education and the level of scientific literacy were positively associated with support for government funding of basic scientific research.
- Those who expressed greater interest in science and technology were more supportive than those with less interest in those subjects.
- Men were slightly more likely than women to support government spending on basic scientific research.

Americans Give High Marks to Government Investment in R&D

Participants in a series of focus groups commissioned by several high-technology companies expressed strong support for government funding of R&D.* The consensus was that R&D should be considered a priority investment in the future quality of life and that R&D expenditures should not be cut to balance the budget (Public Opinion Strategies and Luntz Research and Strategic Services 1996).

Comments heard at sessions include:

- "Japan and Europe are investing heavily in 21st-century technology. If we don't keep pace, we'll be left behind."
- "If a technology is economically critical, the government should support R&D in that area."
- "Technological innovation doesn't just happen; we have to invest in it."
- "R&D keeps us militarily strong."

Although the focus group participants expressed support for strengthening government investment in both basic research and applied research, if they had to choose among competing priorities, they would give more emphasis to applied research projects because of their potential for leading to tangible payoffs in the more immediate future. According to the participants, government-funded R&D projects should:

- be a national priority,
- have potential benefit for a broad number of people,
- improve people's lives, and
- have a favorable cost–benefit calculation.

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*The focus groups were held in 1996 in Lancaster, Pennsylvania (April 11), Columbus, Ohio (April 17), Houston, Texas (April 24), and New Orleans, Louisiana (April 25). The participants were selected for their awareness of current events and their interest in politics; they had a somewhat higher income and education level than the public at large and represented both political parties.

Public Confidence in the People Running Various Institutions

Public confidence in the leadership of various institutions has been tracked for nearly a quarter of a century (Davis and Smith annual series). Participants in the General Social Sur-

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[19] Another poll also did not find high levels of support for increased science research funding (Wirthlin 1995).

[20] As an aside, in the First Amendment Center survey of journalists and scientists (see the section "The Relationship Between Science and the Media: Communicating with the Public"), respondents were asked what percentage of the total Federal budget is devoted to scientific research and technology development. The four choices were less than 1 percent, 1 percent to 10 percent, 11 percent to 20 percent, and more than 20 percent. Half the journalists and 65 percent of the scientists chose the correct response [1 percent to 10 percent; the actual figure is 4 percent (See chapter 2). Most of the rest of the survey participants guessed that less than 1 percent of the Federal budget is invested in science and technology.

Text table 8-4.
Approval of government support for basic scientific and technological research

Variable	European Union (1992)	United States (1995)	Japan (1991)	Canada (1989)
	Percentage strongly agreeing or agreeing			
All adults	80	78	86	88
Level of formal education				
Less than high school	67	67	81	85
High school graduate	83	79	86	89
Baccalaureate degree	89	87	93	98
Sex				
Male	83	79	90	91
Female	77	77	83	84
Civic scientific literacy				
Well informed	91	90	96	98
Moderately well informed	87	87	94	93
Not well informed	74	75	85	86
Attentiveness to science and technology policy				
Attentive public	91	83	89	92
Interested public	89	85	96	90
Residual public	73	70	84	84
Number of cases	6,122	2,006	1,457	2,000

SOURCE: J.D. Miller, R. Pardo, and F. Niwa, *Public Perceptions of Science and Technology: A Comparative Study of the European Union, the United States, Japan, and Canada* (Chicago: Chicago Academy of Sciences,1997).

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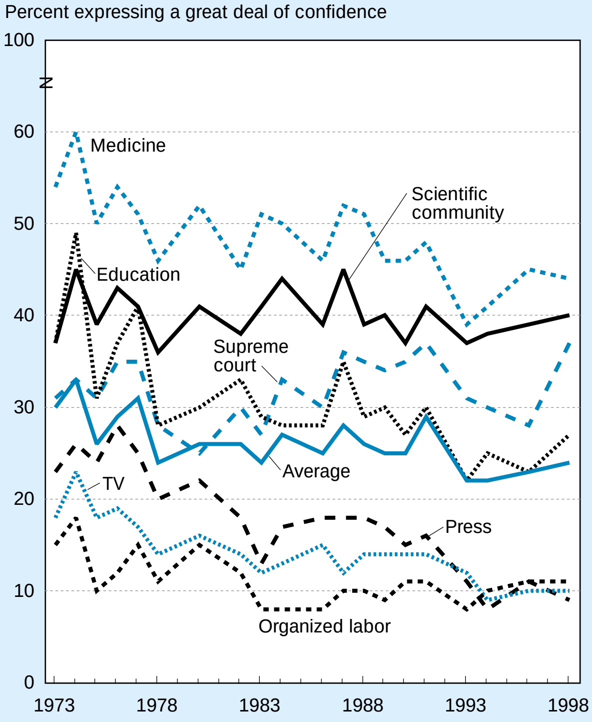
vey were asked whether they have a “great deal of confidence, only some confidence, or hardly any confidence at all” in the leadership of various institutions. In 1998, 40 percent reported that they had a great deal of confidence in the leadership of the scientific community. The only category that exceeded this vote of confidence was the medical community. Science has held the number two spot exclusively since 1978, overtaking education (for the last time) in that year. The Supreme Court, the military, education, major companies, and organized religion filled out the next five spots in 1999. The public has the least confidence in the press and TV; the “great deal of confidence” vote for the leadership of these institutions was 10 percent or less in 1998. (See figure 8-9 and appendix table 8-23.)

Interestingly, although the vote of confidence for the scientific community has fluctuated somewhat during the past quarter-century, it has remained about 40 percent. In contrast, there seems to have been an erosion in confidence in the medical profession. The rating for this group was once as high as 60 percent (1974); that percentage has been gradually declining for most of the past 25 years.

Perceptions of Scientific Research

By an overwhelming majority, Americans consistently believe that the benefits of scientific research outweigh any harmful results. Nearly half (47 percent) of the survey respondents said that the benefits *strongly* outweigh the harms, and another 27 percent said they *slightly* outweigh the harms. These percentages have been fairly stable for the past two

Figure 8-9.
Public confidence in leadership of selected institutions: 1973–98



See appendix table 8-23. *Science & Engineering Indicators – 2000*

decades, as has the percentage of respondents taking the opposite position. That is, between 10 and 20 percent of those queried believe the harms outweigh the benefits. (See figure 8-10 and appendix table 8-24.)

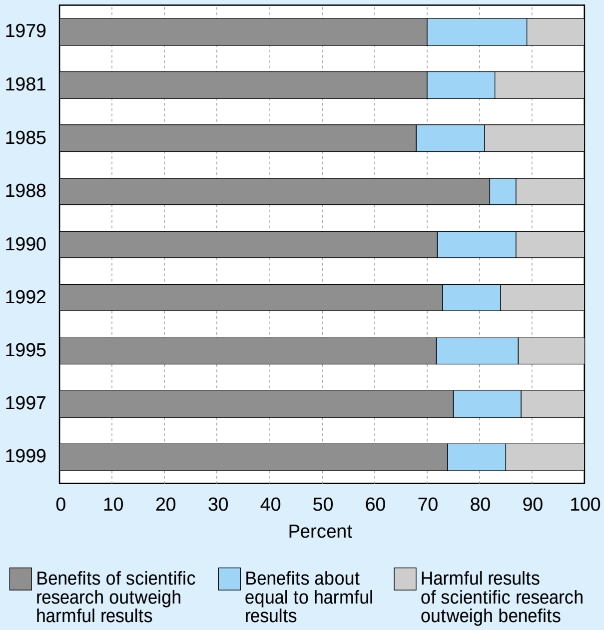
Men express greater surety than women that the benefits of scientific research outweigh the harmful results. In fact, 50 percent of the men in the 1999 survey, compared with 45 percent of the women, said that the benefits *strongly* outweighed the harms. Level of education is also strongly associated with a positive response to this question. Those who did not complete high school are more likely than those with more formal education to believe the harms outweigh the benefits, although it should be noted that half of this group said the benefits outweigh the harms. The comparable percentages for high school graduates and for those with at least a bachelor's degree were 78 percent and 90 percent, respectively, in 1999. (See appendix table 8-24.)

Perceptions of Nuclear Power

Americans are not as positive about all science and technology issues as they are about scientific research in general. For example, they have been evenly divided for more than a decade over the use of nuclear power to generate electricity. In 1999, 48 percent of Americans believed the benefits of nuclear power outweighed the harms, while 37 percent held the opposite view, and 15 percent thought that benefits and harms were equal. (See figure 8-11 and appendix table 8-25.)

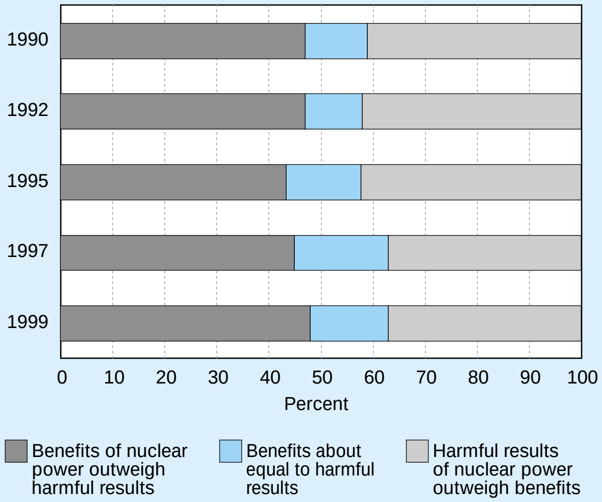
Individuals with more years of formal schooling, men, and those classified as attentive to science and technology policy are slightly more likely than others to believe the benefits of using nuclear power to generate electricity outweigh the harms. However, the correlation between education and attitudes toward use of nuclear power is relatively weak.

Figure 8-10.
Public assessment of scientific research: 1979–99 (selected years)



See appendix table 8-24. *Science & Engineering Indicators – 2000*

Figure 8-11.
Public assessment of nuclear power: 1990–99 (selected years)



See appendix table 8-25. *Science & Engineering Indicators – 2000*

Perceptions of Genetic Engineering

Data on public attitudes toward genetic engineering show no decline in the percentage of survey respondents who believe that the benefits outweigh the harmful results. In 1999, 44 percent of those interviewed agreed that the benefits either strongly or slightly outweigh the harms. (See figure 8-12 and appendix table 8-26.) This proportion is similar to that of the two previous surveys, despite the controversy generated by the widely reported news (in April 1997) about Dolly, the sheep cloned by a Scottish biologist and news (in January 1998) about a Chicago scientist planning to open a clinic for cloning people. (See sidebar, "The Most Closely Followed Science-Related News Stories: 1986–99.") Had the interviewers specifically mentioned cloning, the reaction from respondents may have been different, but the survey question did not include that word.[21]

The percentage of survey respondents who said that the harms outweighed the benefits was 38 percent in 1999. Among those classified as the attentive public for new medical discoveries (who may or may not be college graduates), the percentage agreeing that the harms are greater than the benefits rose from 30 percent in 1997 to 36 percent in 1999. (See figure 8-13.)

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[21] In one poll, approximately 85 percent of the respondents said they oppose cloning human beings (Southern Focus 1998). In another poll, 69 percent of Floridians and 63 percent of Texans supported "research into the altering of human genes to treat disease" (Research! America 1999). Also, see sidebar, "Public Attitudes Toward Biotechnology."

Public Attitudes Toward Biotechnology

Before the recent controversy over genetically modified agricultural products erupted in Britain and other European countries, public opinion surveys on attitudes toward biotechnology were undertaken in Europe, Canada, and the United States.* Survey respondents were asked to assess the usefulness, risk, and moral acceptability of several applications of biotechnology and to say whether or not they would encourage each application (Miller *et al*. 1999).

Two sets of questions pertained to agricultural applications of biotechnology, including the use of genetic engineering in

- producing foods, for example, to make them higher in protein, allow them to keep longer, or change their taste, and
- making crops more resistant to insect pests.

Data collected with the three surveys show Europeans with less favorable attitudes than North Americans toward these two applications—in terms of all four criteria. The differences, however, were not large. For example,

- Fifty-five percent of the European survey participants agreed that genetically modified food is useful, compared with approximately two-thirds of the Canadian and U.S. respondents.
- Three-fifths of the Europeans agreed that genetically altered food is risky, compared with 55 percent and 53 percent of those in Canada and the United States, respectively.
- Half the Europeans said that genetically modified food is morally acceptable, compared with more than three-quarters of the Canadians and two-thirds of the Americans.
- Less than half the Europeans would encourage the production of genetically modified food, compared with nearly three-fifths of the North Americans.

The pattern of responses was similar for attitudes toward genetic modification of crops and other plants, although there seemed to be somewhat less support for this application of biotechnology. It is important to remember that the three surveys were conducted several years before the controversy surrounding genetically engineered food and crops made front-page headlines. Because the subject has received a considerable amount of press coverage, people may be better informed and have different opinions than those expressed when the surveys were conducted. (The author of the U.S. study noted that one of the problems in conducting a survey of public attitudes toward biotechnology is that many people do not have an attitude.)

Three sets of questions in the surveys pertained to medical applications of biotechnology:

- introducing human genes into bacteria to produce medicines or vaccines, e.g., to produce insulin for diabetics,
- using genetic testing to detect inherited diseases, and
- introducing human genes into animals to produce organs for human transplant, such as into pigs for human heart transplants.

The first two of these applications seem to have widespread public support in all three regions, although European support for medicine production lagged behind that of North Americans. However, European support for the genetic testing application was at least equal to that of the North Americans surveyed.

Attitudes toward the organ-transplant application were less favorable than those for the other two medical applications, with Europeans being somewhat more opposed than North Americans to this application, in terms of moral acceptability and whether or not the application should be encouraged.

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*A 1996 Canadian survey, conducted by Professor Edna Einseidel, University of Calgary, used a national probability sample and included telephone interviews with 1,000 adults. The 1996 Eurobarometer on biotechnology was designed by a consortium of European scholars, organized and directed by Dr. John Durant of The Science Museum (London), and included personal interviews with 15,900 adults in the 15 member states of the European Union. A 1997 U.S. survey, directed by Professor Jon D. Miller, Northwestern University and the Chicago Academy of Sciences, used a national quota sample and included telephone interviews with 1,067 adults.

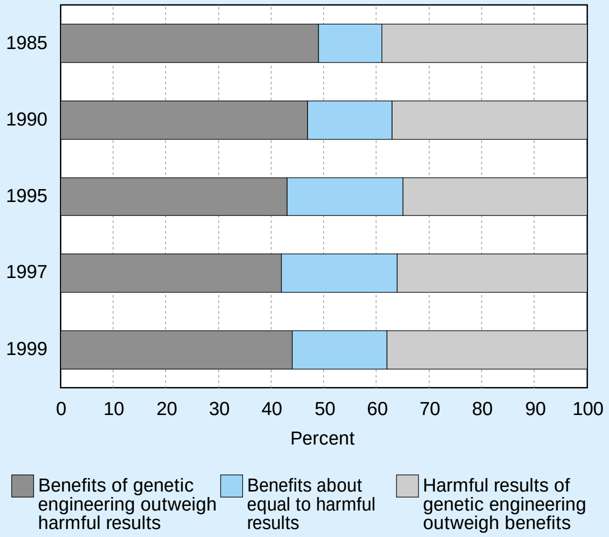
The relationship between a person's level of education and his or her assessment of the benefits and harms of genetic engineering shows some interesting trends. Although positive attitudes seemed to have increased (or stayed the same) between 1995 and 1999 for those without bachelor's degrees, the opposite seems to be true for those with degrees. The percentage of those in the latter group agreeing that the benefits outweigh the harms declined from 65 percent in 1995 to 55 percent in 1997, and then stayed the same in 1999. During the same period, among those with college degrees, the percentage saying the harms are greater than the benefits increased from 20 percent in 1995 to 24 percent in 1997 to 29 percent in 1999. (See figure 8-13.)

There is a significant gender gap in attitudes toward genetic engineering. Women are considerably more likely than men to believe the harms outweigh the benefits. In 1999, 42 percent of women agreed with this statement, compared with only 33 percent of men. The percentage-point difference has been 7 or more in four of the past five NSF surveys. (See figure 8-13 and appendix table 8-26.)

Perceptions of Space Exploration

Before the Challenger accident, more than half the participants in NSF's public attitudes survey agreed that the benefits of space exploration exceeded the costs. Minds changed after the accident. The percentage agreeing that the benefits are greater than the costs fell from 54 percent in 1985 (before the explosion) to 47 percent in 1988 and to 43 percent in 1990. In the 1990s, this trend, an indicator of weakening support for the space program, leveled off. More recently, the percentage of survey respondents agreeing that the benefits are greater than the costs has been rising—from 43 percent in 1992 to 49 percent in 1999, approaching the 1985 level, before the Challenger accident. (See figure 8-14 and appendix table 8-27.)

Figure 8-12.
Public assessment of genetic engineering: 1985–99 (selected years)



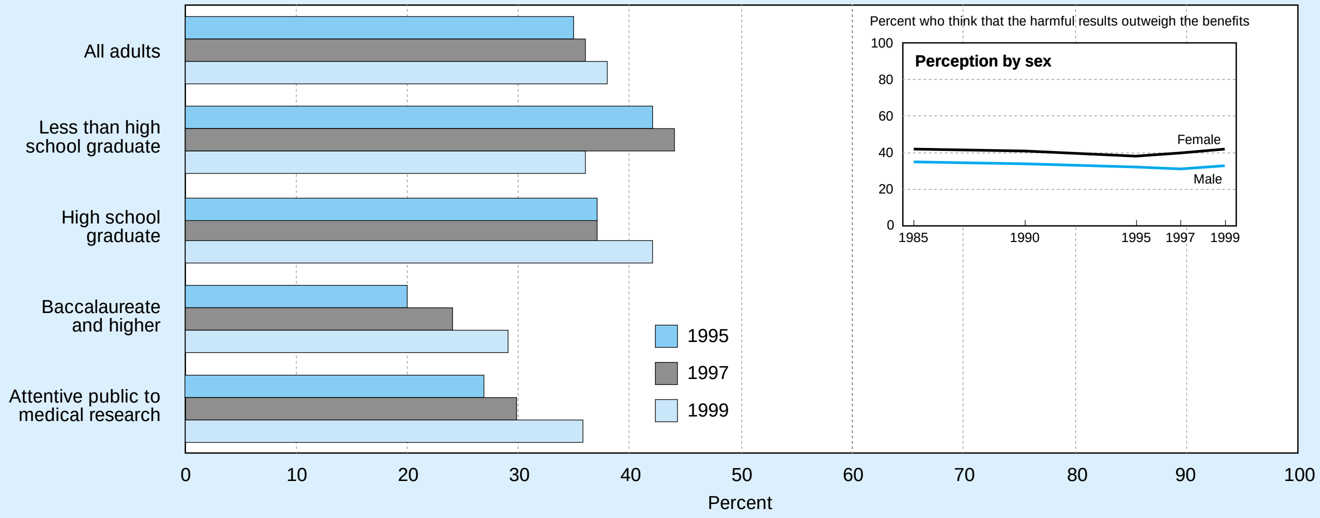
See appendix table 8-26. *Science & Engineering Indicators – 2000*

In another poll, respondents were asked what they thought of the space program. More than half chose the response, "exciting and worthwhile"; 27 percent answered "only necessary to keep up with other nations"; and only 18 percent said it was "a waste of time and money." In response to another question, nearly half said that, in the future, the space program will make life on Earth better because of technological advances; 17 percent thought it would be worse because the money should have been spent on something else; and 32 percent thought the space program would not make life any better or worse (Roper 1996).

Like other issues, there is a sizeable gender gap in public assessment of space exploration. In fact, no other issue in the NSF survey has such a large disparity in opinion between the sexes. Men are more likely than women to champion the benefits over the costs. The gap was 14 percentage points in 1999.

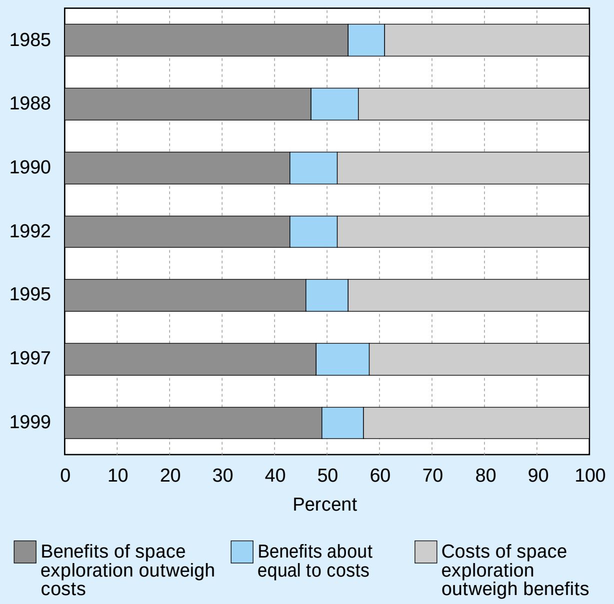
In every year but two (1990 and 1992), a majority of men interviewed for the survey agreed that the benefits outweigh the costs. The percentage stood at 57 percent in 1999, compared with 43 percent for women. In contrast, during the late 1980s and early 1990s, half or more of the women who participated in the survey thought that the costs exceeded the benefits. That is no longer true; the percentage dropped below 50 percent in 1997 and stayed there in 1999.

Figure 8-13.
Percentage of U.S. adults who view the harmful results of genetic engineering as outweighing the benefits: 1995, 1997, 1999



See appendix table 8-26. *Science & Engineering Indicators – 2000*

Figure 8-14.
Public assessment of space exploration: 1985–99 (selected years)



See appendix table 8-27. *Science & Engineering Indicators – 2000*

Those with more formal education are more likely than others to say that the benefits of space exploration exceed the cost. In 1999, only 40 percent of those with less than a high school education agreed that the benefits were greater than the costs, compared with 49 percent of those who graduated from high school and 60 percent of those with at least a bachelor's degree.

Those classified as attentive to science and technology—or to space exploration—are more likely than the public at large to believe that the benefits exceed the costs. At least 60 percent of each attentive group put the benefits ahead of the costs, compared with about half of the public at large.

Finally, about two-thirds of the public favor

- sending a U.S. manned mission to Mars (Roper 1996; and Southern Focus 1998) and
- building a space station (according to the NSF survey results).

Perceptions of the Use of Animals in Scientific Research

Few issues in science are as divisive as the use of animals in scientific research. There seems to be a 50–50 split in public opinion on this issue. (See appendix table 8-28.)

Public attitudes toward research using animals are shaped by:

- The purpose of the research. If animals are used in research on diseases such as cancer and AIDS, there is less opposition than if they are used in endeavors such as cosmetics testing.
- The type of animal. There is more tolerance for the use of mice in scientific experiments than for the use of dogs and chimpanzees.[22]
- The existence of alternatives, such as computer simulations. If they can accomplish the same purpose, then people will oppose the use of animals (Kimmel 1997).

Data from the NSF (and other) surveys show that:

- There was a slight increase in public opposition in the late 1980s.
- Compared with the citizens of other industrialized nations, Americans are more supportive of animal research (Kimmel 1997).

There are two major and long-standing fissures in public opinion on the use of animals in scientific research; that is, there are sex and age-related fault lines.

Women are far more likely than men to say they are opposed to the use of dogs and chimpanzees in scientific research. In 1999, nearly two out of every three women surveyed voiced opposition, whereas about one-third of the men held the same view. (See appendix table 8-28.) This gender gap in opinion cannot be attributed to differences between the sexes in science and mathematics education or differences in science literacy:

- At every education level, men are more likely than women to support the use of dogs and chimpanzees in scientific research. In 1995, 73 percent of men with graduate or professional degrees favored the use of these animals in scientific research, compared with 57 percent of the women in that educational category. For those with less than a high school education, the percentages were 59 percent and 45 percent, respectively.
- In addition, the number of science and mathematics courses taken is strongly related to men's attitudes toward animal research, but not at all related to women's attitudes.
- Among those classified as scientifically literate, 69 percent of the men, compared with only 48 percent of the women, expressed support for the use of dogs and chimpanzees in scientific research (Kimmel 1997).

Until the late 1990s, a fairly consistent relationship existed between age and attitudes toward animal research. Generally, the older the survey respondent, the more likely he or she was to express support for the use of animals in scientific research. It is widely assumed that the reason more positive attitudes are found among the elderly is that older persons

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[22] Fewer people oppose the use of mice in scientific research; 30 percent of those surveyed opposed research on these creatures, compared with 47 percent who opposed research using dogs and chimpanzees. (See appendix tables 8-28 and 8-29.)

experience more health problems and therefore are more attuned to the need for medical research.[23]

In the past few years, the pattern has been less distinct. Now, all that can be said about the relationship between age and attitudes is that the 18- to 24-year-old age group is the *only* age group in which a majority opposes the use of dogs and chimpanzees in scientific research. (See figure 8-15.)

It is noteworthy that, for each age group, men are significantly more likely than women to support animal research. In no age group does a majority of women support the use of dogs and chimpanzees in scientific research.

Use of Computers and Computer Technology in the United States

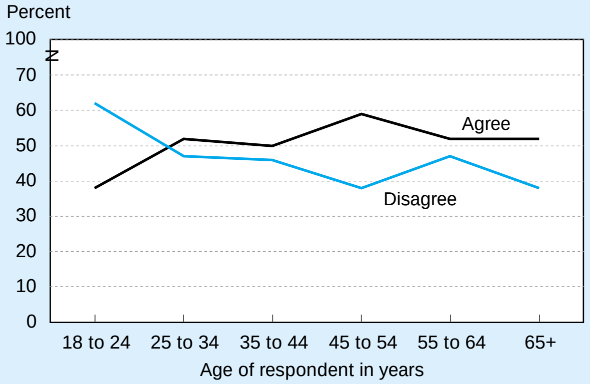
There has been a marked increase in the number and variety of sources providing information about science and technology. (See chapter 9, "Significance of Information Technologies" and sidebar "Where Americans Get Information About Science and Technology.") Computers and computer technologies have become important in facilitating access to these new sources of information. According to the 1999 NSF survey, just over one-fifth of American adults have searched for science- or health-related information on the World Wide Web.

A number of indicators show the growing and widespread use of computers and computer-based technologies in the late 1990s. The increase in the number of home computers is particularly noteworthy.[24] In 1999, for the first time ever, a majority of American adults (54 percent) had at least one computer in their homes. The percentage has been rising steadily since 1983, when only 8 percent had them. (See figure 8-16 and appendix table 8-30.) In addition, among all adults,

- 46 percent had modems (for connection to the Internet) in their home computers, up from 21 percent in 1995;
- 45 percent had CD-ROM readers, up from 14 percent in 1995;
- 32 percent subscribed to an on-line service and had home e-mail addresses, up from 18 percent in 1997; and
- 17 percent had more than one computer in their homes, up from 12 percent in 1997. (See figure 8-17 and appendix table 8-31.)

The average amount of time spent per year using a home computer rose from 103 hours in 1995 to 153 hours in 1999.

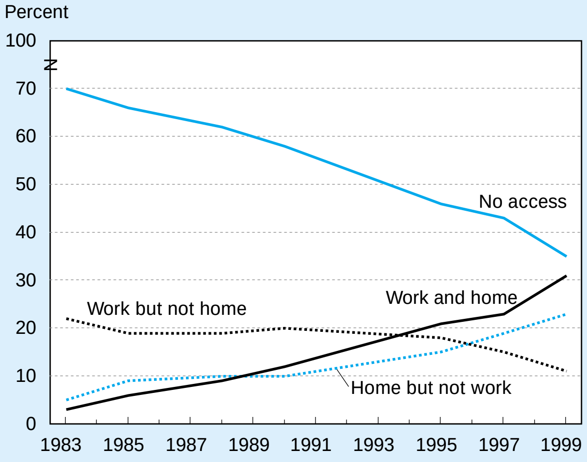
Figure 8-15.
U.S. public support for the use of dogs and chimpanzees in scientific research: 1999



NOTE: Responses are to the following question: "Scientists should be allowed to do research that causes pain and injury to animals such as dogs and chimpanzees if it produces new information about human health problems. Do you strongly agree, agree, disagree, or strongly disagree?"

See appendix table 8-28. *Science & Engineering Indicators – 2000*

Figure 8-16.
Public access to computers: 1983–99



See appendix table 8-30. *Science & Engineering Indicators – 2000*

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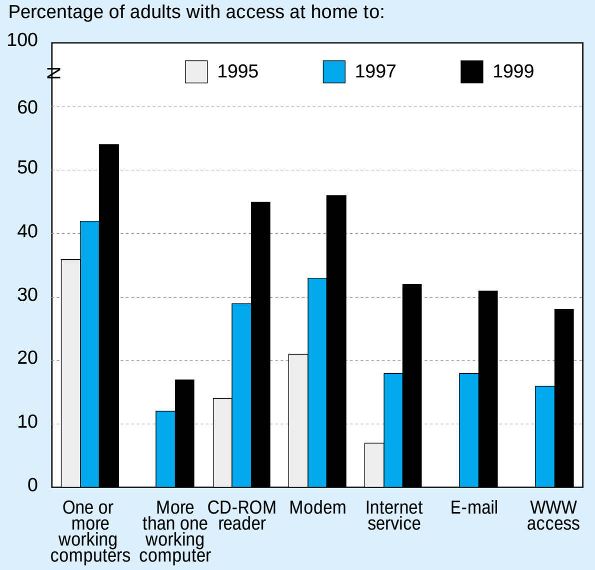
[23] It should be noted that the survey data are cross-sectional, rather than longitudinal. Although it can be assumed that, as adults age and experience more health problems, they become more receptive to the use of animals in scientific research, it is also possible that the older adults who participated in the survey have always been—throughout their lives—more supportive of animal research than the younger participants in the survey. Likewise, it is also possible that the current group of younger adults who participated in the survey will retain their higher level of opposition as they age.

One of the reasons for the high level of opposition to animal research among young adults is that animal rights groups, which distribute brochures to schools and use young celebrities to promote their cause, have been successful in influencing young people, especially girls. One study found that factors beyond educational achievement and science literacy, for example, a strong emotional component, account for the strong opposition among young women. Interestingly, this study revealed that the level of science achievement among girls who opposed animal research was higher than that for girls who favored animal research (Kimmel Pifer 1994).

[24] In a poll conducted in 1996, 43 percent of the respondents said they were very interested, and another 33 percent said they were somewhat interested, in learning more about computers. Among this same group of respondents, 45 percent thought that home computers would make it easier to do things like shopping, paying bills, making travel arrangements, and looking things up electronically instead of going to a library or buying books or newspapers; 16 percent thought using a computer would make doing these activities more complicated (Roper 1996).

Figure 8-17.
Home access to computers: 1995, 1997, 1999



See appendix table 8-31. *Science & Engineering Indicators – 2000*

(See appendix table 8-32.) This increase, however, is almost entirely attributable to growth in the number of home computers. The average amount of time each person spends using his or her home computer remained relatively stable during the late 1990s, around 300 hours per year. (See figure 8-18.) However, a shift occurred in how that time was spent. More time is being spent on the Internet and less on other activities, for example, word processing. Among all home computer users, the amount of time spent on the Internet increased more than tenfold between 1995 and 1999 (from 15 hours per year to approximately 160). In addition, for those with Internet access, the amount of time spent on Internet activities, including using e-mail and visiting Web sites, increased from an average of 80 hours in 1995 to 269 hours in 1999. (See figure 8-18.)

The number of people with access to a computer at work has also been climbing, but the increase has been less dramatic. In 1983, one-fourth of the NSF survey respondents reported using a computer at work, and about one-third said they did in 1990. The proportion was up to 42 percent in 1999. (See figure 8-16 and appendix table 8-30.) In addition,

- Twenty percent of those surveyed had e-mail addresses at work, up from 16 percent two years earlier (see appendix table 8-31).
- The average amount of time spent using a computer at work increased 17 percent between 1995 and 1999, to about 950 hours per year. (See figure 8-18 and text table 8-5.)

The number of people *without* access to a computer either at home or at work fell between 1983 and 1999—from 70 percent down to 35 percent. In 1999, for the first time, there was no gender gap in lack of access. (See appendix table 8-30.)

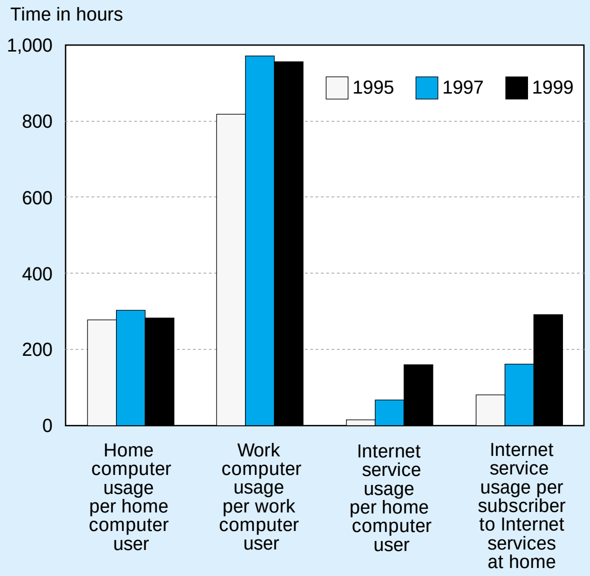
Text table 8-5.
Public's use of home computers, work computers, and the Internet

Variable	1995	1997	1999
Percentage of public with			
Access to a home computer	37	43	54
Access to a computer at work	39	38	42
Subscription to online service at home	7	18	32
Average time spent per year			
On home computer for home computer users in hours	278	302	283
On work computer for work computer users in hours	818	971	957
Average time spent online at home per year in hours			
For the general public	6	29	86
For home computer users	15	67	159
For Internet users	80	161	296

See appendix table 8-32 and previous editions of *Indicators.*

Science & Engineering Indicators – 2000

Figure 8-18.
Computer usage: average hours per year: 1995, 1997, 1999

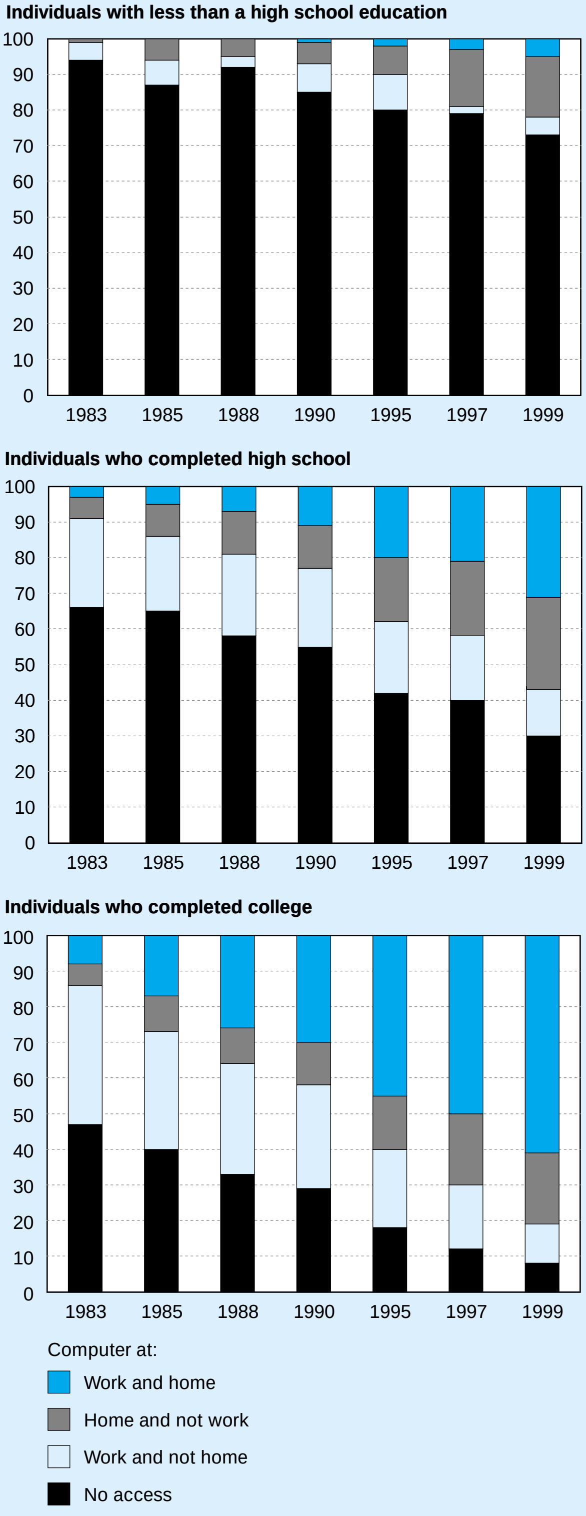


See text table 8-5.

Science & Engineering Indicators – 2000

Differences in computer access, the so-called "digital divide," are quite visible when level of formal education is taken into account. More than 70 percent of those who lack a high school diploma had no access to a computer either at home or at work in 1999. In contrast, only 30 percent of those who graduated from high school, and only 8 percent of those with at least a bachelor's degree, lacked access. Although access has been rising in all three groups, the pace is significantly slower for those with less formal education, and what increase there has been is entirely attributable to home computer acquisition, not access in the workplace. As an illustration, in 1983, less than 1 percent of those without high school diplomas had computers in their homes. By 1990, the proportion had grown to 7 percent, and by 1999, it had increased to 22 percent. During the same 16-year period, access to computers at work did not rise above 10 percent. Clearly, there is a difference in computer acquisition between those who did not finish high school and those with more formal education, but there is an even greater disparity in the use of computers in the workplace. (See figure 8-19 and appendix table 8-30.) For more information on this subject, see the section on “Information Technologies and the Citizen” in chapter 9.

Figure 8-19.
Access to computers, by level of education: 1983–99 (selected years)



See appendix table 8-30. *Science & Engineering Indicators – 2000*

The Relationship Between Science and the Media: Communicating with the Public

Most of what most Americans know about science and technology comes from watching television or reading a newspaper. (See sidebar, “Where Americans Get Information about Science and Technology.”) Thus, the media serve as a crucial conduit between the science and engineering community and the public at large.

Findings from a recent study conducted by the First Amendment Center[25] revealed a general consensus that the science community and the press are missing opportunities to communicate with each other and with the public:

> [T]he frequent inability of science and the media to communicate effectively with each other seriously undermines science literacy among the general public. This, in turn, creates an electorate ill-prepared to make informed judgments about major issues related to science, health, and technology, such as global warming and human cloning, as well as multi-billion-dollar federal investments in research and development (Hartz and Chappell 1997).

The public needs to be informed about the importance of science and technology, because tax dollars fund a sizable portion of the nation’s R&D enterprise—an estimated $66.6 billion in 1998. (See chapter 2, “U.S. and International Research and Development: Funds and Alliances.”) The public should know what it is buying with that investment. In addition, the science and engineering community, which relies fairly heavily on public financing for both its employment and its education, is also dependent on the news media to inform the public about the work that it does.

The relationship between the media and the science and engineering community has been the focus of considerable

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[25] All information in this section (unless otherwise specified) comes from the report *Worlds Apart: How the Distance between Science and Journalism Threatens America’s Future* (Hartz and Chappell 1997). This report contains findings from a study conducted by Jim Hartz (a veteran television and print journalist who has covered science extensively) and Rick Chappell (associate director for science at NASA’s Marshall Space Flight Center in Huntsville, Alabama). The Freedom Forum First Amendment Center is affiliated with Vanderbilt University and its Institute for Public Policy Studies.

Where Americans Get Information about Science and Technology

Television is the leading source of information about new developments in science and technology, followed by books and newspapers.* According to the 1999 NSF survey, each adult watches an average of about 1,000 hours of television per year; 42 percent of those hours are devoted to television news and 4 percent to shows about science.** (See appendix table 8-33.)

Men watch more science shows than women; the 1999 survey data indicate that men watch an average of 46 hours per year, compared with 38 for women. Those with more formal education and those who have taken more science and mathematics courses tend to watch more television shows devoted to science than those with less education, but the differences are not substantial. (See appendix table 8-33.)

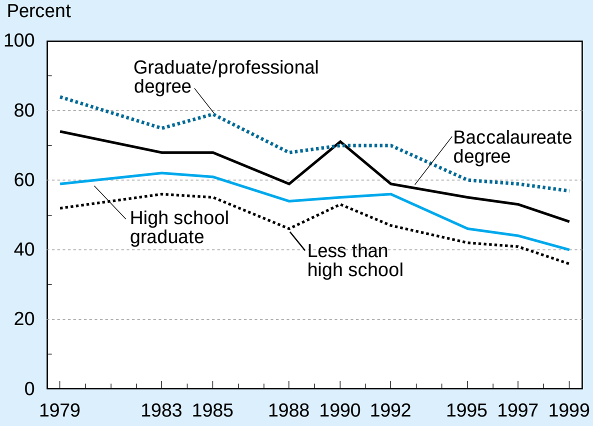
Cable television subscribers watch significantly more science shows than those without cable. The 1999 data indicate that cable subscribers watch an average of 50 hours per year, compared with 20 hours for individuals without the service. (See appendix table 8-33.)

The most recent data show Americans reading an average of 178 newspapers, 11 news magazines, and 3 science magazines per year. (See appendix table 8-33.) However, the percentage of all adults who read a newspaper every day has been declining—from 62 percent in 1983 to 41 percent in 1999.*** (See appendix tables 8-34 and 8-35.) The decline is apparent at all education levels. (See figure 8-20.)

The 1999 data indicate that Americans visit a public library an average of 9 times per year, and they borrow an average of 11 books and 1 videotape during that time frame. Sixty-two percent of those surveyed bought at least one book during the preceding 12-month period, and 33 percent said that they bought at least one book about science, mathematics, or technology (including computer use). (See appendix tables 8-33 and 8-34.)

About three out of every five Americans visit a science museum, natural history museum, zoo, or aquarium at least once per year. Museum attendance is positively related to formal education and attentiveness to science and technology. (See appendix tables 8-34 and 8-36.)

Figure 8-20.
Percentage of the U.S. public reading a newspaper every day: 1979–99



See appendix table 8-35. *Science & Engineering Indicators – 2000*

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*In one survey, 40 percent of the respondents said they pay a lot of attention to programs about science and technology; 46 percent said they pay a lot of attention to news reports about science on evening news shows or programs such as *20/20* or *Nightline* (Roper 1996).

**Since respondents were asked to name the science shows they watch regularly or periodically, this is a credible estimate of viewership.

***A focus group study revealed that *Washington Post* readers spend an average of only 22 minutes per day reading the paper (Suplee 1999).

scrutiny. Interest has grown in the past decade, probably because with the end of the Cold War, Federal support for R&D is not quite as solid as it once was. That is, R&D is facing stiffer competition among competing priorities within the Federal budget. (See chapter 2, “U.S. and International Research and Development: Funds and Alliances.”)

To identify the problems and develop recommendations for improving the relationship between science and the media, the First Amendment Center conducted a survey wherein both journalists and scientists were asked the same series of questions.[26] (Because only about one-third of each group submitted completed questionnaires, these findings should be treated with caution.) In addition, the survey findings were discussed at a forum on the topic.[27] A report was then prepared that contains a comprehensive description of the issues and recommendations for improving the relationship between science and the media. (See footnote 25).

What Are the Problems?

Distrust of the Media

The survey revealed a lack of confidence in the press. Only 11 percent of the scientists reported having a great deal of confidence in the press, and 22 percent said they have hardly any. (Comparable percentages for the journalists were 35 per-

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[26] Questionnaires were sent to 2,328 journalists, including (1) 1,036 individuals identified in the *Editor & Publisher* yearbook as editors, managing editors, or science correspondents or editors working at newspapers with circulations greater than 50,000 and (2) all 1,292 active members of the Radio-Television News Directors Association. For the scientists in the survey, 2,002 names were drawn randomly from the list of medical researchers of the American Medical Association and the membership lists of the American Geophysical Union, the American Physical Society, the Federation of American Societies of Experimental Biology, and the American Astronomical Society. About one-third of both the journalists and the scientists submitted completed questionnaires.

[27] The panel discussion was held on October 3, 1997, as part of a two-day event to commemorate the 40th anniversary of the launch of the Sputnik satellite.

Y2K Awareness and Concerns

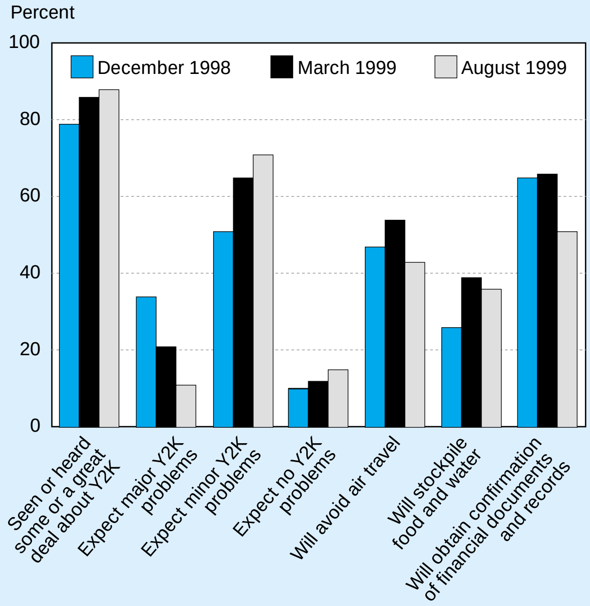
Media publicity about the Y2K problem seems to have worked. (Of course, the Y2K issue turned out to be a non-issue.) Data from several polls—including one conducted in December 1998, another in March 1999, and a third in August 1999—indicated

- A growing awareness of the Y2K issue, which refers to potential problems caused by computers not programmed to recognize dates after December 31, 1999. More than 85 percent of those polled in March and August 1999 said they had seen or heard “some or a great deal” about the so-called Millennium Bug, up from 79 percent in late 1998. (See figure 8-21.)
- A lessening of concern. The percentage of respondents anticipating major problems on January 1, 2000, fell from 34 percent in December 1998 to 21 percent in March 1999 to 11 percent in August 1999. However, concern remained over air travel, food shortages, and financial account accuracy. In August 1999,
    - 35 percent said it is likely that air traffic control systems will fail, down from 43 percent recorded three months earlier;
    - 35 percent said it is likely that food and retail distribution systems will fail (possibly causing grocery and other store shortages), down slightly from the previous surveys; and
    - 48 percent said that it is likely that banking and accounting systems will fail, down from 55 percent in March and 63 percent in December.
- A decrease in the number of people planning to take precautions. In August 1999,
    - 43 percent said they would avoid traveling on airplanes on or around January 1, 2000, down from 54 percent in March;
    - 36 percent said they would stockpile food and water, compared with 39 percent in March; and
    - 51 percent said they would obtain special confirmation or documentation of their bank account balances, retirement funds, or other financial records, down from 66 percent in the previous survey. (See figure 8-21.)

Most of those polled expressed:

- A high level of confidence (more than 80 percent in August 1999) in local, state, and Federal Government agencies’ and large companies’ ability to upgrade their computer systems before the end of 1999.
- Less confidence in other developed and industrialized countries’ governments (49 percent)—and in small companies (65 percent, compared with 91 percent for large companies)—being able to meet the deadline; and
- Little confidence (less than 20 percent) in the governments of Third World or other less developed countries’ ability to make the necessary software revisions.

Figure 8-21.
Public perception of and reaction to the "Year 2000 bug": 1998–99



SOURCE: *USA Today*/NSF/Gallup Poll,1999. “Americans and the Y2K Millennium Computer Bug.”

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cent and 4 percent, respectively.) Confidence in television media was even lower: nearly half (48 percent) of the scientists said they have hardly any confidence in it (compared with 27 percent for the journalists).[28] It is noteworthy that of all groups surveyed by the First Amendment Center (including the clergy, corporate leaders, the military, and even politicians), none was as distrustful of the news media as the scientists.

In addition, the media were faulted for failing to understand the process of scientific investigation, oversimplifying complex issues, and focusing on trendy discoveries:

- The vast majority of the scientists either strongly (52 percent) or somewhat (39 percent) agreed with the statement, “Few members of the news media understand the nature of science and technology, such as the tentativeness of most scientific discovery and the complexities of results.” (Comparable percentages for the journalists were 23 percent and 54 percent, respectively.)

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[28] Interestingly, the journalists’ responses to several questions indicated a higher level of confidence in the scientific community than in their own professional community. Also, the public in general has relatively little confidence in the press and TV. (See figure 8-9 and appendix table 8-23.)

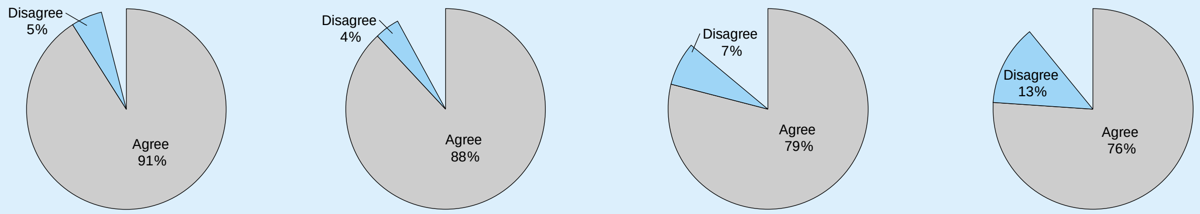
- More than half (56 percent) of the scientists either strongly or somewhat agreed with the statement, “Members of the news media rarely get the technical details about science and technology correct.” (Only one-fifth of the journalists agreed or somewhat agreed with the statement.)
- About three-quarters of the scientists either strongly (30 percent) or somewhat (46 percent) agreed with the statement, “Most members of the news media are more interested in sensationalism than in scientific truth.” (Comparable percentages for the journalists were 5 percent and 17 percent, respectively.) (See figures 8-22 and 8-23.)

Perceived Lack of Interest in Science

News decisionmakers may decide not to cover science stories. Few editors have any formal training in science.[29] These “gatekeepers” may

- believe their readers or listeners are uninterested in science stories and will not be able to understand them;
- allow the bad experiences they may have had with high

Figure 8-22.
Scientists' agreement with various negative statements about the news media



Lack understanding

Few members of the news media understand the nature of science and technology, such as the tentativeness of most scientific discovery and the complexities of results.

Are more interested in sales

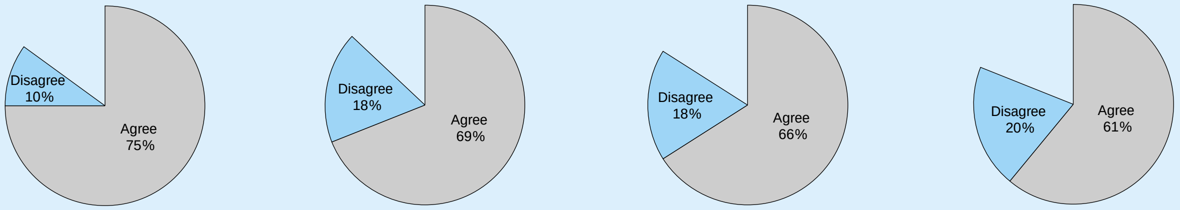
The top managers of the news media are more interested in selling newspapers or increasing viewership than in telling the public what it needs to know.

Focus on the trendy

Members of the news media who cover science and technology concentrate far too much on trendy discoveries rather than on basic research and development.

Seek the sensational

Most members of the news media are more interested in sensationalism than in scientific truth.



Want instant answers

The news media do not cover science because they are interested in instant answers and short-term results.

Are ignorant of process

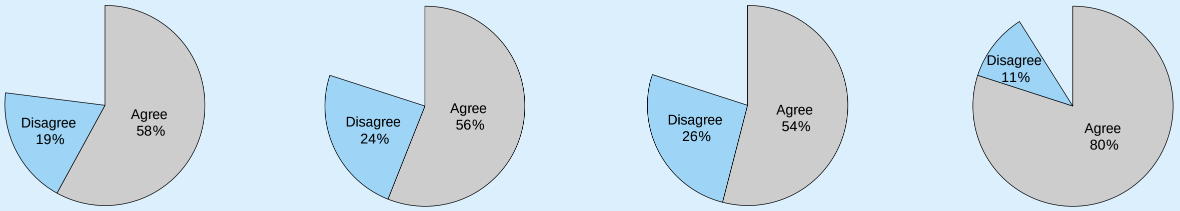
Most members of the news media have no understanding of the process of scientific investigation.

Cannot interpret results

Most reporters have no idea how to interpret scientific results.

Overblow risks

The news media have overblown the risks of consuming many substances or partaking in many activities, unduly alarming the public.



Lack education

Most reporters who cover science are not well enough educated to cover news about scientific and technological affairs.

Rarely get details right

Most members of the news media rarely get the technical details about science and technology correct.

Do not grasp the funding needed

Most members of the news media have no appreciation of the need for funding for basic scientific research and development.

Public misunderstands

Most members of the public do not understand the importance of government funding for research in science and technology.

NOTE: The percentage not accounted for in each of these charts represents those scientists who answered "neither agree nor disagree."

SOURCE: J. Hartz and R. Chappell, *Worlds Apart: How The Distance Between Science and Journalism Threatens America's Future* (Nashville, TN: Freedom Forum First Amendment Center, 1997).

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[29] Although half the journalists who participated in the First Amendment Center survey had covered science, only 6 percent reported having science degrees.

school or college science courses to influence their decisionmaking;

- think that, because their publications or programs are devoting sufficient space or time to stories about medicine and health, they are doing an adequate job of covering science; and
- claim that science sections fail to attract advertisers.[30]

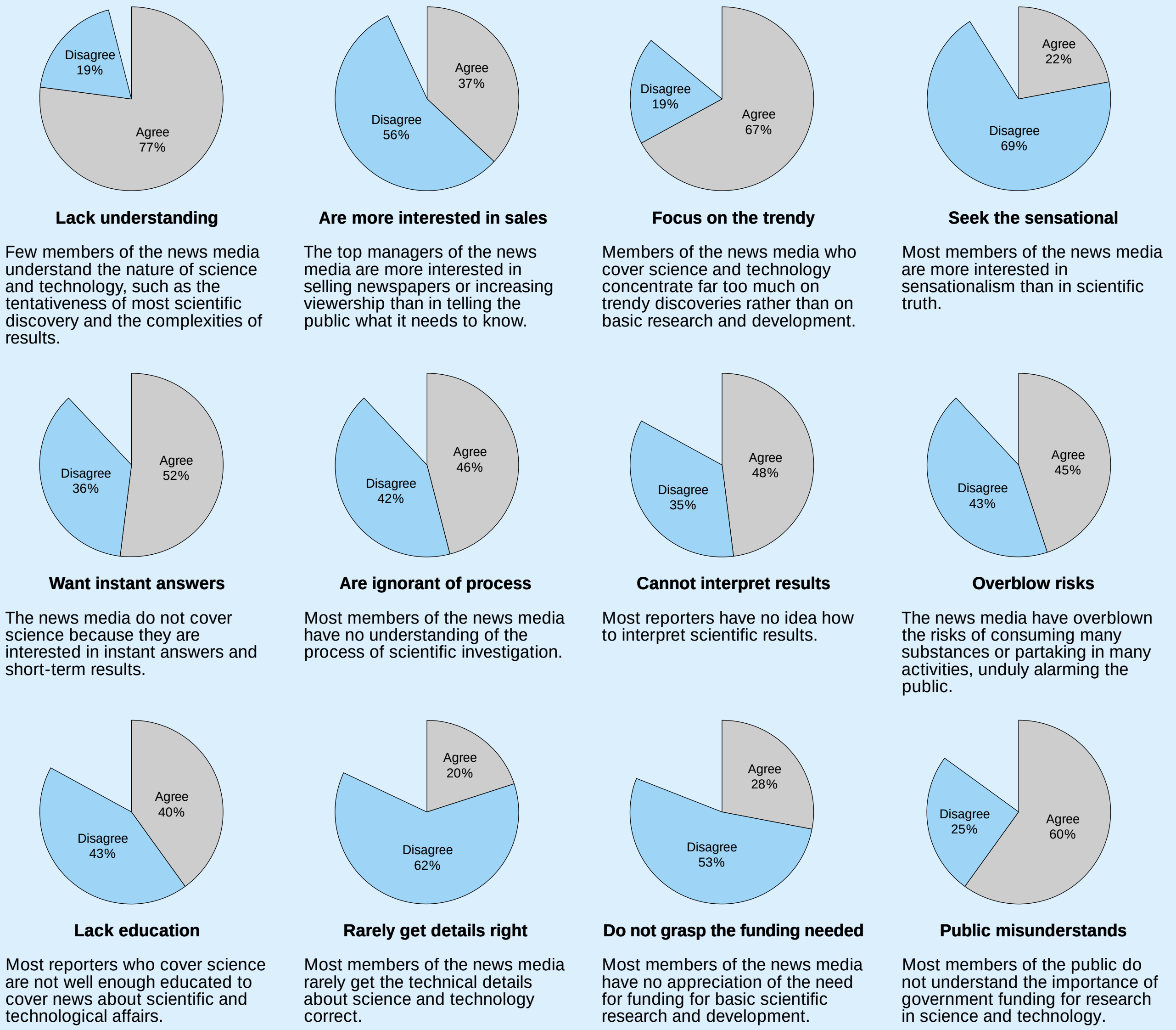
Communication Barriers

Scientists tend to use technical jargon instead of plain English when discussing their work. Also, they have yet to master the “sound bite.” They have a penchant for citing numerous qualifications when describing their findings, rather than summing up their research in one or two sentences. This communication style makes it difficult for science reporters to do their job.

Scientists also have a reputation for not being very good at identifying what is newsworthy and relevant to readers or listeners. According to one reporter, “scientists are sometimes

Figure 8-23.

Journalists' agreement with various negative statements about the news media



Lack understanding

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NOTE: The percentage not accounted for in each of these charts represents those journalists who answered "neither agree nor disagree."

SOURCE: J. Hartz and R. Chappell, *Worlds Apart: How The Distance Between Science and Journalism Threatens America's Future* (Nashville, TN: Freedom Forum First Amendment Center, 1997).

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[30] It is widely assumed that people who read science news are not large purchasers of the type of consumer products most heavily advertised in newspapers. In addition, science sections of major newspapers have traditionally been supported by computer ads and the number of computer manufacturers has been shrinking (Suplee 1999).

bad judges of their best stories" (P. Conti, as quoted in Hartz and Chappell 1997, 92). Therefore, the message to scientists should be:

> ...Two things...are vital and...found in nearly all good stories about science: relevance and context. Since so much of science is incremental, the reporter and the public need special help in placing research in the context of the big picture.(Hartz and Chappell 1997, 93).

Most scientists are unaccustomed to discussing their work with anyone other than their peers or students. Also, in the past, scientists were often able to take funding for granted; that is, they rarely needed to justify and explain their work to the public. This may account for their lack of experience in communicating with lay audiences through speaking engagements, on television, on the radio, and in writing for the popular press.[31]

Scientists are often reluctant to talk to the press, and rarely do so.[32] Undoubtedly, some of this lack of media contact is related to the feelings of distrust discussed previously. Also, scientists may seem overly concerned with how they are perceived by their peers. One of the most frequently cited reasons for scientists' reluctance to talk to the press is the so-called Carl Sagan effect, that is, renowned scientist Carl Sagan was criticized by his fellow scientists who assumed that because Sagan was spending so much time communicating with the public, he must not have been devoting enough time to his research.[33] Another reason that may cause scientists to evade the press is a fear of being misquoted or having their work mischaracterized; in such cases, their colleagues would have no way of knowing whether the scientist or the reporter was at fault.

An Ill-Informed and Poorly Educated Public

Although scientists and journalists do not see eye-to-eye on several issues, both agree that there is a need for a better informed and educated public.[34] In the First Amendment Center survey, more than two-thirds of the journalists and more than three-quarters of the scientists strongly or somewhat agreed with the statement: "The American public is gullible about much science news, easily believing in miracle cures or solutions to difficult problems." Moreover, 60 percent of the journalists and 80 percent of the scientists strongly or somewhat agreed with the statement: "Most members of the public do not understand the importance of government funding for research" and therefore do not understand what they are getting from their investment in R&D. (See figures 8-22 and 8-23.)

The state of science education has been a major concern because scientific and technological advancements are having an increasingly pervasive impact on modern life. (See chapter 5, "Elementary and Secondary Education.") Both sets of respondents cited weaknesses in science education in their survey questionnaires.[35] Not only does the education system not do as good a job as it should in imparting basic scientific knowledge, it also lets too many students slide through without developing good critical thinking skills, skills crucial in a society in which informed decisionmaking is becoming increasingly important and more complex. (See the section "Belief in the Paranormal or Pseudoscience.")

What Should Be Done To Improve the Relationship?

Both scientists and journalists participating in the First Amendment Center project demonstrated a willingness to improve their working relationship. More than three-quarters of the scientists said they would be willing to take a course designed to help them communicate better with journalists and the public, and more than 90 percent said they would be willing to participate in an ongoing dialogue with members of the news media.

After reviewing the survey findings and listening to ideas exchanged at the forum, participants developed the following recommendations, which were included in the First Amendment Center report:

- ♦ Scientists and reporters should engage in an ongoing dialogue with each other to learn how both can do a better job of communicating with the public.
- ♦ Professional societies and other organizations representing scientific disciplines should maintain Web sites that contain the telephone numbers and e-mail addresses of scientists available to talk to the press. These Web sites should also contain information useful to the press and the general public and should have links to a master Web site main-

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[31] The President's Science Advisor, Dr. Neal Lane, often speaks and writes about "the importance of scientists getting out of their labs, off their campuses, away from their computers, and into a dialogue with the American public." According to Dr. Lane, "A partial solution to this disconnect [between the science community and the public] is to educate scientists on how to be better communicators not only about their particular work but about the role and value of science and technology to society" (Neal Lane, speech before the Arlington Rotary Club, July 25, 1996).

[32] Nearly one-fourth of the scientists who participated in the First Amendment Center survey said they had never been interviewed or written about in a science news story; 45 percent answered "every few years." In a recent article, one host of a talk show in the United Kingdom described what a difficult time he had getting scientists to appear on his program: "The excuses varied but I discovered a deep-seated suspicion among British scientists about how they would be received by a nonscientific audience" (Bragg 1998).

[33] Sagan "was actually denied membership in the National Academy of Sciences, in part because many of the members felt it was unseemly for him to be so popular, so well-spoken, to get so many lucrative book contracts" (Hartz and Chappell 1997).

[34] The state of science education was the most frequently mentioned topic among the comments provided by the scientists on their questionnaires. A number of scientists have even observed, with dismay, what may be described as a cultural bias against science literacy. One scientist, who is also a Congressman, noted that it has "become fashionable to be ignorant about science" (The American Institute of Physics 1999).

[35] According to the NSF survey, a majority of Americans believes that the quality of science and mathematics education in U.S. schools is inadequate. But that proportion has been falling. Three-quarters of those surveyed held that view in 1992 and two-thirds did in 1999. (See appendix table 8-37.) In another poll, 57 percent of the respondents strongly agreed, and 28 percent somewhat agreed, with the statement that "unless we put more emphasis on science in the schools, we won't have the trained people we will need for life in the twenty-first century" (Roper 1996).

tained by either the American Association for the Advancement of Science or the National Academy of Sciences.

- Each article published in a scientific journal should include a brief summary—written in plain English—that contains the author's major findings and a brief explanation of the research's importance and relevance.
- Future scientists should be required to take undergraduate courses in communications, and future journalists should be required to take courses in science (to gain a better understanding of the scientific process).
- Journalists should approach what may appear to be groundbreaking research with caution, paying heed to the peer-review process, before reporting on the research.
- The scientific community should train spokespersons for each discipline, and scientists should welcome opportunities to talk about their work with the press and the general public.[36]

Belief in the Paranormal or Pseudoscience[37]

Does it matter if people believe in astrology, extrasensory perception (ESP), or that aliens have landed on Earth? Are people who check their horoscopes, call psychic hotlines, or follow stories about alien abductions just engaging in harmless forms of entertainment? Or, are they displaying signs of scientific illiteracy?

Concerns have been raised, especially in the science community, about widespread belief in paranormal phenomena. Scientists (and others) have observed that people who believe in the existence of paranormal phenomena may have trouble distinguishing fantasy from reality. Their beliefs may indicate an absence of critical thinking skills necessary not only for informed decisionmaking in the voting booth and in other civic venues (for example, jury duty[38]), but also for making wise choices needed for day-to-day living.[39]

Specific harms caused by paranormal beliefs have been summarized as:

- a decline in scientific literacy and critical thinking;
- the inability of citizens to make well-informed decisions;
- monetary losses (psychic hotlines, for example, offer little value for the money spent);
- a diversion of resources that might have been spent on more productive and worthwhile activities (for example, solving society's serious problems);
- the encouragement of a something-for-nothing mentality and that there are easy answers to serious problems, for example, that positive thinking can replace hard work; and
- false hopes and unrealistic expectations (Beyerstein 1998).

For a better understanding of the harms associated with pseudoscience, it is useful to draw a distinction between *science* literacy and *scientific* literacy. The former refers to the possession of technical knowledge. (See "Understanding Terms and Concepts" in the section "Public Understanding of Science and Technology.") Scientific literacy, on the other hand, involves not simply knowing the facts, but also requires the ability to think logically, draw conclusions, and make decisions based on careful scrutiny and analysis of those facts (Maienschein 1999; Peccei and Eiserling 1996).

The amount of information now available can be overwhelming and seems to be increasing exponentially. This has led to "information pollution," which includes the presentation of fiction as fact. Thus, being able to distinguish fact from fiction has become just as important as knowing what is true and what is not. The lack of this ability is what worries scientists (and others), leading them to conclude that pseudoscientific beliefs can have a detrimental effect on the well-being of society.[40] (See "An Ill-Informed and Poorly Educated Public" in the section "The Relationship between Science and the Media: Communicating with the Public.")

Belief in the Paranormal: How Common Is It?

Belief in the paranormal seems to be widespread. Various polls have shown that

- As many as one-third of Americans believe in astrology, that is, that the position of the stars and planets can affect people's lives (Harris 1998, Gallup 1996, and Southern Focus 1998). In 1999, 7 percent of those queried in the NSF survey said that astrology is "very scientific" and 29 percent answered "sort of scientific." (See figure 8-24.) Twelve percent said they read their horoscope every day

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[36] One journalist advises scientists to "track the ways that the popular media report basic research and interpret its value." According to the writer, "scientists can get clues [about how to improve] their communication skills with the media by noting what editors choose to cover, what they dismiss as uninteresting, and, more subtly, how they sometimes fail to make connections or provide perspective" (Lewis 1996).

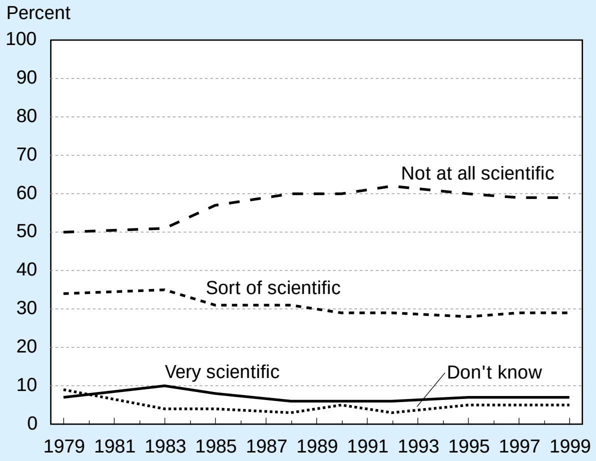
[37] Pseudoscience has been defined as "claims presented so that they appear [to be] scientific even though they lack supporting evidence and plausibility." In contrast, science is "a set of methods designed to describe and interpret observed and inferred phenomena, past or present, and aimed at building a testable body of knowledge open to rejection or confirmation" (Shermer 1997). Paranormal topics include yogic flying, therapeutic touch, astrology, fire walking, voodoo magical thinking, Uri Geller, placebo, alternative medicine, channeling, Carlos hoax, psychic hotlines and detectives, near death experiences, UFOs, the Bermuda Triangle, homeopathy, faith healing, and reincarnation (Committee for the Scientific Investigation of Claims of the Paranormal).

[38] Because of several well-publicized court cases, considerable attention has been focused on the role of science in the courtroom and the ability of judges and juries to make sound decisions in cases involving highly complex, science- or technology-based evidence. (See Angell 1996 and Frankel 1998.)

[39] A fairly common example that reflects a dearth of critical thinking skills is the number of people who become victims of get-rich-quick (for example, pyramid) schemes.

[40] According to J. Randi, "acceptance of nonsense as mere harmless aberrations can be dangerous to us. We live in an international society that is enlarging the boundaries of knowledge at an unprecedented rate, and we cannot keep up with much more than a small portion of what is made available to us. To mix our data input with childish notions of magic and fantasy is to cripple our perception of the world around us. We must reach for the truth, not for the ghosts of dead absurdities" (Randi 1992).

Figure 8-24.
Public perception of whether astrology is scientific: 1979–99



See appendix table 8-38. *Science & Engineering Indicators – 2000*

or “quite often”; 32 percent answered “just occasionally.”[41] (See appendix tables 8-38 and 8-39.)

- ♦ Nearly half or more believe in extrasensory perception or ESP (Gallup 1996; Southern Focus 1998). According to one poll, the number of people who have consulted a fortune-teller or a psychic may be increasing: in 1996, 17 percent of the respondents reported contact with a fortune-teller or psychic, up from 14 percent in 1990 (Gallup 1996).[42]
- ♦ Between one-third and one-half of Americans believe in unidentified flying objects (UFOs). A somewhat smaller percentage believes that aliens have landed on Earth (Gallup 1996; Southern Focus 1998).

Other polls have shown one-fifth to one-half of the respondents believing in haunted houses and ghosts (Harris 1998; Gallup 1996; Sparks, Nelson, and Campbell 1997), faith healing (Roper 1994, *USA Today* 1998), communication with the dead (Gallup 1996), and lucky numbers. (See appendix table 8-40.) Some surveys repeated periodically even show increasing belief in these examples of pseudoscience (*USA Today* 1998).

Belief in most—but not all—paranormal phenomena is higher among women than men. More women than men believe in ESP (especially telepathy and precognition), astrology, hauntings, and psychic healing. On the other hand, men have stronger beliefs in UFOs and bizarre life forms, for example, the Loch Ness monster (Irwin 1993). In the NSF survey, 39 percent of the women, compared with 32 percent of the men, said astrology is “very” or “sort of” scientific; 56 percent of the women, compared with 63 percent of the men, answered “not at all scientific.”[43] (See appendix table 8-38.)

Not surprisingly, belief in astrology is negatively associated with level of education.[44] Among those without high school diplomas, only 41 percent said that astrology is “not at all scientific.” The comparable percentages for high school and college graduates are 60 percent and 76 percent, respectively. (See appendix table 8-38.)

Do the Media Have a Role in Fostering Belief in the Paranormal?

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. Because not everyone who watches shows with paranormal themes perceives such fare as merely entertaining fiction, there is concern that the unchallenged manner in which some mainstream media portray paranormal activities is exacerbating the problem and contributing to the public’s scientific illiteracy.[45]

In recent years, studies have been undertaken to determine whether televised depictions of paranormal events and beliefs influence television viewers’ conceptions of reality (Sparks 1998). Although the results of these studies are tentative and require replication, all of them suggest that the way television presents paranormal subjects does have an effect on what viewers believe. For example,

- ♦ Those who regularly watch shows like *The X-Files*, *Unsolved Mysteries*, *Sightings*, and *Psychic Friends* were significantly more likely than those who did not watch these programs to endorse paranormal beliefs (Sparks, Nelson, and Campbell 1997).[46]
- ♦ Shows about paranormal phenomena, including UFOs, without disclaimers are more likely than those with disclaimers to foster belief in the paranormal. (Sparks, Hansen, and Shah 1994; Sparks and Pellechia 1997).
- ♦ Some fans of *The X-Files* find the show’s storylines “highly plausible,” and also believe that the government is currently conducting clandestine investigations similar to those depicted on the series (Evans 1996).

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[41] In the 1996 Gallup Poll, 18 percent of respondents said they read an astrology column regularly.

[42] At the First Amendment Center’s forum on science and the media, one of the participants cited what he called the “most frightening” results of a poll of students in Columbia’s graduate school of journalism: 57 percent of the student journalists believed in ESP; 57 percent believed in dousing; 47 percent in aura reading; and 25 percent in the lost continent of Atlantis (J. Franklin cited in Hartz and Chappell 1997).

[43] In an earlier NSF survey, 6 percent of the female—compared with 3 percent of the male—respondents reported changing their behavior because of an astrology report.

[44] A survey of 1,500 first-year college students found that 48.5 percent of arts—and 33.4 percent of science—students considered both astronomy and astrology scientific (De Robertis and Delaney 1993).

[45] Examples of pseudoscience that receive a considerable amount of coverage in the mainstream media are unproven health-related therapies. Also, as Carl Sagan pointed out, almost every newspaper has an astrology column, but not many have even a weekly column devoted to science.

[46] This result could simply mean that people who believe in the paranormal are more likely than others to watch such programs. However, the findings are consistent with the conclusions of earlier experiments conducted by the same researcher (Sparks 1998).

What Is Being Done To Present the Other Side?

The Committee for the Scientific Investigation of Claims of the Paranormal (CSICOP) is a nonprofit scientific and educational organization started in 1976 by scientists (including several Nobel laureates), members of the academic community, and science writers. Members of CSICOP, frequently referred to as *skeptics*, advocate the scientific investigation of paranormal claims and the dissemination of factual information to counter those claims. CSICOP's mission includes taking advantage of opportunities to promote critical thinking, science education, and the use of reason to determine the merits of important issues.[47]

The Council for Media Integrity, an educational outreach and advocacy program of CSICOP, was established in 1996. Its objective is to promote the accurate depiction of science by the media. The Council, which includes distinguished international scientists, academics, and members of the media, believes it is necessary to counteract the entertainment industry's portrayal of paranormal phenomena because:

- television has such a pervasive impact on what people believe;
- an increasing number of shows are devoted to the paranormal, and they attract large audiences;
- a number of shows use a documentary style to promote belief in the reality of UFOs, government coverups, and alien abductions;
- opposing views are seldom heard in shows that advocate belief in the paranormal; and
- some shows contribute to scientific illiteracy by promoting unproven ideas and beliefs as real, instilling a distrust of scientists[48] and fostering misunderstanding of the methods of scientific inquiry.

To promote media responsibility—particularly within the entertainment industry—and to publicize irresponsibility—the Council established two awards[49]:

- The "Candle in the Dark Award" is given to television programs that have made a major contribution to advancing the public's understanding of science and scientific principles. The 1997 and 1998 awards went to two PBS programs: *Bill Nye—The Science Guy* and *Scientific American Frontiers*.
- The "Snuffed Candle Award" is given to television programs that impede public understanding of the methods of scientific inquiry. The 1997 and 1998 winners were Dan Akroyd, for promoting the paranormal on the show *Psi-Factor*, and Art Bell, whose radio talk-show promoted belief in UFOs and alien abductions.

In its efforts to debunk pseudoscience, the Council also urges TV producers to label documentary-type shows depicting the paranormal as either entertainment or fiction, provide the media with the names of expert spokespersons, ask U.S. newspapers to print disclaimers with horoscope columns, and use "media watchdogs" to monitor programs and encourage responsibility on the part of television producers.

Finally, various skeptics groups and renowned skeptic James Randi have long-standing offers of large sums of money to anyone who can prove a paranormal claim. Randi and members of his "2000 Club" are offering more than a million dollars. So far, no one has met the challenge.

Conclusion

Americans express a high level of interest in science and technology. Despite this interest, they lack confidence in their knowledge of these subjects; in 1999, only 17 percent thought they were well informed about science and technology. 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 and to believe that they are well informed about them.

Data on science literacy in the United States indicate that most Americans do not know a lot about science and technology. The percentage of correct responses to a battery of questions designed to assess the level of knowledge about, and understanding of, science terms and concepts has not changed appreciably in the past few years. In addition, approximately three-quarters of Americans do not understand the nature of scientific inquiry. Individuals with more years of formal schooling and who have taken 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 science and technology, strongly support the Federal Government's investment in basic research, and have high regard for the science community. However, some individuals harbor reservations, especially about technology and its effect on society. In addition, the use of nuclear energy and the use of dogs and chimpanzees in scientific research do not have widespread support. Also, a sizeable minority of the public questions the value of the space program; however, support has been gaining ground in recent years. Finally, in the past few years, new pockets of concern about genetic engineering have arisen among the well-educated and those most attentive to medical issues.

Americans get most of their information about public policy issues from television news and newspapers. There is widespread consensus—among both scientists and journal-

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[47] CSICOP's official journal *The Skeptical Inquirer* is a vehicle for disseminating and publicizing the results of scientific studies of paranormal claims.

[48] According to one study, scientists are portrayed more negatively than members of any other profession on prime-time entertainment shows. They are more likely to be killed or to kill someone. In fact, the study found that 10 percent of the scientists on fictional TV shows get killed and 5 percent kill someone (Gerbner 1987).

[49] The award titles were inspired by Carl Sagan's book, *The Demon Haunted World: Science as a Candle in the Dark* (Sagan 1996).

ists—that important information about science and technology and their value to society is not reaching the public. 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.

Computers and computer technology represent a relatively new way of acquiring information, including information about science and technology. Computer usage—including access to the Internet and the use of e-mail—has skyrocketed. This phenomenon is thoroughly explored in chapter 9, "Significance of Information Technologies."

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Chapter 9
Significance of Information Technologies

Contents

Highlights

IT and the Economy

- **The Internet and the World Wide Web are expanding rapidly, domestically and internationally.** The number of Internet hosts (computers connected to the Web) has grown from about 1 million in 1992 to 60 million in mid-1999. The United States is second to Finland in the number of Internet hosts per capita.
- **The information technology (IT) industry has contributed substantially to U.S. economic performance**. Growth in the IT industry contributed an estimated 29 percent of growth in real Gross Domestic Income in 1998. Declining prices in IT-producing industries contributed to reduced inflation in the overall economy.
- **Internet-based electronic commerce is growing rapidly and changing the impact of IT on the economy**. Private market research firms estimated that the value of transactions conducted over the Internet will reach $1 trillion by 2003 (up from $40–100 billion in 1998).
- **Electronic commerce is encouraging international efforts to develop more consistent and predictable legal regimes.** National and subnational laws and regulation come into conflict on the Internet in intellectual property, privacy, content, and other areas.
- **An increase in income inequity has coincided with the computerization of the workplace.** IT appears to have increased the demand for high-skill jobs in absolute terms as well as relative to low-skill jobs.
- **There has been a strong growth in the demand for workers with IT skills.** The Bureau of Labor Statistics projects that more than 1.3 million new computer scientists, computer engineers, systems analysts, and computer programmers will be needed between 1996 and 2006.

IT, Education, and Knowledge Creation

- **Schools are rapidly connecting to the Internet.** By 1998, 89 percent of public schools were connected to the Internet (up from 35 percent in 1994). In 1998, 51 percent of instructional rooms in public schools were connected to the Internet—up from 3 percent in 1994 and 27 percent in 1997.
- **Colleges are increasingly using IT in instruction**. The percentage of college courses using e-mail, Internet resources, class Web pages, and other forms of information technology in instruction increased rapidly between 1994 and 1998.
- **The effectiveness of information technology in education is still unclear.** Many studies show that information technology has positive effects on learning, but its cost-effectiveness relative to other investments in education is less clear.
- **Distance education using information technology is expanding rapidly and opens educational opportunities for nontraditional students.** It also raises new issues regarding ownership of intellectual property rights in instructional material and concerns about the future of traditional education.
- **Electronic scholarly communication is expanding rapidly.** The number of electronic journals doubled between 1996 and 1997. Preprint servers have proven to be very efficient modes of scholarly communication and have become major modes of communications in some fields.
- **The amount of information on the World Wide Web is approaching the amount of text in the largest libraries.** The World Wide Web was estimated to contain 6 trillion bytes of text in February 1999—equivalent to 6 million books. About 6 percent of Web servers are based at universities, colleges, or research laboratories.
- **IT is increasingly important in research**. In addition to the traditional use of computing in the physical sciences and engineering, information technologies are having increasing impact in biology (especially genomics) and are providing new tools for research collaboration.

IT and the Citizen

- **Home access to personal computers and the Internet is increasing rapidly.** The percentage of U.S. households owning a home computer increased from 24 percent in 1994 to 42 percent in 1998. The percentage of households with access to the Internet increased from 2 percent in 1994 to 26 percent in 1998.
- **There are differences in home adoption of IT by income level, race/ethnicity, and geographic location.** People who are more affluent, more highly educated, and in higher-status occupations are more likely to have home personal computers and Internet access. Even after controlling for differences in income, blacks lag whites in ownership of home computers and in linking to the Internet.
- **Home use of the Internet is primarily for e-mail and World Wide Web activity.** Health and medicine are the most popular Internet subjects.
- **Governments around the world are using the Internet and the World Wide Web to communicate with constituencies.** Most countries have Web sites for some of their agencies. Almost 40 had Web sites for 70 percent or more of their top-level agencies.

Introduction

Chapter Overview

The revolution in information technology (IT) has been likened to the industrial revolution in terms of its potential scope and impact on society (Alberts and Papp 1997; Castells 1996; Freeman, Soete, and Efendioglu 1995; Kranzberg 1989). Few other modern advances in technology have had the capacity to affect so fundamentally the way people work, live, learn, play, communicate, and govern themselves. As IT extends human capabilities and takes over other functions previously performed by humans, it can even affect what it means to be human.

It is far from clear what the total effects of IT on society will be. As Vannevar Bush (1945) noted more than 50 years ago, "The world has arrived at an age of cheap complex devices of great reliability; and something is bound to come of it." The question is, What has become of it? As with automobiles and television earlier in the 20th century, information technologies can be expected to have diverse and far reaching effects on society—some good, some bad, and many unanticipated.

The IT revolution raises many policy issues: How will IT affect the development and safety of children and the privacy of adults? How will IT affect the distribution of knowledge, wealth, and power among different groups in the United States and around the world? Will there be a "digital divide" between IT-rich and IT-poor groups that increases current inequalities? How will IT affect national sovereignty and international law? How will IT affect education and the future of libraries, universities, and scholarly communication? What measures are needed to make electronic commerce markets operate efficiently and fairly? Which issues can best be handled adequately in the private sector, and which require the involvement of the public sector? Although many of these questions are beginning to come into focus, data and research to answer these questions are lagging the changes that are occurring.

The information revolution is not new. The United States began moving toward an information-based economy in the 1960s, as information intensive services began to grow. At that time, computers were used mostly in the research and development (R&D) community and in the offices of large companies and agencies. In the past 20 years, however, IT has become increasingly pervasive in society. It has spread to the point that nearly everyone uses some form of IT every day. It has become common in schools, libraries, homes, offices, and shops. Corner grocery stores use IT for sales and electronic transactions; automobile repair shops use IT to diagnose failures and search for parts. In the past few years, the Internet and the World Wide Web in particular have contributed to the rapid expansion of IT. Innovations in IT now directly affect nearly everyone—not just the few in computer-intensive jobs.

As the market for IT has expanded, private investment in new technologies and manufacturing has increased—which in turn has led to new, better, and cheaper technologies. Costs have come down dramatically, and many new applications have been developed. Many of these advances provide return benefits to the science and engineering enterprise. For example, more powerful work stations, improved networking, and better databases all aid in research.

A discussion of IT in a collection of science and engineering indicators is important for two reasons. First, IT constitutes an important part of science and engineering's effect on society and the economy. It embodies advances in numerous fields, including computer science, computer engineering, electrical engineering, material science, mathematics, and physics. IT illustrates the effects of federal and private investment in R&D. Much IT has been developed by and for the R&D community, and the R&D community is an early user of many information technologies. Many of the effects of IT, such as the use of e-mail for communication or the World Wide Web for publication, take place first in the R&D community.

Second, IT is a major force affecting the U.S. and global science and engineering system. IT producers employ scientists and engineers, implement the results of academic research, and conduct significant amounts of applied research and development. IT affects the pipeline for science and engineering through its effects on the demand for people with technical skills and through its use in education at all levels. IT also affects the conduct of R&D in all disciplines. For example, the physical sciences make extensive use of computer modeling and simulation, and many aspects of biology (notably genomics) have become more information intensive. Advances in networking, meanwhile, facilitate the global nature of research collaboration.

This chapter provides an overview of the significance of IT for society and the economy; it focuses especially on the effects of IT on education and research. A complete discussion of the impact of information technology on society and the economy, however, is beyond the scope of this (or perhaps any) chapter. Other federal agencies and other organizations are addressing some areas. This chapter provides references and Web citations to direct the reader to more detailed and frequently updated information.

IT Data and Measurement

One major difficulty in analyzing the effect of IT on society is the difficulty in obtaining reliable national and internationally comparable data (CSTB 1998). There is little reliable, accepted, long-term data on either the diffusion of IT or its effects on society. The rate of technological change since the early 1980s has often outpaced our ability to define what we want to know and what data ought to be collected. Metrics are confounded by the changing nature of IT as a concept and the interactive effects of so many social variables—including age, ethnicity, income, learning processes, individual attitudes, organizational structures, culture, and management styles. In many cases, the effects of IT depend largely on how it is used. Positive effects often depend on appropriate organizational structures and managerial style, as well as the adequacy of training and the attitudes of individuals using IT.

Quantitative indicators of IT diffusion are relatively abundant but not standardized. Much of the available data is in the form of quickly developed, easily obtained information rather than long-term studies. Studies in many areas of interest often are not regularly repeated with the same methods. This lack of comparable data partly reflects the complexity and dynamism of IT: The most interesting things to measure change rapidly.

Indicators of the effects of IT—as opposed to the use of IT—on individuals, institutions, and markets are especially difficult to establish. This difficulty inhibits our ability to draw any definitive conclusions about the impacts of IT on society. Experts have had difficulty measuring productivity in service industries, in education, and in research and development. Consequently, determining the effects of IT on productivity in these areas is even more difficult. Moreover, IT often has effects in conflicting directions. There is evidence, for example, that IT can both increase and decrease productivity and contribute to both lowering and upgrading of skills in the labor force. Computer-aided instruction may enhance some forms of student learning, but extensive use of some computing environments may impede other aspects of child development.

This chapter attempts to compile relevant existing data and indicators; it also identifies the limitations of existing data and suggests how improvements to the data would be helpful. Data and measurement issues are identified throughout this chapter and are further discussed in the conclusion.

Information Technologies

Information technology, 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. The foundation of modern information technologies and products is the ability to represent text, data, sound, and visual information digitally. By integrating computing and telecommunications equipment, IT offers the ability to access stored (or real-time) information and perform an extraordinary variety of tasks.

IT is not a single technology; it is a system of technologies in combination. There are literally hundreds of commercial products—ranging from telephones to supercomputers—that can be used singly or, increasingly, in various combinations in an information processing system. The different functions of many of these products contribute to a sense of fuzziness about IT's technological boundaries.

One approach is to group IT into four technological elements: human interface devices, communication links (including networks), information processing hardware and software, and storage media. (See figure 9-1.) There are substantial overlaps among the categories. For example, most human interface devices also have some information processing and storage capabilities.

The rapid social and economic diffusion of IT since 1980 has been stimulated by rapid changes in computing power, applications, telecommunications, and networks, as well as concurrent reductions in the cost of technology and, in some cases, improvements in ease of use. The most dramatic manifestations are enormous improvements in performance and reductions in cost of integrated circuits brought about by rapid miniaturization. (See sidebar, "Moore's Law.") Similar but less dramatic improvements in cost and performance have occurred in disk drives and other computer hardware.

In addition, new capabilities are being added to chips. For example, microelectromechanical systems such as sensors and actuators and digital signal processors are being put on chips, enabling cost reductions in these technologies and extending information technologies into new types of devices.

Another key development in IT is the growing connectivity of computers and information. Computers are increasingly connected in networks, including local area networks (LANs) and wide area networks (WANs). Many early commercial computer networks, such as those used by automated teller machines (ATMs) 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. Almost three-fourths of the personal computers in the United States are networked (WITSA 1999, 55). Worldwide, there were

Figure 9-1.
Technological components of an information processing system

Human interface devices
- Computers
- Telephones
- Scanners
- TVs
- Displays
- Printers
- Digital cameras
- Automated teller machines
- Personal digital assistants

Communication links
- Internet
- Intranets
- LANs
- Telephone lines
- Routing and switching
- Coaxial cable
- Fiber-optic lines
- Satellite
- Cellular

Information processing
- Computer hardware
  - servers
  - work stations
  - PCs
- Software
  - systems software
  - business and home applications
  - information searching and filtering

Storage media
- Hard drives
- Floppy disks
- Optical disks
- Magnetic tape
- Memory chips and cards

Science & Engineering Indicators – 2000

Moore's Law

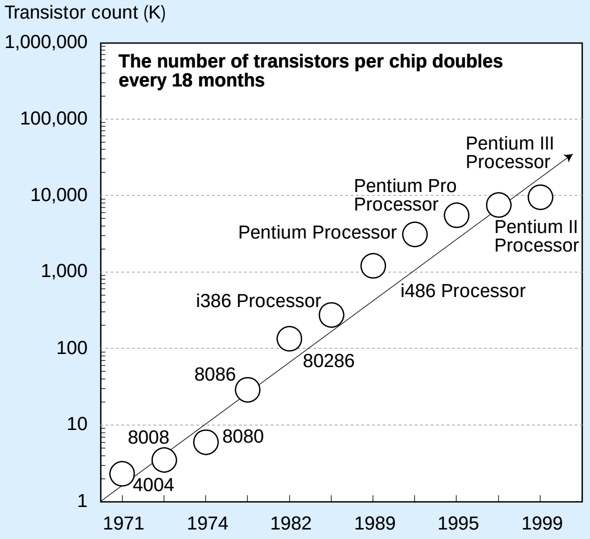
The number of transistors on a chip has doubled approximately every 12–18 months for the past 30 years—a trend referred to as Moore's Law. (See figure 9-2.) This trend is named for Gordon Moore of Intel, who first observed it. As Moore (1999) noted:

> I first observed the "doubling of transistor density on a manufactured die every year" in 1965, just four years after the first planar integrated circuit was discovered. The press called this "Moore's Law" and the name has stuck. To be honest, I did not expect this law to still be true some 30 years later, but I am now confident that it will be true for another 20 years.

Performance has increased along with the number of transistors per chips, while the cost of chips has remained fairly stable. These factors have driven enormous improvements in the performance/cost ratio. (See figure 9-3.)

The complexity and cost of developing new chips and new semiconductor manufacturing equipment also have increased. As a result, the industry has been driven toward greater economies of scale and industry-wide collaboration. Moore's Law—which began as the observation of an individual in a single company—has become a self-fulfilling prediction that drives industry-wide planning. Since 1992, the U.S. Semiconductor Industry Association (SIA) has developed a National Technology Roadmap for Semiconductors, which charts the steps the industry must take to maintain its rate of improvement. In 1998, this effort evolved into the International Technology Roadmap for Semiconductors, with participation by the Japanese, European, and South Korean semiconductor industries. The 1998 update projects the number of transistors per chip increasing to 3.6 billion in 2014 (SIA 1998).

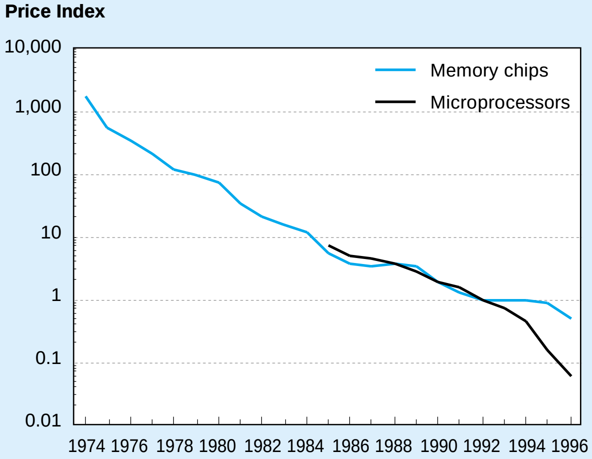
Figure 9-2.
Moore's Law



SOURCE: Intel. Available from <<http://www.intel.com/pressroom/kits/processors/quickref.htm>>.

See appendix table 9-1. *Science & Engineering Indicators – 2000*

Figure 9-3.
Price index for memory chips and microprocessors



NOTE: 1992 = 100 (Log scale)

SOURCE: Grimm, B.T. "Price Indexes for Selected Semiconductors, 1974–96." *Survey of Current Business* (February 1998). Available from <<http://www.bea.doc.gov/bea/ARTICLES/NATIONAL/NIPA/1998/0298od.pdf>>.

Science & Engineering Indicators – 2000

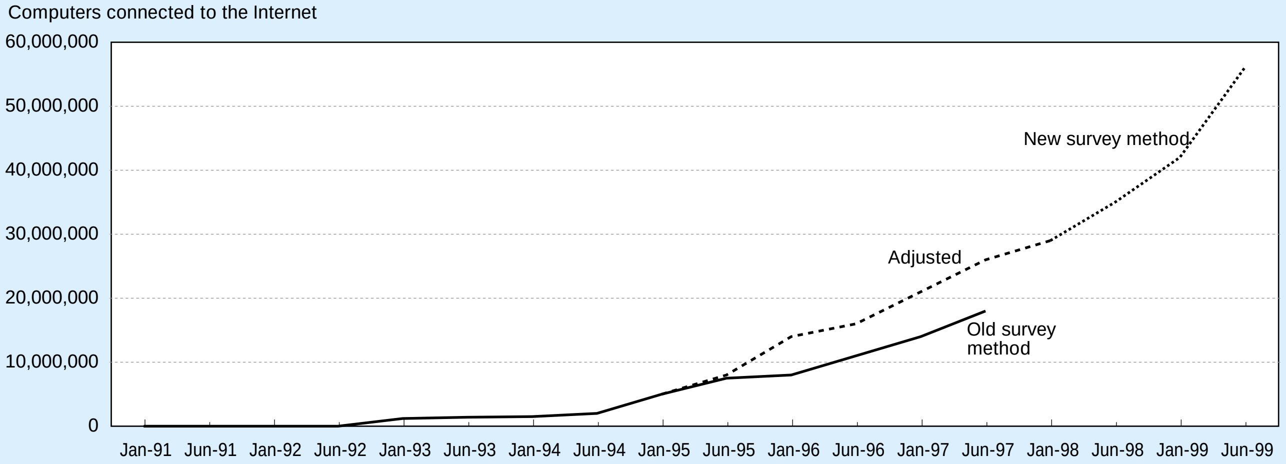
more than 56 million Internet hosts—computers connected to the Internet—in July 1999, up from about 30 million at the beginning of 1998. (See figure 9-4 and appendix table 9-2.)

Information Technology Over the Past 50 Years

IT and the National Science Foundation (NSF) have come of age together. In this year that marks the 50th anniversary of NSF, few areas demonstrate as vividly as IT the progress that has been made in science and engineering in the past half-century.

In 1945, the same year that Vannevar Bush outlined his ideas for what became the National Science Foundation in *Science—the Endless Frontier*, he also wrote an article in the *Atlantic Monthly* that described his vision for capturing and accessing information. (See sidebar, "Excerpts from 'As We May Think'.") In the *Atlantic* article, Bush proposed the development of a kind of work station, which he called a "memex," that would store and provide access to the equivalent of a million volumes of books. The memex would also employ a way of linking documents "whereby any item may be caused at will to select immediately and automatically another"—allowing the user to build a trail between multiple

Figure 9-4.
Internet domain survey host count



SOURCE: Internet Software Consortium. Available from <<http://www.isc.org/>>.

See appendix table 9-2.

Science & Engineering Indicators – 2000

documents. Although Bush proposed using photographic methods for storage and mechanical means for retrieval, and the exact technological capability he dreamed of has not yet come to pass, the proposed function of his memex is remarkably similar to hypertext today.

When Bush thought about the capabilities that would be dramatically useful to knowledge workers, he envisioned not capable calculators or word processors but capabilities to store and access information that current technology is just now achieving—using quite different approaches. Much R&D and innovation have been necessary to reach these capabilities.

In the same year that Bush's *Atlantic* article appeared, developments were taking place that would provide a different path for achieving his vision. At the University of Pennsylvania, John P. Eckert and John W. Mauchly were completing, with Army funding, what is commonly recognized as the first successful high-speed digital computer—the ENIAC. Dedicated in January 1946 and built at a cost of $487,802 (Moye 1996), the ENIAC used 18,000 vacuum tubes, covered 1,800 square feet of floor space, and consumed 180,000 watts of electrical power. It was programmed by wiring cable connections and setting 3,000 switches. It could perform 5,000 operations per second (CSTB 1998).

Also in 1945, Hungarian-born Princeton mathematician John von Neumann developed the stored program concept, which enabled computers to be programmed without rewiring. The von Neumann architecture—which refers to a computer with a central processing unit that executes instructions sequentially; a slow-to-access storage area; and secondary fast-access memory—became the basis for most of the computers that followed. Since the middle of the 20th century, software development has emerged as a discipline with its own challenges and skill requirements, complementing the more visible advances in hardware and enabling great systems complexity.

Over the succeeding 50 years, a vast number of innovations and developments occurred. (See sidebar, "IT Timeline.")

Innovations in IT over this period came from a remarkable diversity of sources and institutional settings, as well as a remarkable interplay among industry, universities, and government. Transistors and integrated circuits were invented by industry. Early computers and advances such as core memory, time-sharing, artificial intelligence, and Internet browsers were developed in universities, primarily with government funding. The World Wide Web was developed at the European Center for Particle Research (CERN), a high-energy physics laboratory. The mouse and windows were developed at a nonprofit research institute, with government funding. High-performance computers were mostly developed in industry with federal funds and with the involvement of federal laboratories. The diversity and close interaction between these institutions clearly contribute to the vitality of innovation in IT.

Innovation in IT has benefited from the support of a diverse set of federal agencies—including the Department of Defense (DOD), including the Defense Advanced Research Projects Agency (DARPA) and the services; NSF; the National Aeronautics and Space Administration (NASA); the Department of Energy (DOE); and the National Institutes of Health (NIH). Federal support has been particularly important in long-range fundamental research in areas such as computer architecture, computer graphics, and artificial intelligence, as well as in the development or procurement of large systems that advanced the technology—such as ARPANET, the Internet (See sidebar "Growth of the Internet"), and high-performance computers (CSTB 1998).

Often there has been complementary work supported by the Federal Government and industry. In many cases the Federal Government has supported the initial work in technologies that were later developed by the private sector. In other cases Federal research expanded on earlier industrial research. Higher-level computer languages were developed in industry and moved to universities. IBM pioneered relational databases and reduced-instruction-set computing, which were further developed with NSF support. Collaboration between industry and university researchers has facilitated the commercialization of computing research. (See figure 9-5.)[1]

Most of the relentless cost-cutting that has been so important in the expansion of IT has been driven by the private sector in response to competitive pressures in commercial markets, although here too federal investment—such as in semiconductor manufacturing technologies—has played an important role in some areas.

Excerpts from "As We May Think"

Atlantic Monthly (July 1945)
by Vannevar Bush

Professionally our methods of transmitting and reviewing the results of research are generations old and by now are totally inadequate for their purpose...The difficulty seems to be, not so much that we publish unduly in view of the extent and variety of present day interests, but rather that publication has been extended far beyond our present ability to make real use of the record. The summation of human experience is being expanded at a prodigious rate, and the means we use for threading through the consequent maze to the momentarily important item is the same as was used in the days of square-rigged ships.

Consider a future device for individual use, which is a sort of mechanized private file and library. It needs a name, and, to coin one at random, "memex" will do. A memex is a device in which an individual stores all his books, records, and communications, and which is mechanized so that it may be consulted with exceeding speed and flexibility. It is an enlarged intimate supplement to his memory.

It consists of a desk, and while it can presumably be operated from a distance, it is primarily the piece of furniture at which he works. On the top are slanting translucent screens, on which material can be projected for convenient reading. There is a keyboard, and sets of buttons and levers. Otherwise it looks like an ordinary desk.

In one end is the stored material. The matter of bulk is well taken care of by improved microfilm. Only a small part of the interior of the memex is devoted to storage, the rest to mechanism. Yet if the user inserted 5,000 pages of material a day it would take him hundreds of years to fill the repository, so he can be profligate and enter material freely. It affords an immediate step…to associative indexing, the basic idea of which is a provision whereby any item may be caused at will to select immediately and automatically another. This is the essential feature of the memex. The process of tying two items together is the important thing.

When the user is building a trail, he names it, inserts the name in a code book, and taps it out on his keyboard. Before him are the two items to be joined, projected onto adjacent viewing positions. At the bottom of each there are a number of blank code spaces, and a pointer is set to indicate one of these on each item. The user taps a single key, and the items are permanently joined. In each code space appears the code word. Out of view, but also in the code space, is inserted a set of dots for photocell viewing; and on each item these dots by their positions designate the index number of the other item.

Thereafter, at any time, when one of these items is in view, the other can be instantly recalled merely by tapping a button below the corresponding code space. Moreover, when numerous items have been thus joined together to form a trail, they can be reviewed in turn, rapidly or slowly, by deflecting a lever like that used for turning the pages of a book. It is exactly as though the physical items had been gathered together from widely separated sources and bound together to form a new book. It is more than this, for any item can be joined into numerous trails.

The owner of the memex, let us say, is interested in the origin and properties of the bow and arrow. Specifically he is studying why the short Turkish bow was apparently superior to the English long bow in the skirmishes of the Crusades. He has dozens of possibly pertinent books and articles in his memex.

First he runs through an encyclopedia, finds an interesting but sketchy article, leaves it projected. Next, in a history, he finds another pertinent item, and ties the two together. Thus he goes, building a trail of many items. Occasionally he inserts a comment of his own, either linking it into the main trail or joining it by a side trail to a particular item. When it becomes evident that the elastic properties of available materials had a great deal to do with the bow, he branches off on a side trail which takes him through textbooks on elasticity and tables of physical constants. He inserts a page of longhand analysis of his own. Thus he builds a trail of his interest through the maze of materials available to him.

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[1] For a more complete description of industry and government roles in developing information technologies, see CSTB (1998).

IT Timeline

1945: The ENIAC, the first high-speed digital computer, is built at the University of Pennsylvania for the U.S. Army's Ballistics Research Laboratory to help prepare artillery firing tables.

1947: Bell Telephone Laboratories develops the transistor.

1949: The concept for core memory is patented by An Wang at Harvard University. Core memory and random access memory (RAM) are further developed by the Whirlwind Project at MIT.

1951: UNIVAC, the first commercial computer, is developed and delivered to the Census Bureau.

1952: G.W. Dummer, a radar expert from the British Royal Radar Establishment, proposes that electronic equipment be manufactured as a solid block with no connecting wires; he receives little support for his research.

1953: IBM enters the computer business with the 700 series computer.

1959: Texas Instruments and Fairchild Semiconductor both announce the integrated circuit.

Late 1950s–early 1960s: Timesharing (the concept of linking a large numbers of users to a single computer via remote terminals) is developed at MIT.

1961: Fairchild Semiconductor markets the first commercial integrated circuits.

1964: The IBM 360 is introduced and becomes the standard institutional mainframe computer.

1965: Gordon Moore predicts that the number of components in an integrated circuit will double every year (Moore's Law).

1968: Doug Engelbart of Stanford Research Institute demonstrates a word processor, a mouse, an early hypertext system, and windows. Gordon Moore and Robert Noyce found Intel.

1969: ARPANET goes online. Xerox establishes the Palo Alto Research Center to explore the "architecture of information."

1970: Fairchild Semiconductor introduces a 256-bit RAM chip.

1971: Intel introduces the 4004, a 4-bit microprocessor.

1972: Intel introduces the 8008, the first 8-bit microprocessor. E-mail is introduced over ARPANET.

1973: Robert Kahn and Vinton Cerf develop the basic ideas of the Internet.

1975: The MITS Altair 8800 is hailed as the first "personal" computer. Paul Allen and Bill Gates develop BASIC for the Altair 8800.

1976: Microsoft and Apple are founded.

1977: Apple markets the Apple II for $1,195; it includes 16K of RAM but no monitor.

1979: Software Arts develops the first spreadsheet program, Visicalc, which is an immediate success.

1981: The IBM PC is released.

1982: TCP/IP (Transmission Control Protocol and Internet Protocol) is established as a standard for ARPANET.

1984: The Apple Macintosh is released, featuring a simple, graphical interface.

1986: NSF establishes NSFNET and five supercomputing centers.

1987: The number of network hosts exceeds 10,000.

1989: The number of network hosts exceeds 100,000.

1989: Microsoft's annual sales reach $1 billion. The World Wide Web is developed at CERN.

1992: The number of Internet hosts exceeds 1 million.

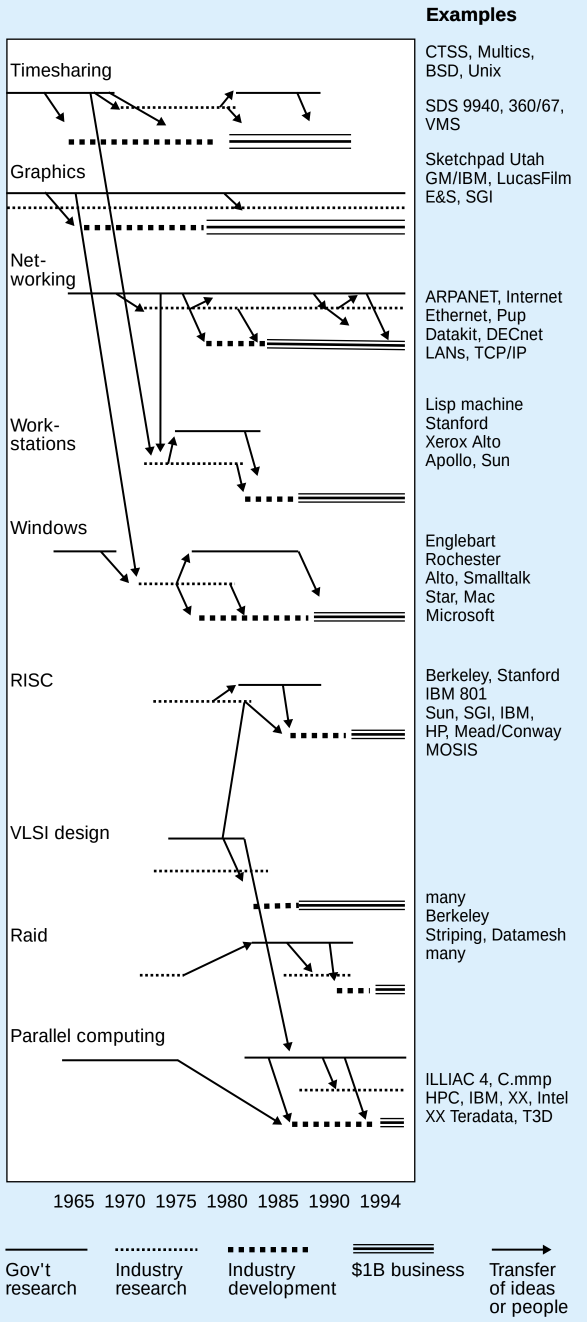
1993: Mosaic, the first Web browser, is developed at the NSF-funded National Center for Supercomputer Applications at the University of Illinois, leading to rapid growth of the World Wide Web.

1994: Main U.S. Internet backbone traffic begins routing through commercial providers.

1995: NSFNET privatized.

SOURCES: PBS Online companion Web site for television special "Triumph of the Nerds: The Rise of Accidental Empires," <<http://www.pbs.org/nerds/timeline/micro.html>>; Virginia Tech Virtual Museum of Computing, Chronology of Events in Computer History, <<http://video.cs.vt.edu:90/cgi-bin/Lobby?Method=Chronology>>; Leiner et al. (1998).

Figure 9-5.
Government support for computing research



SOURCE: National Research Council, Computer Science and Telecommunications Board, *Funding a Revolution; Government Support for Computed Research* (Washington, DC: National Academy Press, 1999). *Science & Engineering Indicators – 2000*

Growth of the Internet

The Internet is a meta-network for a variety of subnetworks and applications such as the World Wide Web, bulletin boards, Usenet newsgroups, e-mail, scientific data exchange, and more. The foundation for the Internet was ARPANET, which started as four computer nodes in 1969. ARPANET was initiated by DARPA and was based on a then-new telecommunications technology called packet switching. ARPANET flourished as a medium for information and data exchange among universities and research laboratories. Moreover, it stimulated the development of TCP/IP, a communications protocol that enabled the interconnection of diverse networks. By the late 1970s, ARPANET comprised hundreds of computer nodes and integrated several separate computer networks, including one based on satellite technology.

The Internet grew out of the ARPANET, which converted to the TCP/IP protocol in 1983. NSF sponsored CSNET and later NSFNET (a high-speed network to link supercomputing centers), which became the backbone for the Internet. NSFNET replaced ARPANET in 1990 and expanded to include a variety of regional networks that linked universities into the backbone network. Many smaller networks linked into NSFNET. By early 1994, commercial networks became widespread, and almost half of all registered users of the network were commercial entities.

Two other events dramatically reshaped the character of the Internet. First, in 1989, scientists at CERN developed the World Wide Web and introduced it in experimental form. Second, in 1993, a team of programmers at NSF's National Center for Supercomputing Applications at the University of Illinois introduced Mosaic, a graphical (hypermedia) browser for exploring the Web. Mosaic was made available on the Internet at no cost, and Web use soared. (See figure 9-4.)

NSFNET was fully privatized in 1995, when there were enough commercial Internet service providers, Web browsers, and search engines to sustain the network's operations and management. The Internet continues to evolve. The Next Generation Internet Initiative is developing a higher-speed, more functional telecommunications network.

For more information on the Internet, see Cerf (1997) and Leiner et al. (1998).

IT and the Economy

In recent years, there has been considerable discussion of the role of information technology in transforming the economy. Terms such as the "digital economy" (Tapscott 1996; U.S. Department of Commerce 1998, 1999a), the "Internet economy" (Center for Research in Electronic Commerce 1999), the "knowledge-based economy" (OECD 1999c), and the "new economy" (Atkinson and Court 1998) have come into common usage. Although these terms have somewhat different meanings, they all suggest that the U.S. economy is transforming in a way that produces higher productivity growth and greater innovation—and that personal computers, high-speed telecommunications, and the Internet are at the heart of this transformation.

Federal Reserve Chairman Alan Greenspan has recently begun to discuss the impact of IT on the economy: "Innovations in information technology—so-called IT—have begun to alter the manner in which we do business and create value, often in ways not readily foreseeable even five years ago" (Greenspan 1999). Greenspan credits information technologies with improving companies' knowledge of customers' needs, inventories, and material flows, enabling businesses to remove redundancies. He suggests that IT has also reduced delivery lead-times and streamlined the distribution system.

Large productivity increases and economic transformations, however, have been expected from information technologies for a long time. At least until recently, economists have found little evidence of expected productivity increases or other positive changes from information technology. It is appropriate, therefore, to approach statements about IT-induced transformations of the economy with a degree of caution.

The effect of IT on the economy is a large and complex issue. There are a variety of effects that vary according to the sector of the economy and the organizational and management practices of firms. Moreover, the effects may be rapidly changing as Internet-based electronic commerce expands. This section cannot cover in detail the full range of these issue; it focuses instead on evidence related to five questions:

- How is IT used in business?
- What are the effects of IT on productivity and economic growth?
- How has IT affected the composition of the economy?
- What are the effects of IT on income and employment?
- What are the international implications of electronic commerce?

Use of IT in Business

IT is being used in so many ways and in so many kinds of business that it is possible only to sketch that landscape here. At its most basic, IT automates a variety of activities, from control production systems in manufacturing to office-work basics such as word processing and financial calculations. In more sophisticated applications, IT involves databases and information retrieval that assist management, customer service, and logistics and aid product design, marketing, and competitive analysis. IT can combine computing and communications to support ordering and product tracking. These functions are often implemented as mechanization of older processes; ideally, however, they involve fundamental redesign of processes. These functions began using—and in many instances continue to rely on—components such as mainframe, mini-, and microcomputers, as well as telephone networks (the public switched network and leased-line private or virtual private networks). What marks the turn of the century is a move to broader integration of systems and, through them, enterprises. The spread of Internet technology and the proliferation of portable computing and communications devices have accelerated trends that began in past decades and now are hailed as "electronic commerce."

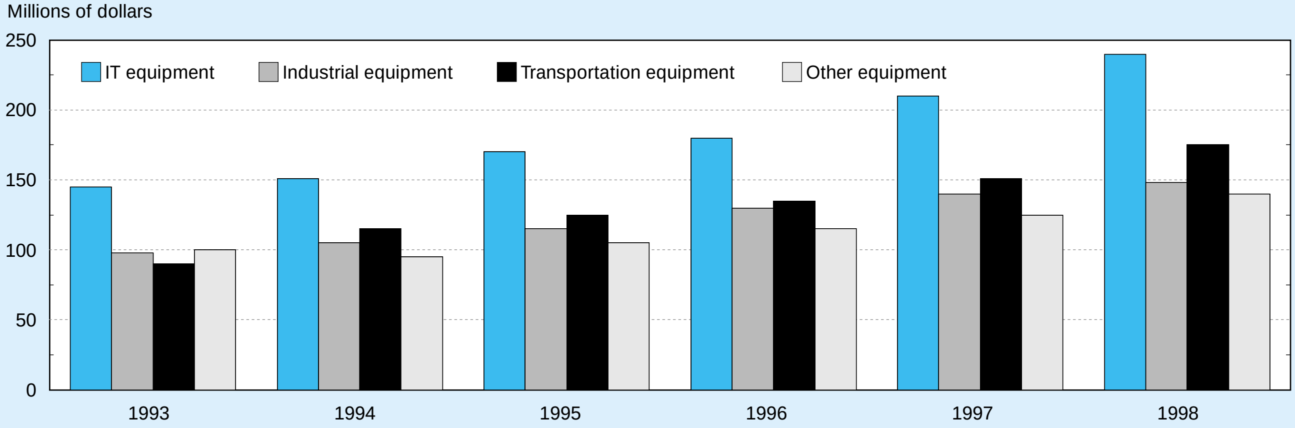
Although IT has the potential to transform business practices, there are substantial costs and barriers to implementation. IT equipment continues to be the largest category of industry spending for all types of capital equipment (including industrial equipment, transportation equipment, and other types of equipment). In current dollars, industry spending on IT equipment rose from $142 billion in 1993 to $233 billion in 1998. (See figure 9-6.)

Using IT in business is expensive not only in terms of initial costs but also in terms of the cost to maintain and upgrade the systems, train the people, and make the organizational changes required to benefit from IT. These costs may greatly exceed the original investment in IT equipment. Organizational changes often are especially difficult. Nevertheless, IT costs of all kinds are regarded as necessary elements for more and more businesses.

Electronic commerce (e-commerce) as a category of business use of IT deserves special attention because of its rapid growth and its potential to affect many business processes. The definition of electronic commerce is a matter of dispute. In one definition of e-commerce, transactions use Internet-based systems, rather than paper or proprietary electronic systems. By this definition, getting money from an ATM is not e-commerce, but transferring funds using the Web is. (See sidebar, "What is Electronic Commerce?")

E-commerce includes retail and business-to-business commerce. To date, business to business e-commerce has predominated. For example, Forrester Research projects that inter-company Internet commerce will reach $1.3 trillion by 2003 and that online retail trade will reach $184 billion by 2004 (Forrester Research 1998, 1999). In some cases—such as with flowers, books, computers, or industrial parts—the parties use the Internet to make the transaction, but the goods are still delivered physically. In other cases—such as with sales of software, electronic journals, or music—the goods may be delivered electronically. The mix of products made and sold through e-commerce is changing. The rise of electronic trading of securities illustrates the potential for considerable growth of essentially all-electronic business.

Figure 9-6.
Industry spending on IT equipment in the 1990s (current dollars)



SOURCE: U.S. Department of Commerce (1999a), *The Emerging Digital Economy II,* using data from the Bureau of Economic Analysis.

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What is Electronic Commerce?

Definitions of electronic commerce vary. Some definitions include all financial and commercial transactions that take place electronically, including electronic funds transfer (EFT), electronic data interchange (EDI), and credit card activity. These transactions have been going on for years and involve trillions of dollars of funds transfers per day (OECD 1999b). Other definitions limit e-commerce to transactions that take place entirely on open networks such as the Internet. These transactions are still in their infancy.

Definitions also differ in that some groups define e-commerce to include only transactions in which goods or services are ordered and paid for online, whereas other groups include transactions in which goods or services have been ordered, but not paid for, online.

The Organisation for Economic Co-operation and Development (OECD) and its member countries are working to develop standard definitions. OECD (1999b) and the U.S. Department of Commerce (1999a) define e-commerce as business occurring over networks that use nonproprietary protocols that are established through open standard-setting processes such as the Internet. The emphasis on the use of nonproprietary protocols is central. Earlier forms of electronic business, such as EDI and EFT, required preexisting relationships, specialized software, and dedicated communication links. Consequently, such commerce was used mainly to create two-way links between specific parties, such as large businesses and their main suppliers. Commerce over open systems such as the Internet allows communication between diverse computers and communications systems using standard interfaces. These interfaces allow communication among many different customers or suppliers without additional investment, lowering costs and vastly increasing options. This structure has made this form of commerce attractive to many more companies and consumers. Much of the rapidly expanding Internet-based e-commerce, however, is built on experience with earlier (non-Internet) forms of electronic business.

Retail e-commerce has spawned many new businesses that have no physical stores but can deliver a wide variety of goods on request. This mode of operating is often more economical than traditional retail stores. In response, many traditional retail stores have launched their own e-commerce strategies.

Another mode of retail e-commerce that has expanded rapidly is online auctions, which put buyers and sellers directly in touch with each other to negotiate a price. As of September 1999, eBay (one of the first and largest online auction enterprises) offered more than 3 million items for sale in more than 1,500 categories. Hundreds of other online auction enterprises have been established, and many other early e-commerce retailers—such as Amazon.com and Dell Computer—have added auctions as additional features of their Web sites. The mix of distribution channels is changing, and the extent to which new modes replace or complement the old remains to be seen.

Business-to-business e-commerce, like business-to-consumer e-commerce, can enable businesses to offer additional services and improved communication to their customers. Increased communication is enabling firms to outsource more easily, and to streamline and augment supply chain processes. It can also allow businesses to eliminate some intermediary organizations between customer and supplier and give rise to new classes of business intermediaries (such as online auctions). Because business-to-business e-commerce is built on the history of pre-Internet electronic transactions, there is substantial related expertise in place in many companies, and business-to-business e-commerce has expanded rapidly.

Although official nationwide government statistics for e-commerce have not yet been gathered, private studies and market research firms have collected information related to e-commerce. Although these estimates and forecasts do not agree on the definition or value of electronic commerce, they agree that Internet-based commerce is large and growing rapidly. (See text table 9-1.) The wide variation in the estimates reinforces the need for consistent definitions and data collection methods.

The growth of e-commerce has altered much of the discussion of the role of IT in the economy. Previously, much discussion had focused on the application of IT inside companies to improve their internal operations. Electronic commerce is shifting the focus to how businesses are using IT to communicate with customers and suppliers, including new distribution chains and new methods of marketing and selling. Because this arena appears to be changing so quickly, the effects of IT on the economy may change rapidly as well.

International Context of Electronic Commerce

Although the United States has been the world leader in information technology and especially in the Internet, these technologies are expanding rapidly around the globe. Several other countries match or are close to the United States in terms of penetration of personal computers into the home and the office. (See figures 9-7 and 9-8.)

Text table 9-1.
Forecasts of growth in Internet commerce

Study	Date	Result
Forrester Research	12/1998	U.S. inter-company trade of hard goods over the Internet will be $43 billion in 1998; $1.3 trillion in 2003.
University of Texas Center for Research in Electronic Commerce ...	5/1999	Value of 1998 Internet commerce was $102 billion.
International Data Corporation	6/1999	Internet-based worldwide commerce to reach $1 trillion by 2003.

SOURCES: Center for Research in Electronic Commerce (1999), Forrester Research (1998), and International Data Corporation (1999).

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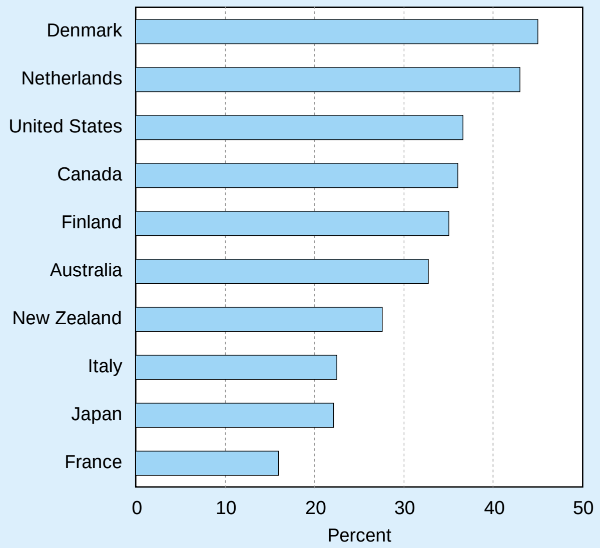
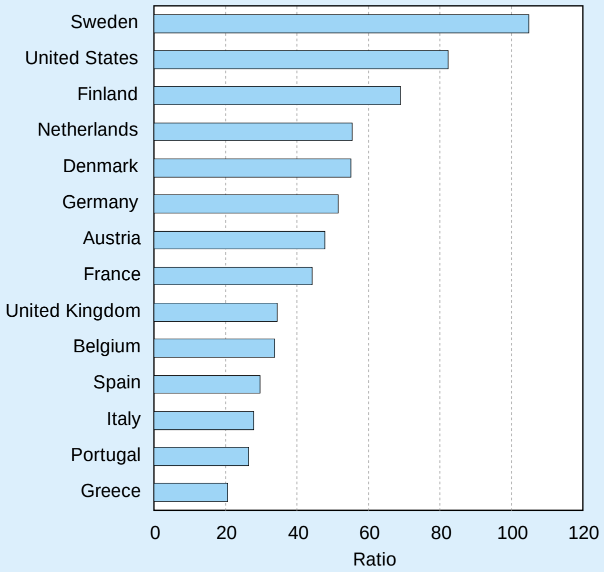
The Scandinavian countries and Canada roughly match the United States in the number of Internet hosts per capita; Finland exceeds the United States in this measure. (See figure 9-9.) Based on the number of secure Web servers (those using encryption and third-party certification, which are suitable for e-commerce) per 100,000 inhabitants, the United States is one of the leading countries in e-commerce, but

Figure 9-7.
PC penetration in households, 1997 or latest year



SOURCE: OECD, compiled from National Statistical Offices, March 1999. *Science & Engineering Indicators – 2000*

Figure 9-8.
PCs per 100 white-collar workers, 1997



SOURCE: OECD, based on ILO and IDC data, March 1999.

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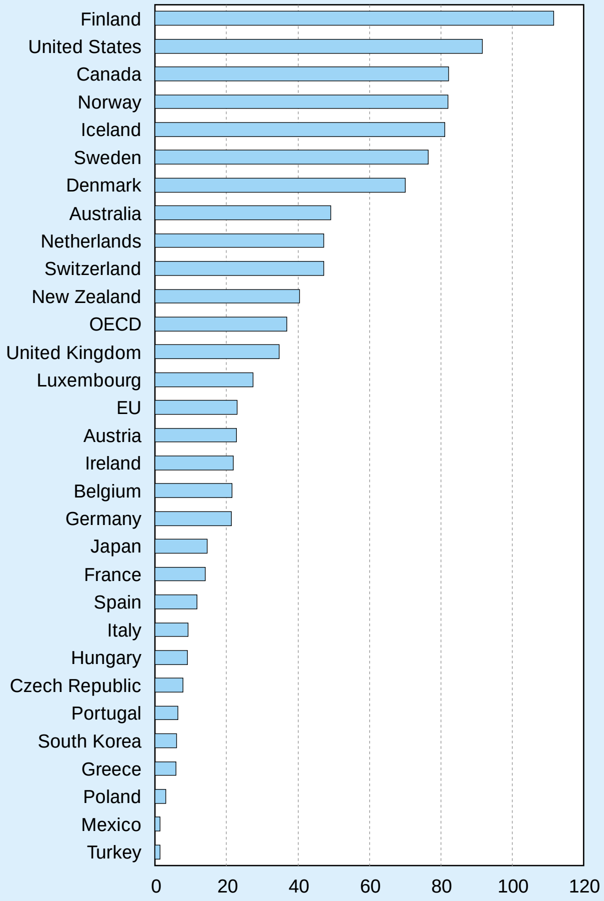
Figure 9-9.
Number of Internet hosts per 1,000 inhabitants: January 1999



SOURCE: Network Wizards and OECD.

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servers suitable for e-commerce are dispersing around the globe. (See figure 9-10.) Countries other than the United States are expected to account for almost half of worldwide Internet commerce by 2003 (IDC 1999).

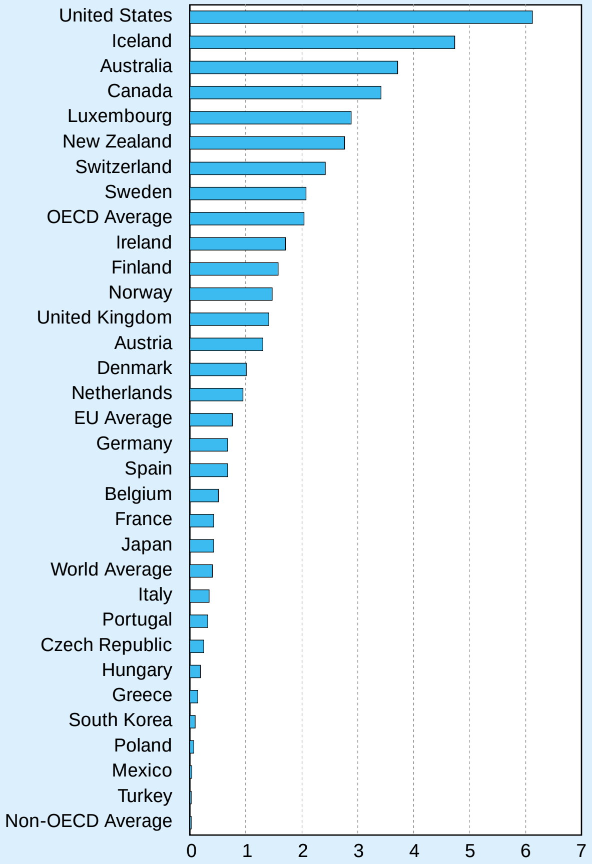
The international diffusion of e-commerce raises many policy issues. On the Internet, information crosses national borders readily, cheaply, and freely. Transactions involving the citizens of one country may fall under the jurisdiction of another country with different laws and regulations governing the transaction. The laws and regulations of many nations frequently come into conflict. For example, trademarks posted in the Internet in one country may violate trademarks in another country. Advertising that is legal in one country may be illegal or objectionable in countries whose residents can view the information on the Web. Collection and use of personal information on Web sites may be legal in one country and illegal in another. International e-commerce may find itself subject to ambiguous or duplicative tax, contract, and intellectual property laws. Although many of these issues have some precedents in the pre-Internet world, they are amplified by the expansion and diffusion of e-commerce. Many small companies without multinational operational or legal experience are increasingly engaged in international markets. E-commerce appears to lower barriers to entry and levels the playing field between large and small companies and large and small countries. E-commerce also appears to be putting pressure on countries around the world to create more harmonized legal environments, working through multinational and nongovernmental organizations.

Effects of IT on Productivity and Economic Growth

Productivity

In spite of the investment in and obvious capabilities of IT, there has been little evidence—until recently—that IT has improved productivity in the aggregate. Solow (1987) termed this inability to find a statistical association between IT investments and productivity in the private sector the "productivity paradox." Many econometric analyses have failed to

Figure 9-10.
Secure Web servers for electronic commerce per 100,000 inhabitants: August 1998



SOURCE: OECD Communications Outlook 1999.

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find any productivity benefits for IT (for reviews of this literature, see Brynjolfsson and Yang 1996 and CSTB 1994a). These studies failed to find a positive and significant contribution of IT to productivity in any sector (neither services nor manufacturing), by any measure (a variety of data sets and methods were used), at any level of analysis (the macroeconomy or specific industries and sectors), or at any time (from the late 1960s to the late 1980s). Positive effects were found only in limited case studies of a single industry or small set of firms.

Brynjolfsson and Hitt (1995, 1996, 1998), however, have found large and significant contributions by IT to productivity using a firm-level database. Every additional dollar of computer capital stock was associated with an increase in marginal output of 81 cents, and every additional dollar spent on IT-related labor was associated with an increase in marginal output of $2.62. Brynjolfsson and Hitt found that although there is a positive correlation between IT and productivity, there is substantial variation between firms. Firm-level variables can account for half of the variation in IT's contribution to marginal productivity. This finding suggests that the effectiveness of IT depends on how a firm uses it. 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.

Several factors may explain the contrast between the findings of Brynjolfsson and Hitt and the earlier productivity studies. The later time period of their study (1987–91); the use of a larger data set; more detailed, firm-level data; and the inclusion of IT-related labor may all be reasons why their findings are more positive than those resulting from earlier research. Using similar data and methods, other analysts have also found significant positive rates of return at the firm level, including Lichtenberg (1995) and Link and Scott (1998).

Oliner and Sichel (1994) found that from 1970 to 1992, computer hardware contributed 0.15 percentage points to the total U.S. output growth rate of 2.8 percent. When software and computer-related labor are included, this contribution doubles to 0.31 percentage points for the period 1987–93 (11 percent of total growth). Other capital and labor inputs, as well as multifactor productivity gains, account for about 90 percent of the growth in U.S. output during this period. Oliner and Sichel note that computing-related inputs are a very small portion of total capital and labor and have only recently grown large enough to have a measurable impact. They conclude that "computing equipment can be productive at the firm level and yet make little contribution to aggregate growth, precisely because computers remain a relatively minor factor of production" (Oliner and Sichel 1994, 286).

More recently, the U.S. Department of Commerce has examined the gross product originating—or value added—per worker (GPO/W) as a measure of productivity (U.S. Department of Commerce 1999a). Nonfarm industries were divided into IT-producing, IT-using, and non–IT-intensive and then further divided into goods and services industries. IT-producing industries have experienced strong growth in GPO/W; in contrast, IT-using industries, especially in the services, have experienced slight GPO/W shrinkage. (See text table 9-2.)

Although growth in GPO/W was greater for IT-using industries than for non–IT-intensive industries in the goods producing sector, it was less for IT-using industries than for non–IT-intensive industries in the services sector.

There are two common explanations for the productivity paradox. First, there are measurement problems. As Brynjolfsson and Hitt (1998) observe, two aspects of productivity have increasingly defied precise measurement: output and input. The measurement problems are substantial (Baily and Chakrabarti 1988; Brynjolfsson 1993; CSTB 1994a; Griliches 1997; Oliner and Sichel 1994).

Regarding inputs, there are issues about what constitutes IT. Is it capital investments only, or does it include labor (which represents the bulk of IT operating costs)? Do IT capital investments include more than computers and software, and if so, what? Choices about what to count as an IT equipment expense include computing hardware and software, communications equipment, and a variety of office machines (such as photocopiers and some instruments). This choice is further complicated by the fact that IT is increasingly embedded in other systems, such as machine tools, automobiles, and appliances. At present, there is little consistency among studies, and sources of IT investment data vary from aggregate government data to private survey-based firm data.

Another measurement issue is how to assign dollar values to IT as a factor input. IT can be measured as a flow (annual expenses or purchases) or as a stock (the cumulation of equipment over time). In both instances, price deflators are required to compare stocks or flows over time by converting them to "real" dollars. IT equipment is especially problematic for establishing reliable deflators. For example, not only has the sales price of computing equipment been falling rapidly, but because quality has increased exponentially, existing computing stock becomes obsolete very quickly and therefore is difficult to evaluate adequately.

The pace of technological change in IT greatly complicates analysts' abilities to construct quality-adjusted price deflators and appropriate depreciation rates. The Bureau of Economic Analysis (BEA) and the Bureau of Labor Statistics (BLS) have developed price indices that reflect changes in IT quality. The values used significantly affect research outcomes by influencing the value of expenses and stocks in different periods.

A third measurement difficulty relates to how to measure the output of information processing. IT is used extensively for activities that do not result in tangible market outputs (e.g., accounting, scheduling, reporting). Consequently, it is difficult to assign a dollar value to the output of IT—a measurement that is essential for accurate productivity analysis. This measurement challenge is exacerbated in the services sector, where output measures must also capture qualitative differences in services (Mark 1982, Noyelle 1990). Services are hard to measure; according to Department of Commerce classification, almost 90 percent of the nonfarm U.S. economy

Text table 9-2.
Gross product originating per worker, annual growth rate: 1990–97

Gross product	Annual growth rate (1990–97)
Total private nonfarm	1.4
IT-producing	10.4
Goods	23.9
Services	5.8
IT-using	-0.1
Goods	2.4
Services	-0.3
Non-IT intensive	1.1
Goods	1.3
Services	1.3
All industries other than IT-producing	0.5

SOURCE: U.S. Department of Commerce, *The Emerging Digital Economy II.* (Washington, DC: 1999). Available from <<http://www.ecommerce.gov>>.

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that is IT-using is in the service sector.[2] (See text table 9-3.)

A fourth measurement issue concerns how to value IT benefits that do not show up as classical efficiency gains, such as qualitative improvements in customer service. These benefits might include enhanced timeliness, performance, functionality, flexibility, accuracy, precision, customization, cycle times, variety, and responsiveness (Bradley, Hausman, and Nolan 1993; Byrne 1996; CSTB 1994a). These qualitative dimensions are much more likely to show up as downstream benefits to the consumer (Bresnahan 1986) or as greater competitiveness for a firm (Baily and Chakrabarti 1988; Banker and Kauffman 1988; Brynjolfsson 1993; Porter and Millar 1985).

Another explanation of the productivity paradox is that it is a real but temporary phenomenon. Sociologists and economic historians have long argued that society's ability to fully exploit a new technology lags—often by decades—introduction of the technology itself (Ogburn 1964, Perez 1983). Similarly, in organizational change scholarship, institutional resistance to change is the norm. David (1989) found, for example, that nearly 20 years elapsed before the electric generator—an invention comparable to IT in scope and consequence—had a measurable effect on industrial productivity. With respect to IT specifically, firm-level performance can vary considerably, and the effective use of IT is apparently contingent on moderating variables at the organizational level—including strategy, leadership, attitudes, organizational structure, appropriate task and process reengineering, individual and organizational learning, and managerial style and decisionmaking (Allen and Morton 1994; Banker, Kauffman, and Mahmood 1993; Cron and Sobol 1983; Curley and Pyburn 1982; Danziger and Kraemer 1986; Graham 1976; Khosrowpour 1994; Landauer 1995; Tapscott 1996; Thurow 1987).

The banking and trucking industries are two very different sectors that illustrate some of the effects—and some of the difficulties in measuring those effects—of IT in specific sectors. (See sidebars, "IT and the Banking Industry" and "IT and the Trucking Industry.") The banking industry is a white-collar service industry that has long been at the forefront of IT use. The trucking industry is a predominately blue-collar industry that has not been considered IT-intensive. IT has strong but difficult to measure effects on productivity and work in both of these industries.

Effects on Inflation and Growth

IT appears to be having positive effects on inflation and growth in the economy as a whole. These effects relate primarily to growth and declining prices in the IT sector rather than the effects of application of IT.

The U.S. Department of Commerce (1999a) found that declining prices in IT-producing industries have helped to reduce inflation in the economy as a whole. (See text table 9-4.) Decreasing IT costs may also have helped other industries control their costs. The department also found that IT-producing industries have contributed substantially to economic growth in the United States. The department estimates that over the past four years, IT industries have contributed more than one-third of the growth of real output for the overall economy. (See text table 9-5.)

Effects on Composition of the Economy

In addition to causing changes in the overall economy, IT is causing changes in the structure of the economy. One obvious change is growth in the IT-producing sector. Because that sector has been growing faster than the economy as a whole, its share of the economy has increased. (See figure 9-12.)

IT also is commonly credited as a key factor in the structural shift from manufacturing to services in the U.S. economy. Growth in existing services such as banking and the creation of new industries such as software engineering are attributed to the widespread diffusion of IT (CSTB 1994a, Link and Scott 1998). From 1959 to 1997, the service sector grew from 49 percent of U.S. gross domestic product (GDP) to 64 per-

Text table 9-3.
Percentage share of total private nonfarm gross product originating by sector, United States: 1990–97

Sector	Goods	Services	Total
IT-producing	2.0	6.2	8.2
IT-using	5.0	43.3	48.3
Non-IT intensive	23.0	20.6	43.6
Total	30.0	70.0	100.0

SOURCE: U.S. Department of Commerce, *The Emerging Digital Economy II.* (Washington, DC: 1999). Available from <<http://www.ecommerce.gov>>.

See appendix table 9-3. *Science & Engineering Indicators – 2000*

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[2] Agriculture can also be IT-intensive.

cent of GDP, while manufacturing declined from 28 percent of GDP to 17 percent of GDP.

The expansion of the service sector has been driven by industries that are often classified as “knowledge” industries (see Machlup 1962)—finance, insurance, and real estate (FIRE)—as well as professional services such as health and education. The share of GDP accounted for by wholesale and retail trade declined from 1959 to 1997, while personal services and transportation and utilities remained essentially unchanged. (See appendix table 9-4.) In contrast, FIRE’s share of GDP grew by 5.8 percentage points, and that of professional services increased by 7.7 percentage points.

IT and the Banking Industry

The banking industry reflects most of the empirical dilemmas associated with measuring the impacts of IT: heavy investment in IT; little measurable improvement in productivity traced to IT; and effects that reflect quality improvements, rapid product diversification, and substantial growth in volume of commercial transactions. IT has changed the structure and service quality of banking and appears to have a positive effect on cost reduction. It has taken decades to achieve these results, however, and traditional productivity analyses still do not detect positive associations between IT investments and productivity in the commercial banking sector.

Banking industry investments in IT increased substantially from the late 1960s to the late 1980s. Annual investments in IT (in constant 1982 dollars) grew from $0.1 billion in 1969 to $1.6 billion in 1980 to $13.8 billion in 1989 (CTSB 1994a). By 1989, the banking industry was investing more funds in IT annually than all of the other major service industries except telecommunications.

IT applications in banking included accounts management and check processing via magnetic ink character recognition. Automated clearinghouses, which enabled electronic funds transfer (EFT), were introduced in the early 1970s, and ATMs were introduced in the late 1970s. EFT, ATMs, and telephone transaction capabilities have replaced a wide variety of paper and in-person transactions in banking, including account deposits and withdrawals, accounts management, credit applications and approvals, cash dispensing, funds transfers, point-of-sale transactions, credit card payments, and consolidation of banking operations.

Major cross-sector studies (see Brynjolfsson and Yang 1996 for reviews), however, failed to detect positive productivity returns for IT in the banking industry, and Franke’s (1989) study of the financial sector (insurance and banking combined) suggested that IT is associated with negative productivity effects. On the other hand, labor productivity has been steadily improving in the banking industry. Productivity improved substantially from 1982 through 1997. The difficulty is in empirically linking these improvements to investment in IT.

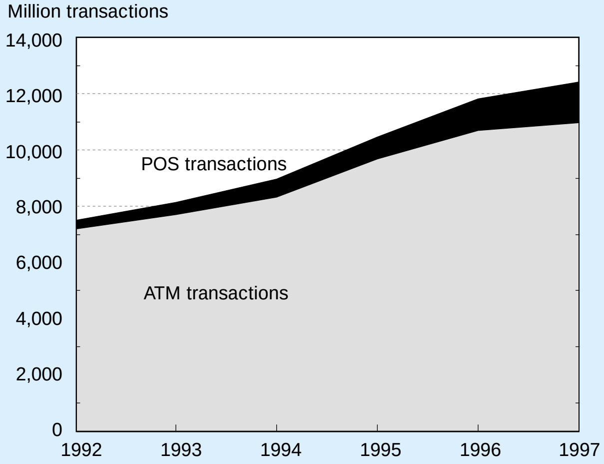
IT-related productivity growth may have been slow because of problems with early generations of information technologies and organizational adaptation. The National Research Council reported that early applications of IT were costly and cumbersome; software and equipment had to be updated and replaced frequently, and IT systems required large amounts of tailoring, training, upgrading, and updating. Cost control, management skills, and productivity tracking systems lagged the new technologies in a rapidly changing, competitive marketplace (CSTB 1994a, 80–81).

In addition, many of the benefits of IT were in areas that productivity indicators did not capture. These benefits included expansion of banking products and services, time and cost savings, and competitive positioning. Banking products and services have proliferated with the use of EFT, ATMs, telephone transactions, and automated credit and loan procedures. Banks thus process billions of transactions a year—including clearing individual checks, ATM cash dispersal, account inquiries, and loan approvals—a volume of interactions that would not be possible without automation. For example, automated clearing house payments, which include direct deposit of payroll payments, expense reimbursements, government benefits and tax refunds, and direct payments of bills, totaled more that 5.3 billion payments worth $16.4 trillion in 1998 (National Automated Clearing House Association 1999). The number of electronic cash transactions and payments for goods and services was more than 12 billion in 1997, compared with 7.5 billion in 1992. (See figure 9-11.)

Bresnahan (1986) estimates that the benefits to consumers from the use of mainframe computers for financial services were five times greater than the investments in the computers themselves. Qualitative improvement in customer convenience, ease, and scope of access to financial resources is reflected in the overall growth of electronic transactions. Time and cost savings for the industry are also notable. The processing time for credit card authorizations has shrunk dramatically, and banks have been able to reduce their staffs while increasing the number of transactions (CSTB 1994a, 83–84). ATM transactions cost an estimated 27 cents, compared to $1.07 for a human teller transaction; automated telephone transactions cost about $0.35, compared to $1.82 for a phone call processed by bank personnel (Morisi 1996). In a study of 759 banks, Alpar and Kim (1991) found that a 10 percent increase in IT expenses led to a 1.9 percent decrease in total bank costs.

Although productivity measures do not find a link between banking industry output and IT investments, it is important to note that while the volume of financial transactions has been increasing at a dramatic rate, employment in the sector has been falling. By 1996, employment in the commercial banking industry was 100,000 employees below its historic peak in 1990.

Figure 9-11.
U.S. electronic funds transfer volume



NOTES: Electronic funds transfer includes automated teller machine (ATM) transactions and transactions at point-of-sale (POS) terminals. POS terminals are electronic terminals in retail stores that allow a customer to pay for goods through a direct debit to a customer's account at the bank.

SOURCE: Statistical Abstract of the United States, table 825. Data from: Faulkner & Gray, Chicago, IL, Faulkner & Gray/EFT Network Data Book-1998. September 26, 1997 (copyright).

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IT has not been empirically linked in a definitive way to the expansion of the service sector, however. In a detailed study of several key service industries (banking, insurance, air transport, and telecommunications), the National Research Council concluded that although the benefits of IT for individual industries could be qualitatively described, IT could not be causally linked to gross product output of the individual industry for methodological reasons (CSTB 1994a). Expansion of the air transport, banking, finance, and trade industries probably would not have been as great in the absence of IT (CSTB 1994a). Moreover, IT is particularly concentrated in service industries that have experienced rapid expansion.

IT may also be contributing to other shifts in the economy. Home based e-commerce may be displacing traditional banking, travel, legal, and educational services to some extent. To the extent that home-based IT replaces services that previously were paid for and captured in economic indicators, this effect may lead to an understatement of economic growth. To date, home users have been disproportionately persons with higher income and more education (see chapter 8, "Science and Technology: Public Attitudes and Public Understanding" and "IT and the Citizen" in this chapter). If that pattern persists, the distribution of real income, including nonmarket production, may become less equitable. Understanding the distribution of work between the household and the market may once again emerge as a critical element in understanding economic growth.

IT and the Trucking Industry*

Transportation is an important sector of the U.S. economy. Nearly 75 percent of all freight is transported by truck at some point in the distribution chain. Many changes have occurred in the industry over the past 15 years—reflecting deregulation, increased fuel efficiency, and increased sizes of trucks. More recent changes have related to the use of IT, including scheduling, dispatching, and onboard communications systems (such as cellular phones and computers).

Existing evidence suggests a substantial boost in productivity from rather modest investments in IT—particularly from more effective routing and scheduling, such as with "just-in-time" delivery systems. This productivity increase is important because trucking is not one of the industries that shows up as substantially dependent on IT. Trucking is not considered an IT-dependent industry in terms of IT expenditures as a share of capital costs or IT per worker. Yet with input from sources external to the industry, IT appears to play a significant role in trucking.

Approaches to the use of IT are heterogeneous at the firm level. Some trucking firms have been innovative leaders, others distant followers; still other firms have been operating in crisis mode to catch up to the rest of the fleet. Investment in IT may not correlate directly to productivity because the innovative leaders and firms acting in crisis mode may spend more—but less cost-effectively—on IT than the distant followers. The lack of training of the workforce and limited IT training of managers seems not to be fatal in the adoption of IT. Many workers make only passive use of the technology. Rising productivity may benefit company earnings and consumers more than it benefits drivers, who do not appear to receive pay increases that reflect their increased productivity. IT benefits also may accrue to those who develop and implement the dispatching software systems, rather than to drivers.

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*The information in this box is based on the work of the University of Michigan Trucking Industry Program (UMTIP). See Belman et al. (1998) and Nagarajan et al. (1999).

Effects on Income and Employment

Information technology creates some new jobs and eliminates others. As jobs are created or eliminated, the labor markets adjust in complex ways. Wages go up in areas where the demand for skills exceeds the supply and go down in areas where 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.

In a review of the literature on computerization and wages, Katz (1999) notes that many authors have found that wage inequities and educational wage differentials have increased in the United States in the past two decades—coinciding with

Text table 9-4.
Price changes, IT-producing and all other industries

	1993	1994	1995	1996	1997
IT-producing industries	–2.4	–2.6	–4.9	–7.0	–7.5
Rest of the economy	3.0	2.7	2.8	2.6	2.6
GDP	2.6	2.4	2.3	1.9	1.9

SOURCE: U.S. Department of Commerce, *The Emerging Digital Workforce II.* (Washington, DC: 1999). Available from <<http://www.ecommerce.gov>>. Based on BEA and Census data.

See appendix table 9-3.

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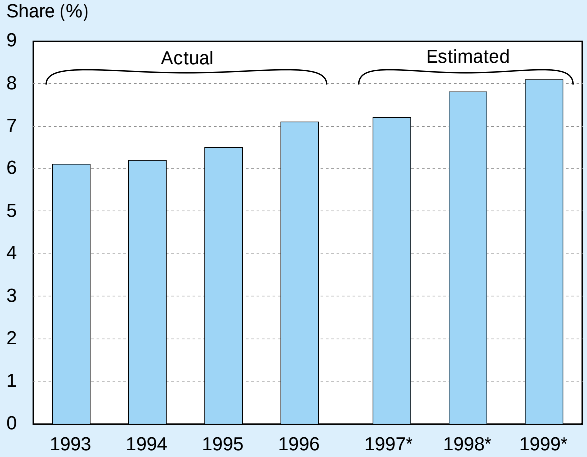
Figure 9-12.
IT-producing industries' share of the economy: 1993–99



SOURCES: U.S. Department of Commerce, *The Emerging Digital Economy II* (Washington, DC: 1999). Available from <<http://www.ecommerce.gov>>. ESA estimates derived from BEA and Census data for 1993–1996. ESA estimates for 1997-1999 derived using DOC's "Industry and Trade Outook."

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the computerization of the workplace. From 1973 to 1995, wages have increased in the top 30 percentiles and have decreased in the bottom 70. (See appendix table 9-10.) Rising wages and labor income of educated workers, combined with rising relative supply, are consistent with a model in which IT allows skilled workers to produce things previously in the domain of the less-skilled. This trend deteriorates the terms of trade of the less skilled workers, reducing their relative income (Gomery 1994, Johnson and Stafford 1998).

Katz (1999) notes that relative employment and wages have both increased within industries for more educated workers during the 1980s and 1990s, indicating shifts favoring more skilled workers. He finds that skill-based and organizational changes that have accompanied the computer revolution appear to have contributed to faster growth in the demand for skilled labor starting in the 1970s. Factors other than technological change—including the slowdown in the increase of college-educated people entering the labor force, globalization (especially outsourcing of low-skilled work), and the weakening of unions—may also play a role in creating rising wage inequities, however.

Although evidence suggests that IT should increase the demand for workers who manipulate and analyze information relative to the demand for non-knowledge workers or those who simply enter and collate data, there is also a popular fear that automation will reduce the demands on an individual's conceptual talents and facility with machinery, equipment, and tools. Individual case studies of specific industries, occupations, and information technologies illustrate that IT can sometimes reduce and sometimes increase the skills required in particular jobs (for reviews, see Attewell and Rule 1994, Cyert and Mowery 1987).

On balance, however, several studies—using different data sets and methodologies—suggest that no overall lessening of skills is occurring in the workforce and that upgrading may be widespread. For example, Castells (1996) finds that em-

Text table 9-5.
IT-producing industries: contribution to real economic growth

	1993	1994	1995	1996	1997 est.	1998 est.
(1) Change in real gross domestic income* (GDI)	2.2	4.1	2.9	3.5	4.2	4.1
Percentage points						
(2) IT contribution	0.6	0.6	1.2	1.5	1.2	1.2
(3) All other industries	1.6	3.5	1.7	2.0	3.0	2.9
(4) IT portion (percent) of GDI change (2)÷(1)	26.0	15.0	41.0	42.0	28.0	29.0

*GDI is equal to the income that originates in the production of goods and services attributable to labor and property located in the United States.

SOURCE: U.S. Department of Commerce (1999) from ESA estimates derived from BEA and Census data for 1993–96. ESA estimates for 1997–98 derived from DOC's "Industry and Trade Outlook '99."

See appendix table 9-3.

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ployment in managerial, professional, and technical classes has been expanding at a faster rate than employment in non- and semi-skilled occupations. Howell and Wolff (1993) reach much the same conclusion; using detailed data on cognitive and motor skills required for specific occupations from 1959 to 1990, they found that skill restructuring (principally upgrading) in the labor force began in the 1970s and continued in the 1980s in patterns that are "broadly consistent with what one might expect from the rapid expansion of new [information] technology" (Howell and Wolff 1993, 12). Howell and Wolff also found that demand for the most cognitively skilled information occupations grew more rapidly than demand for other occupations during some periods. Analyzing data from the Annual Survey of Manufacturers, Berman, Bound, and Griliches (1994) document significant skill upgrading throughout the manufacturing sector during the 1980s—which they attribute in part to computerization of the workplace. Their findings indicate a distinct shift in the demand for labor in the United States from less skilled to more highly (cognitively) skilled labor—a shift that has been linked theoretically and empirically to the diffusion of IT. Autor, Katz, and Krueger (1997) found that those industries that experienced the largest growth in computer use also tended to shift their employee mix from administrative and support workers toward managers and professionals (a finding consistent with Castells 1996).

In addition to the effects of IT on wages, Katz (1999) identifies several other issues relating to IT and employment that merit further study. For example, how does the growth of the Internet affect the geographic distribution of work among large cities, smaller cities, suburban areas, and rural areas? What is the promise of telecommuting, and what is the reality? What are the sources of employee training in the rapidly changing digital economy? How do Internet job searching and computer-oriented labor market intermediaries (e.g., the temporary help industry) affect the labor market? These topics suggest a rich area for further study.

IT Workforce

With rapid expansion of IT development and application, and with the overall U.S. economy running at full employment, it is not surprising that there have been recent concerns about the availability of IT workers. Demand for IT workers has been growing steadily for years. (See figure 9-13.)

The IT industry itself has asserted that there is a serious shortage of IT workers. The U.S. Department of Commerce (1997, 1999b) published Bureau of Labor Statistics projections on future U.S. demand for three core occupational classifications of IT workers—computer scientists and engineers, systems analysts, and computer programmers. These projections indicated that between 1996 and 2006, the United States would require more than 1.3 million new IT workers in these three occupations. (See text table 9-6.)

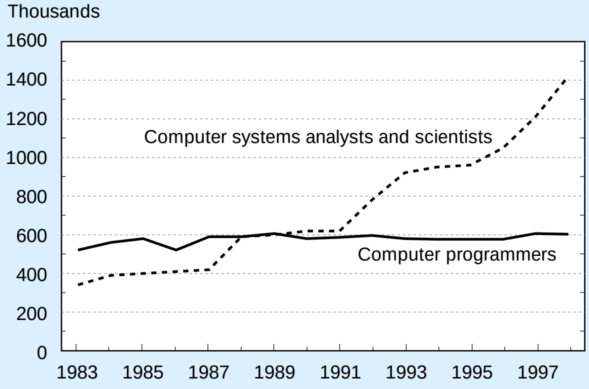
After increasing sharply in the early 1980s, the number of computer science degrees awarded declined sharply after 1986 and has been flat for the past few years. (See chapter 4, "Higher Education in Science and Engineering.")

The assertion that there is a shortage of IT workers has been contentious. Although many people in industry believe that they need more IT-trained workers to meet the growing demand, some employee groups believe that there are enough trained technical professionals in the United States—but that industry has not tapped these existing labor pools (especially older engineers). The debate has been especially polarized over the issue of whether to allow more foreign technically trained workers to enter the country on temporary H-1B visas.

Other studies have examined the IT workforce issue (Freeman and Aspray 1999, Johnson and Bobo 1998, Lerman 1998, U.S. Department of Commerce 1999b; see also chapter 3, "Science and Engineering Workforce"). These studies have generally concluded that:

- The IT labor market appears to be tight (to a somewhat greater extent than the overall job market), but existing data cannot prove or disprove that there is a shortage. Federal data are limited by untimely reporting, out-of-date occupational descriptions, and incompatibilities between supply and demand data collected by different agencies.
- The IT labor market is not homogeneous. Supply and demand characteristics vary by region, by industry segment, and by specific skills. Because product cycle times are very fast in much of the IT industry, a premium is paid for people with specific current skills rather than people who require training to be effective. Competition is especially intense for people with specific "hot" skills in specific markets.
- People enter IT careers from a variety of directions. IT workers include people who majored in IT-related disciplines at the associate, bachelor's, master's, and doctoral

Figure 9-13.
Employment in core IT occupations: 1983–98



SOURCE: U.S. Department of Commerce, *The Digital Workforce: Building Infotech Skills at the Speed of Innovation* (Washington, DC: 1999). Available from <<http://www.ta.doc.gov/reports/itsw/digital.pdf>>.

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Text table 9-6.
Employment projections for core IT occupations
(Thousands)

Occupation	Employment 1996	Employment 2006	Change, 1996-2006 Number	Change, 1996-2006 Percentage	Net Replacements	Total Job Openings (growth and net replacement)
Computer scientists	212	461	249	118	19	268
Computer engineers	216	451	235	109	15	250
Systems analysts	506	1,025	520	103	34	554
Computer programmers	568	697	129	23	177	306
Total	1,502	2,634	1,133	75	245	1,378

SOURCE: U.S. Department of Commerce, *The Digital Work Force: Building Infotech Skills at the Speed of Innovation.* (Washington, DC: 1999); and U.S. Department of Labor Statistics, 1996 industry-occupation employment matrix.

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levels; people from other science, engineering, and business fields; and people from nontechnical disciplines who have taken some courses in IT subjects. Many people also enter the field through continuing education programs and for-profit schools. New modes of instruction delivery, such as distance learning are being used. (See "Distance Education.")

- The job market is showing signs of responding—if imperfectly—to the tight IT labor markets. Wage increases are attracting more people to the field. A large number of initiatives around the country have been started to address the problem. Enrollments are increasing in training programs and in 4-year degree programs.

IT and Education

Information technologies are likely to have a substantial effect on the entire spectrum of education by affecting how we learn, what we know, and where we obtain knowledge and information. IT influences the creation of scientifically derived knowledge; how children learn in schools; lifelong learning by adults; and the storage of a society's cumulative knowledge, history, and culture. IT can bring new information and types of instruction into the classroom; it can provide students with new tools for finding and manipulating information; and it can provide resources that are not available in a particular geographical area. At the same time, IT may impose new costs in equipment, software, and the time it takes to learn new systems; it also threatens to disrupt existing methods of knowledge creation and transfer, as well as the archiving of knowledge.

This section reviews the role of IT in classrooms, in distance education, in the storage and dissemination of knowledge, and in the creation of new knowledge. In each of these areas, similar technologies can be applied from K–12 education to leading-edge research. Much of the attention in each of these categories, however, is directed at one level. Most discussion of IT in the classroom, for example, focuses on K–12 education. Distance education is being used most in higher education. Discussion of the creation, storage, and dissemination of knowledge focuses on the research community. Although this discussion concentrates on these areas, virtually all of the technologies discussed here can be used—and are being used—at many levels in the education/research system. Other chapters of this report discuss the use of information technology in specific parts of the education system: For example, chapter 5 discusses IT at the K–12 level.

IT in the Classroom

In recent years there has been a great deal of emphasis in the United States on increasing the use of information technologies in U.S. elementary and secondary schools (Children's Partnership 1996, McKinsey and Company 1995, NIIAC 1995, PCAST 1997). Greater use of IT at the precollege level is frequently regarded as providing the training students need to be competent members of the information society and to enjoy the benefits of information technology. Schools are expected to expose all children to information technologies so society does not become stratified into information-rich and information-poor classes. A 1992 survey of elementary and high school principals found that the three main reasons schools adopt computer technologies are to give students the experience they will need with computers for the future, to keep the curriculum and teaching methods current, and to improve student achievement (Pelgrum, Janssen, and Plomp 1993).

Assumptions about the educational benefits of IT are not universal, however. *Silicon Snake Oil: Second Thoughts on the Information Highway* (Stoll 1995) represents one critique of claims about the social payoff of IT (including educational benefits). Scholar Larry Cuban (1994) has questioned the use of computers in classrooms, and journalist Todd Oppenheimer (1997) has described the opportunity costs of spending educational funds on IT.

The fundamental dilemma of IT-based education is that it has not been proven to be more cost-effective than other forms of instruction (Cuban 1994, Kulik and Kulik 1991, Rosenberg

1997). Although real IT learning benefits have been demonstrated, we do not know whether the magnitude of those benefits is sufficiently large to justify consuming substantial resources and actively displacing other school curricula and programs.

Others (e.g., Papert 1995) suggest that the question at stake is no longer whether technology can change education or whether this change is desirable. Technology is a major factor in changing the entire learning environment, and schools will need to change in fundamental ways to keep pace.

The budget issues and educational opportunity costs associated with IT are significant. In a report to the U.S. Advisory Committee on the National Information Infrastructure, McKinsey and Company (1995) estimated that about 1.3 percent of the national school budget is spent on instructional technology. Increasing the level of IT in K–12 public schools could require raising this spending to as much as 3.9 percent of the national school budget, depending on the degree of IT intensity desired.[3] Moreover, these figures do not include IT operational expenses or the cost of teacher training—a significant factor in the effectiveness of computer-based instruction (CBI) (McKinsey and Company 1995, PCAST 1997, Ryan 1991, OTA 1995). Because school districts are under increasing fiscal stress, expanding IT resources could mean cutting other important programs. Oppenheimer (1997) details sacrifices in art, music, physical education, vocational classes, and textbook purchases that have been made so that computers could be placed in the schools. The negative effects of these sacrifices on learning and job skills are not usually considered in the growing emphasis on CBI.

Uncertainty about the effect of information technology in the classroom is not surprising. Computers are powerful tools that can be used in many different ways in education. CBI is a broad category that includes computer-assisted instruction (typically drill-and-practice exercises or tutorial instruction), computer-managed instruction (in which the computer monitors student performance and progress and guides student use of instructional materials), and computer-enriched instruction (in which the computer functions as a problem-solving tool). Computers have a variety of potential uses in education: generic information handling, real-time data acquisition, simulations, multimedia, educational games, cognitive tools, intelligent tutors, construction environments, virtual communities, information access environments, information construction environments, and computer-aided instruction (Rubin 1996). Software (courseware) for inquiry-based learning[4] is the ultimate goal of most CBI advocates and the most cognitively demanding form of learning (Kulik and Kulik 1991, McKinsey and Company 1995, PCAST 1997). Given the diversity of applications, from drill and practice exercise to participating in global environmental projects, generalizing about the costs and benefits of computers in the classroom is difficult. (See sidebar, "Innovative Education Projects.")

Diffusion of IT in Education

Over the past 20 years, computers and other information technologies have been diffused widely in the U.S. K–12 educational system. One measure of IT in schools is the ratio of students to computers. In 1998 there were approximately six students per instructional computer in public schools. (See figure 9-14.) Medium-sized schools (300–999 students) and large schools (1,000 or more students) had less access to instructional computers per student than small schools (fewer than 300 students). Schools located in cities had more students per instructional computer than schools in the urban fringes, towns, and rural areas.

Another measure is the degree to which schools are connected to the Internet. Schools have been connecting to the Internet at a rapid rate. By 1998, 89 percent of public schools were connected to the Internet—up from 35 percent in 1994. Although schools with large numbers of students in poverty and large minority populations were much less likely to be connected to the Internet a few years ago, by 1998 most of these differences had decreased sharply (NCES 1999).

The percentage of instructional rooms with access to the Internet also has been growing. In 1998, 51 percent of instructional rooms in public schools were connected to the Internet—nearly double that of 1997. As one might expect, wealthier schools tend to be better connected to the Internet. Public schools with high minority enrollments are likely to have a smaller percentage of instructional rooms connected to the Internet. Similarly, public schools with more students eligible for free or reduced-price school lunch had fewer instructional rooms wired. There are also regional differences. Schools in the Northeast had a lower proportion of rooms connected to the Internet than schools in the Southeast, Central, and West regions.

These differences do not appear to be permanent, however. Schools with high minority or subsidized lunch ratios were about as well connected to the Internet in 1998 as the most connected categories of schools were in 1997. (See appendix table 9-5.)

Schools are also upgrading their Internet connections. The percentage of schools using dial-up connections has dropped from 74 percent of public schools with Internet access in 1996 to 22 percent in 1998. (See figure 9-15.) The percentage of higher-speed connections using dedicated lines has increased from 39 percent in 1996 to 65 percent in 1998. The rapid increase in Internet connection reflects interventions through several programs to increase the use of IT in the schools. These initiatives include National Telecommunications and Information Administration programs to support novel application of information technology; NetDay volunteer efforts to connect schools and classrooms to the Internet; the e-rate pro-

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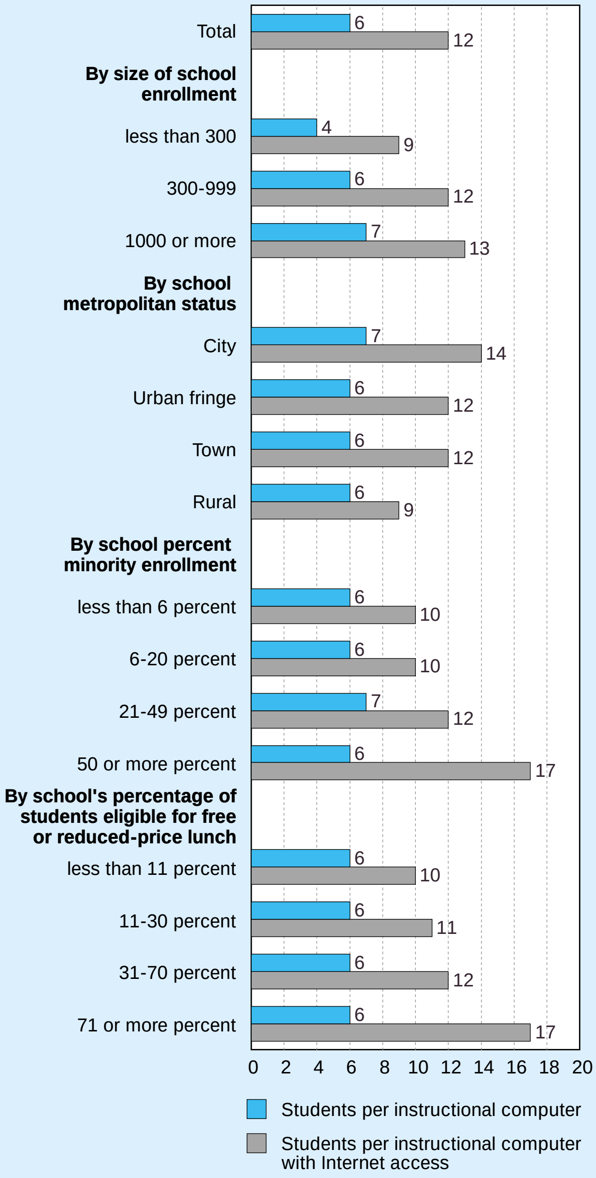
[3] For example, ensuring adequate pupil-to-computer ratios and Internet connections to the school versus universal classroom deployment of full multimedia computers, Internet connections, and school networks. The McKinsey report details three alternative IT models and estimated costs.

[4] Inquiry-based learning represents active learning on the part of a student rather than passive assimilation of information that is "taught" by an instructor. Inquiry-based learning reflects active construction of models for conceptual understanding, the ability to connect knowledge to the world outside the classroom, self-reflection about one's own learning style, and a cultivated sense of curiosity. See Rubin (1996).

Figure 9-14.
Ratio of students per instructional computer and students per instructional computer with Internet access, by school characteristics: Fall 1998



SOURCES: U.S. Department of Education, National Center for Education Statistics, Fast Response Survey System, "Internet Access in Public Schools," NCES 98-031, and "Survey on Internet Access in U.S. Public Schools, Fall 1998," FRSS 69 (1998).

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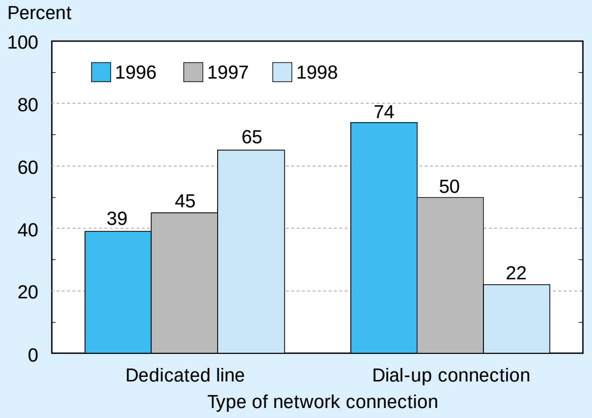
Figure 9-15.
Percentage of public schools with Internet access, by type of Internet connection: Fall 1996–98



NOTE: Data were also collected for ISDN, cable modem, and wireless connections.

SOURCES: U.S. Department of Education, National Center for Education Statistics, Fast Response Survey System, "Advanced Telecommunications in Public Elementary and Secondary Schools, 1996," NCES 97-944, "Internet Access in Public Schools," NCES 98-031, and data from the "Survey on Internet Access in U.S. Public Schools, Fall 1998," FRSS 69, 1998.

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gram to subsidize telecommunication charges for schools; and many other programs by private corporations and foundations.

The Campus Computing Project (1998) has found that information technologies increasingly are being used in college courses as well. E-mail, the Internet, course Web pages, simulation, and other technologies are being used in more courses every year. (See figure 9-16.) In some cases, the decision to use more IT in college courses is largely left to the professor. On the other hand, universities such as UCLA have required professors to establish Web pages for each course and to put syllabuses online. As with IT in K–12 education, support for the increased use of IT in college campuses has not been universal. Many professors and administrators are enthusiastic early users of the new technologies; others prefer to wait for other institutions to find out which new technologies are useful in improving the quality of education.

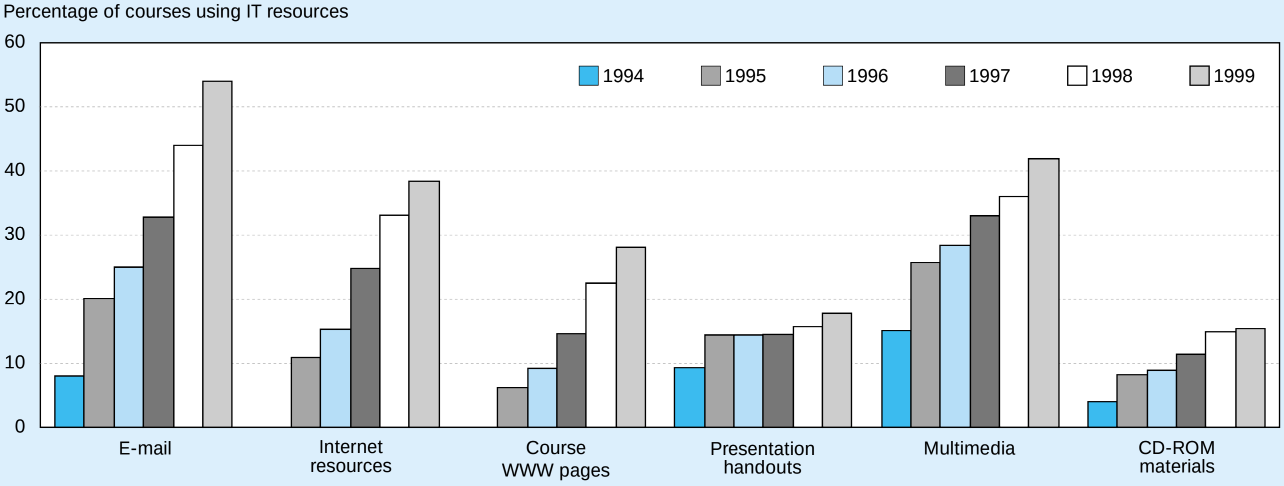
Many of the new information technologies being used in scholarly communication and research can be used in education as well. Scientific and scholarly literature is increasingly available online, students can learn from computer modeling and simulation, and there are opportunities to participate in scientific experiments online. The types of IT that can be incorporated into education can be expected to expand.

Effectiveness of IT in Education

As with the economic effects of IT, measuring the application of IT in education is much easier than measuring its effects or cost-effectiveness. Several factors explain why IT has not yet shown up in overall educational performance measures.

- There are measurement difficulties because people disagree on the appropriate ways to measure performance in education and the relevance of standardized test scores.
- It will take time for the educational system to figure out the best ways to use information technologies.

Figure 9-16.
Use of information technology in higher education instruction: 1994–99



SOURCE: Campus Computing Project (November 1999); and 1999 National Survey of Information Technology in Higher Education, available from <<http://www.campuscomputing.net/>>.

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- Factors other than the technology itself, such as infrastructure support, school organization, and teacher training influence the effectiveness of the technology.
- The technologies are rapidly changing. The technologies that are available today—the Internet, multimedia and simulation software—are substantially different from those available even five years ago. Findings on the effectiveness of IT in the classroom from five years ago may be obsolete.

Many variables in the classroom influence the effectiveness of CBI in the classroom. Schofield (1995) found that the social organization of the school and classrooms affect computer-related learning, behavior, attitudes, and outcomes. Systematic understanding of the social and cognitive complexity of computer-based learning is limited. As the President's Committee of Advisors on Science and Technology (PCAST) Panel on Educational Technology noted:

> In 1995, less than 0.1 percent of our nation's expenditures for elementary and secondary education were invested to determine which educational techniques actually work, and to find ways to improve them (PCAST 1997).

A keyword search of the Educational Resources Information Center (ERIC) (http://www.accesseric.org/)—the primary bibliographic database used for educational research—yields thousands of citations related to computer-assisted instruction and student achievement. The notable characteristic of this research is its diversity: Studies range from anecdotal reports to formal experimental designs, many of which control for different sets of variables and include different types of computer use in different subject areas. Moreover, interest in the effects of computers on young people is not limited to learning and achievement. Concerns about the emotional and psychological effects of prolonged exposure to computing environments have also been raised.

Several syntheses and reviews of this literature have been carried out. Some are standard literature reviews, which can flexibly interpret the differences among studies but also may reflect the author's biases in selecting and interpreting studies. Other syntheses are "meta-analyses." Meta-analysis refers to the statistical analysis of the results of many studies to integrate the findings. Meta-analysis allows researchers to cumulate the findings of multiple studies into a single measure of outcome and estimate the magnitude of an independent variable's impact. A number of meta-analyses have been conducted on the effects of computer-based instruction.

Kulik and Kulik (1991) performed meta-analysis on 254 studies conducted between 1966 and 1986 that covered many different educational levels and instructional technologies. In a subset of this study, Kulik and Kulik analyzed 68 studies on computer-assisted instruction at the precollege level; they found that students using computer-based instruction scored (on average) in the 64th percentile on measures of learning and achievement, compared to the 50th percentile for students in a traditional class.

Ryan's (1991) meta-analysis of 40 studies[5] conducted between 1984 and 1989 found the average K–6 student using a microcomputer as an instructional tool performed in the 62nd percentile on tests, compared to the 50th percentile for the average K–6 student who did not use a microcomputer. Ryan

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[5] Ryan also had a precise set of stringent selection criteria, including requirements that the study reflect experimental or quasi-experimental design, that the sample size be at least 40 students (a minimum of 20 students in the treatment and control groups), and that the treatment last eight weeks or longer.

also evaluated several sets of variables other than CBI that may have had an impact on the size of the effect. Of these variables, only the degree of teacher pretraining was statistically significant. In experimental groups in which teachers had fewer than 10 hours of computer pretraining, the effect size of CBI was negligible and, in some instances, negative. In groups in which teacher pretraining exceeded 10 hours, students in the experimental group performed at the equivalent of the 70th percentile—equivalent to a gain of half a school year gain over the control. These findings reinforce those of other studies that identify the crucial role of teacher preparedness in effective CBI (PCAST 1997; OTA 1995).

Schacter (1999) reviewed seven studies of educational technology:

- a meta-analysis of more than 500 studies (Kulik 1999);
- a review of 219 research studies from 1990 to 1997 (Sivin-Kachala 1998);
- an evaluation of the Apple Classrooms of Tomorrow (Baker, Gearhart, and Herman 1994);
- a study of West Virginia's Basic Skills/Computer Education statewide program (Mann et al. 1999);
- a national study of the effects of simulation and higher order thinking technologies on math achievement (Wenglinsky 1998);
- work on collaborative computer application in schools (Scardamalia and Bereiter 1996); and
- the work of the learning and epistemology group at MIT (Harel 1990; Harel and Papert 1991).

Collectively, these studies cover more than 700 empirical research studies and focus on the most recent work. On the basis of this review, Schacter (1999) concludes that "students with access to: (a) computer-assisted instruction or (b) integrated learning systems technology or (c) simulations and software that teach higher-order thinking or (d) collaborative networked technologies or (e) design and programming technologies show positive gains in achievements on research constructed tests, standardized tests, and national tests." Schacter also found evidence, however, that learning technology is less effective or ineffective when learning objectives are unclear and the purpose of the technology is unfocused.

Innovative Education Projects

Several special projects merit note. The Higher Order Thinking Skills (HOTS) Program, for example, is an intervention program for economically disadvantaged students in the fourth through seventh grades. Students were taken from their traditional classrooms and taught through an innovative curriculum that integrated computer-assisted instruction, drama, and the Socratic method. Students in the HOTS Program outperformed other disadvantaged students in a control group on all measures and had double the national average gains on standardized tests in reading and mathematics (Costa and Liebmann 1997).

The Buddy Project in Indiana, in which students in some classrooms were given home computers, also reported highly positive results across a variety of skills. Similar results were reported for the Computers Helping Instruction and Learning Development (CHILD) program in Florida, an elementary school program that emphasized student empowerment, teacher training and teamwork, and independent learning (ETS 1997). These studies suggest that the use of computers in enriched, nontraditional learning environments might achieve the fundamental changes in student learning that advocates of computer-based instruction desire.

Another innovative IT-based program is the Global Learning and Observations to Benefit the Environment (GLOBE) program (<<http://www.globe.gov/>>)—a worldwide network of students, teachers, and scientists working together to study and understand the global environment. Students and teachers from more than 7,000 schools in more than 80 countries are working with research scientists to learn more about our planet. GLOBE students make environmental observations at or near their schools and report their data through the Internet. Scientists use GLOBE data in their research and provide feedback to students to enrich their science education. Global images based on GLOBE student data are displayed on the World Wide Web, enabling students and other visitors to visualize the student environmental observations.

Distance Education

Distance education is not new. An estimated 100 million Americans have taken 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. Information technologies are providing significant new tools for distance education. Many schools are establishing distance education programs for the first time or expanding their existing distance education courses.

In online distance courses, students are likely to use e-mail to communicate with instructors and fellow students. The instructor typically sends "lectures" via e-mail or posts them on a Web page, and students submit assignments and have "discussions" via e-mail. Courses often supplement textbooks with Web-based readings. These courses may also meet in a chat room at a certain time for online discussions. Classes may also have online bulletin boards or Web conferences in which people ask and respond to questions over time. In the not-too-distant future, as Internet bandwidth increases, video lectures and videoconferencing will become more common additions to the online courses. Some classes may also use more elaborate systems called MUD/MOOs[6] for group interaction as well as many groupware programs that often involve simultaneous viewing of graphics and use of a shared writing space (i.e., electronic white board) (Kearsley 1997). Other classes may make use of computer simulations over the Internet.

Distance education offers several potential advantages. It may allow students to take courses not available in their geographical area, and it may allow students to take courses in a way that fits in with their career and family life. It makes education more available to working students with Internet access—especially older, mid-career students and those who have family responsibilities. For universities, it offers a way to expand enrollment without increasing the size of their physical plant.

Although distance education traditionally is regarded as education or training courses delivered to remote locations, distance education techniques—especially online education—can be incorporated as part of on-campus instruction as well. Universities are finding that significant numbers of on-campus students will take distance education courses when such courses are offered. At the University of Colorado at Denver, for example, more than 500 of 609 students enrolled in distance-education courses were also enrolled in regular courses (Guernsey 1998). Online courses can be more convenient for on-campus students, allowing them to better fit courses into their schedules. Such courses can also allow professors to augment course material with Web-based materials or guest lecturers in remote sites.

Trends in Distance Education

- The National Center for Education Statistics has conducted two surveys of distance education in post-secondary education institutions, the first in the fall of 1995 and the second in 1997/98 (NCES 1999b). The first survey covered only higher education institutions, while the second survey covered all post-secondary educational institutions. These surveys document that distance education is now a common feature of many higher education institutions and is growing rapidly. 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 the fall of 1995, 33 percent of 2-year and 4-year higher education institutions offered distance education courses. By 1997/98, the figure had grown to 44 percent. (See appendix table 9-6.) In 1995, 62 percent of public 4-year institutions offered distance education; by 1997/1998, 79 percent offered distance education. Private 4-year colleges are much less likely to offer distance education, but are also increasing their use of it. The percentage of private 4-year colleges offering distance education increased from 12 percent in 1995 to 22 percent in 1997/98.

- Distance education course and enrollments are growing more rapidly than the number of institutions offering distance education. The number of courses offered in 2-year and 4-year higher education institutions doubled from 25,730 in 1994/95 to 52,270 in 1997/98. (See appendix table 9-7.) The increases were fairly similar across all categories of higher education institutions (2-year and 4-year schools, public and private institutions, and all size categories). Course enrollments were also up sharply, more than doubling from 753,640 in 1994/95 to 1,632,350 in 1997/98 (NCES 1999b).

- Of those higher education institutions that offer distance education, the percentage that offer degrees that can be completed exclusively with distance education courses has remained essentially constant, 22 percent in 1997/98 compared to 23 percent in 1995 (NCES 1999b).

- There has been a significant change in the technologies used for distance education. (See appendix table 9-8.) In 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 at 56 percent and 48 percent, respectively. Internet-based courses, however, expanded greatly. The percentage of institutions offering Internet courses using asynchronous (not requiring student participation at any set time of day or week) computer-based instruction was 60 percent in 1997/98. The percentage of institutions that offered Internet courses using synchronous (real-time) computer-based instruction was 19 percent in 1997/98 (NCES 1999b).

Significance of Distance Education

Despite substantial and growing experience with online education, there have been relatively few thorough assessments. Frank Mayadas of the Sloan Foundation (which supports asynchronous learning[7]) suggests that because online education provides access to education to a new student population, it does not need to be directly compared to on-campus education (Miller, n.d.). Instead, asynchronous learning should be assessed according to degree of access provided, the extent to which learning meets or exceed goals set by faculty and the institution, the extent to which it is a satisfying experience for faculty, its cost-effectiveness, and its student satisfaction.

There is evidence that, at least in some circumstances, online education can be very effective. The rapid growth and success of some online education providers suggests that they are providing acceptable learning experiences. At the same time, there are many other case studies that report at least initial frustrating experiences with online education.

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[6] MUD stands for "multiple user dimension, dialogue, or dungeon." MOO stands for "MUD, object oriented."

[7] Asynchronous learning refers to distance learning that uses technologies that allow participants to interact without having to be available at the same time.

Kearsley, Lynch, and Wizer (1995) reviewed the literature that examines the use of computer conferencing in higher education and found that, in comparison with traditional classes, student satisfaction with online courses is higher, measures of student achievement are the same or better, and there is usually more discussion among students and instructors in a course.

Schutte (1997) reported on an experiment carried out during a fall 1996 social statistics course at California State University, Northridge, in which students were randomly divided into two groups—one taught in a traditional classroom and the other taught virtually on the World Wide Web. Text, lectures, and exams were standardized between the two groups. Schutte found that, contrary to expectations, the virtual class scored an average of 20 percent higher than the traditional class on both examinations.

At the same time, distance education raises issues concerning broader effects on the university. Although online education may expand the pool of people who have access to education, it also may take students away from traditional education, and some scholars express concern that it will undermine the traditional college experience. Some people question whether the quality of distance education can match that of face-to-face instruction. Moreover, creating the kind of intellectual or social community that characterize colleges may be much harder through distance learning.

Distance education also 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 in other geographic areas. Top-tier universities such as Stanford and Duke are beginning to market Internet-based master's degrees to national audiences. New distance education–based universities—such as Jones International University (<<http://www.jonesinternational.edu>>), the first online-only university to gain accreditation; the University of Phoenix online (<<http://online.uophx.edu>>); and the Western Governors University (<<http://www.wgu.edu>>)—are also marketing courses that compete with universities and community colleges that have in the past been providers of continuing education services in their region. Others see opportunities to market American university degrees to large potential student populations abroad. The reverse is also happening. The United Kingdom's Open University, which has established a good reputation as a provider of distance education in the U.K. since 1971, has started an operation in the United States (Blumenstyk 1999a).

In addition, distance education is creating new markets for companies selling course materials and software to assist in online courses (Blumenstyk 1999b). Publishers such as McGraw-Hill and software companies such as Microsoft and Oracle have developed and are marketing online courses (Morris 1999).

Some people regard distance education technologies as providing new tools to professors. Others foresee mass production education, in which packaged multimedia courses will reduce the importance of professors (Noble 1998). As one indicator of concern, more than 850 faculty members at the University of Washington signed a letter to Governor Gary Locke protesting the state's plans for investing in information technology (Monaghan 1998). The expanding and potentially lucrative new market for online course materials has also raised the issue of whether professors or the university should own the intellectual property embodied in online courses. The American Association of University Professors (AAUP) has taken the position that professors rather than institutions should retain primary property rights for online course materials (Schneider 1999) and has questioned the accreditation of Jones International University (Olsen 1999).

The issues raised by IT in education are still in their infancy and will probably take years to resolve.

IT, Research, and Knowledge Creation

Information technology is having broad and substantial effects on research and the creation of knowledge. IT facilitates:

- new ways of communicating and storing scholarly information;
- new methods of research and new fields of science; and
- new forms of scientific collaboration.

The effects of IT on research and knowledge creation are important for two reasons. First, they have significant effects on the research community, which in turn affects innovation and education in society. Second, many applications of IT that have been used first in the research community, such as e-mail and the World Wide Web, have later diffused more widely and have had major effects outside of the research community.

Scholarly Communication

In his 1945 *Atlantic Monthly* article, Vannevar Bush illustrated how helpful it would be to researchers to have access at their desk to the great body of the world's knowledge. In the past few years, that vision has come much closer to reality. The Internet and the World Wide Web, originally developed as tools for scientific communication, have become increasingly powerful. An increasing amount of scholarly information is stored in electronic forms and is available through digital media—primarily the World Wide Web.

Scholars derive many advantages from having scholarly information in digital form. They can find information they want more easily using search tools. They can get the information without leaving their desks, and they do not have to worry about journals being missing from the library. They can get more complete information because electronic publications are not constrained by page limits as printed journals commonly are. Multimedia presentations and software can be combined with text, enriching the information and facilitating further work with it. Additional references, comments from other readers, or communication with the author can be a mouse-click away.

There are also advantages for libraries. Many patrons can access the same electronic information at the same time, possibly without having to visit the library facility; electronic archives do not take up the space held by old journal collections; and libraries can stretch limited financial resources, especially for accessions. All of these factors exert strong pressures for making scholarly information available electronically.

The traditional system of printed academic journals, however, performs functions other than information transmission. 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. Similarly, traditional libraries have played roles in scholarship that go beyond storing books and journals. The library is a place for students and scholars to congregate, and it often has been the intellectual center of a university.

Electronic publications also raise issues about the archiving of information. Rapidly changing IT means that publications stored in one format may not be readily accessible to future users. This problem may become increasingly difficult when electronic "publications" include hyperlinks, multimedia presentations, or software programs.

There are several different ways to put scholarly information online, all of which are expanding. These "media" include individual Web pages, preprint servers, electronic journals, and electronic versions of print journals.

Many scholars put their own work on personal or research-group Web pages. These sites may include "reprints" of published material, preprints, working papers, talks and other unpublished material, bibliographies, data sets, related course material, and other information of use to other scholars. This approach provides an efficient way for scholars to respond to requests for information from colleagues or students.

Another rapidly growing form of electronic publication has been preprint or reprint servers, whereby authors in a specified field post their articles. These servers enable readers to find papers of interest, accelerate dissemination of new knowledge, and provide a focal point for information in a field. The original and most widely copied preprint server is the Los Alamos physics preprint server (<<http://xxx.lanl.gov/>>). This site was started in 1991 by Los Alamos physicist Paul Ginsparg as a service to a small subfield of physics; it has grown to cover many fields of physics, astronomy, mathematics, and computation. By mid-1999 it was receiving more than 2,000 new submissions each month and had close to 100,000 connections each day (e.g., for searching, reading, or downloading papers) from approximately 8,000 different hosts. (See figures 9-17 and 9-18.) It has become the main mode of communication in some fields of physics. Fourteen other places around the globe have established mirror sites that copy the information on the Los Alamos server to provide alternative access to the information. One effect of the server is that physicists around the world who do not have access to major research libraries can keep abreast of the latest developments in physics.

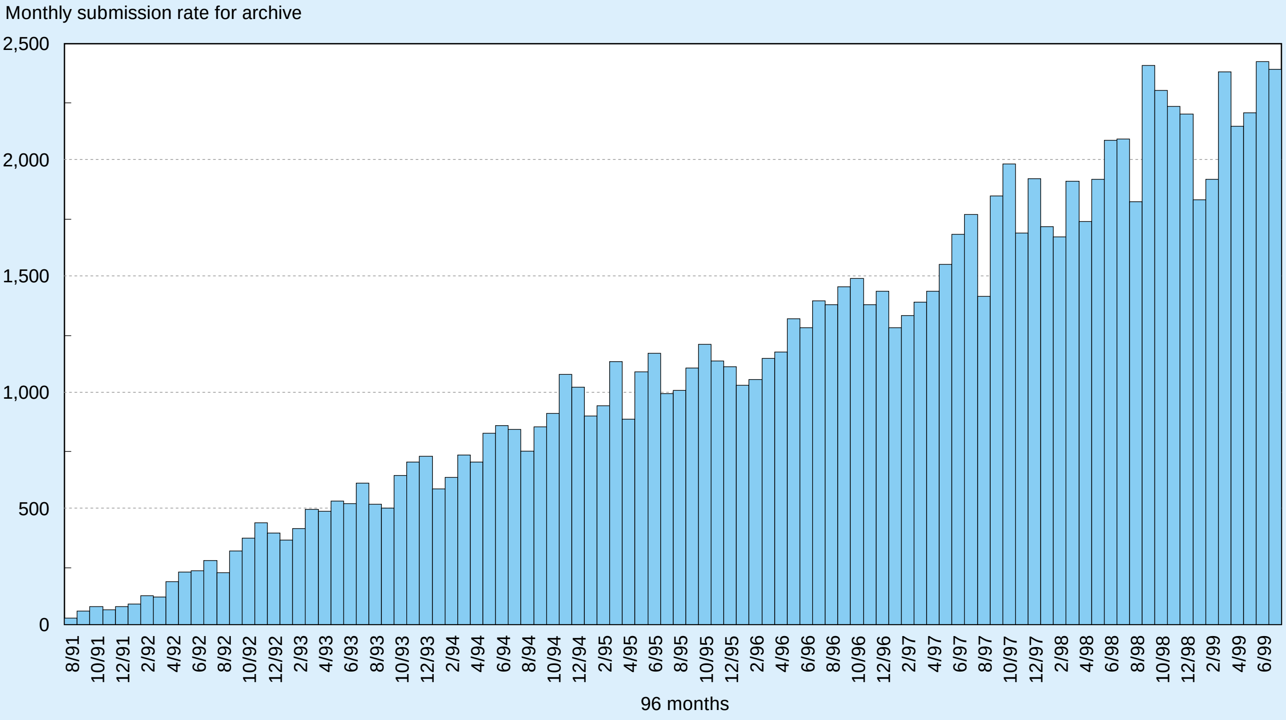
The preprint server is a very efficient mode of communication. Odlyzko (1997) estimates that the Los Alamos server costs $5–$75 per article (the upper estimate is based on deliberately inflated assumptions about costs), compared to costs of $2,000–$4,000 per article for an average scholarly print journal. The server does not provide refereeing of articles, but it does provide a means for scientists to comment on papers that are posted as well as to respond to the comments of others. It also provides a forum for electronic discussions in various fields. The Los Alamos server is frequently regarded as a model. Other preprint servers modeled after the Los Alamos server include the Economics Working Paper Archive hosted by the Economics Department of Washington University (<<http://econwpa.wustl.edu/wpawelcome.html>>) and a Chemical Physics Preprint Database operated by the Department of Chemistry at Brown University and the Theoretical Chemistry and Molecular Physics Group at the Los Alamos National Laboratory (<<http://www.chem.brown.edu/chem-ph.html>>). As other preprint servers develop, it will become easier to understand how much the Los Alamos success derives from the particular nature of the research and researchers in physics and how much can be generalized.

Implementation issues associated with scholarly electronic publishing were underscored by the 1999 proposal by NIH director Harold Varmus for a Web-based repository of biomedical literature to be hosted by NIH originally called E-biomed (Varmus 1999). In the original proposal, this repository was intended to be a preprint server, modeled after the Los Alamos server; that proposal was revised, however, after extensive public comment and discussion in the press. Some people expressed concern that unrefereed medical publications might be a public health risk. Others suggested that NIH, as the funding agency for biomedical research, should not itself publish research results. Much of the criticism came from professional societies and the publishers of academic journals, who regarded E-biomed as a threat to their circulation and revenue. In response to these comments, NIH revised the proposal to create a "reprint" server that would work with existing journals to post the text of those journals after they are published. (NIH also changed the name, first to E-biosci, and then to PubMed Central.) Although this proposal is less threatening to publishers, the benefits to them of participation are not yet clear (Marshall 1999).

The controversy over the Varmus proposal shows that key players include not only researchers and publishers but also the broader public that may access electronic publication. Research posted on the Web that has direct public health or policy implications is likely to receive more scrutiny than research with a primarily scientific audience. As regulatory attention to health information on Web sites illustrates, the quality of some kinds of information may trigger more concern—and intervention—than others.

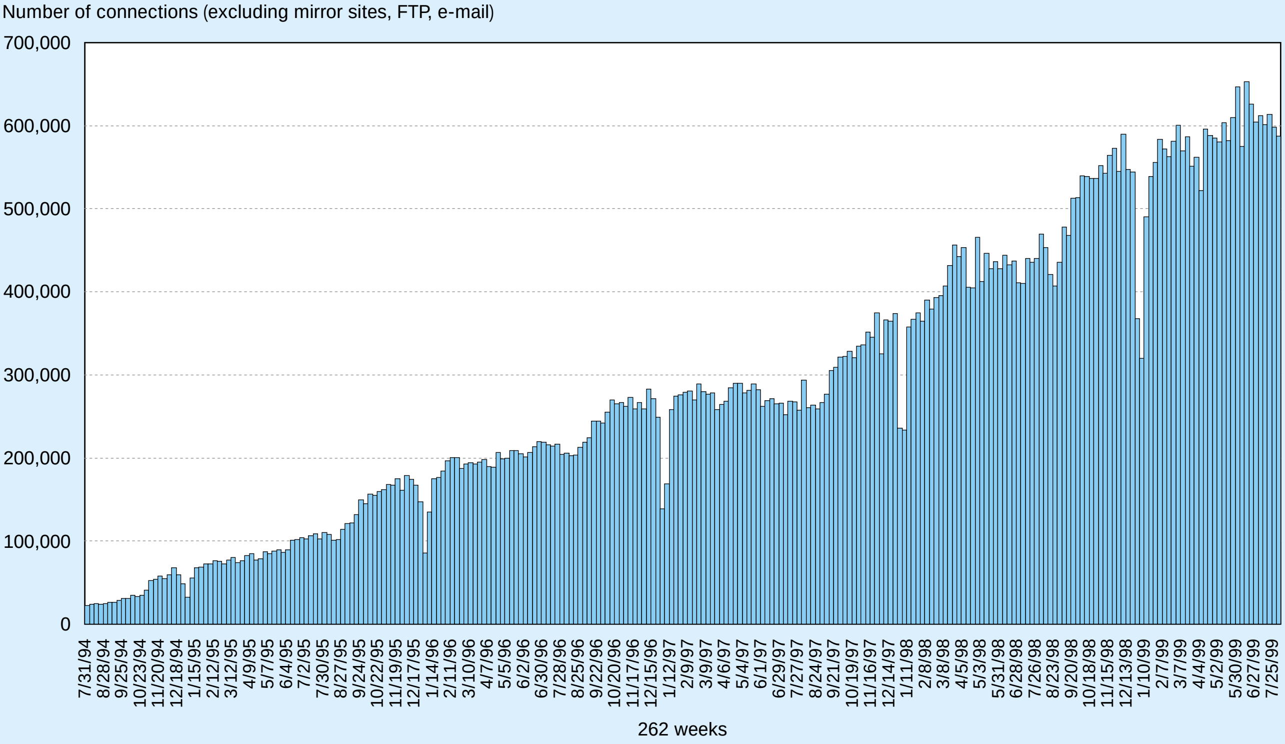
Electronic journals have also been expanding rapidly. The Association of Research Libraries' (ARL) 1997 directory of electronic journals, newsletters, and academic discussion lists included 3,400 serial titles—twice as many as in 1996. Of

Figure 9-17.
Number of new submissions received at Los Alamos preprint server each month since August 1991



SOURCE: Los Alamos preprint server available from <<http://xxx.lanl.gov/>>. *Science & Engineering Indicators – 2000*

Figure 9-18.
Number of connections each week at Los Alamos preprint server: 7/31/94–8/1/99

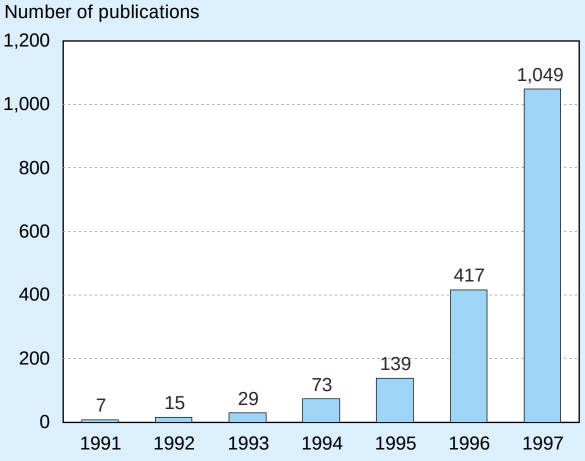


SOURCE: Los Alamos preprint server available from <<http://xxx.lanl.gov/>>. *Science & Engineering Indicators – 2000* that total, 1,465 titles were categorized as electronic journals; of these, 1,002 were peer-reviewed, and 708 charge in some manner for access. The number of peer-reviewed electronic publications (which includes some publications not classified as journals) has increased rapidly since 1991. (See figure 9-19.) The 1999 ARL directory is expected to list more than 3,000 peer-reviewed titles (Mogge 1999). The increase reflects the fact that traditional print publishers are moving to make their titles available electronically—both as electronic versions of their paper products and as electronic supplements or replacements for the print journal.

Electronic journals can be offered either directly by publishers or through intermediary services that aggregate the titles from many publishers in one service (Machovec 1997). Publishers are currently experimenting with different ways of pricing electronic journals. Some provide separate subscriptions for electronic versions that may be higher or lower cost than the print version. Others provide the electronic version at no charge with a subscription to the print version. Some publishers offer free online access to selected articles from the print version and regard the online version as advertising for the print version (Machovec 1997). Publishers of fee-based electronic journals generally protect their information from unauthorized access by restricting access to certain Internet domains (such as those of universities that have acquired a site license) or through passwords.

Print publishers who move to electronic publishing have found that their costs remain significant (Getz 1997). A large proportion of the cost of most journals covers editing and refereeing of manuscripts and general administration—which, at least initially, remains about the same for electronic journals. In addition, there are costs associated with new information technology and with formatting manuscripts for electronic publication. Some of these costs might decline with time, experience, and improved technology.

Figure 9-19.
Peer-reviewed electronic publications



SOURCE: Mogge, D., *ARL Directory of Electronic Journals, Newsletters and Academic Discussion* (1997): Foreward. Available from <<http://www.arl.org:591/foreword.html>>.

Science & Engineering Indicators – 2000

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 may decline. Moreover, electronic journals may be less attractive to advertisers than print versions.

Some electronic-only journals—generally run by an unpaid editor and distributed on the Internet at no cost to the user—are operated at low cost. They can provide a similar filtering function to that of print journals (using, as do other scholarly journals, unpaid reviewers), but they generally have lower administrative and publishing costs. Many free journals are subsidized, directly or indirectly, by another organization; some charge authors fees for articles that are printed to cover their costs. Odlyzko (1997) estimates that these journals can operate at $250–$1,000 per article (again, compared to $2,000–$4,000 per article for average academic publications).

The system of scholarly communication is changing rapidly, but the direction of that change remains uncertain. Although scholars want to be able to access information in electronic form, and the costs of electronic publishing can be lower, there are some barriers to electronic publishing. Scholars, who do not directly bear the cost of journals, tend to submit their articles to print journals rather than electronic journals because they still regard print journals as more prestigious (Kiernan 1999). (They may also post their articles on the Web for convenience.) Research libraries, which are under pressure to cut journal costs, also must continue to meet the needs of their research communities to provide access to the most important journals (which are mostly still print journals), and libraries have trouble affording print and electronic versions of the same journals. Libraries are seeking new strategies, such as negotiating university-system wide packages for electronic journals to lower costs (Biemiller 1999) or even supporting new, lower cost journals to compete with high-cost journals (ARL 1999).

Digital Libraries

The term "digital library" does not refer to a library in the conventional sense of a central repository of information. Rather, the term encompasses a broad range of methods of storing materials in electronic format and manipulating large collections of those materials effectively. Some digital library projects focus on digitizing perishable or fragile photographs, artwork, documents, recordings, films, and artifacts to preserve their record and allow people to view items that could otherwise not be displayed publicly. Others are digital museums, which allow millions of individuals access to history and culture they would not otherwise have.

One example is JSTOR, an Andrew W. Mellon Foundation-funded project to convert the back issues of paper journals into electronic formats (JSTOR 1999). The goals of this project are to save space in libraries, to improve access to journal content, and to solve preservation problems associated with storing paper volumes. High-resolution (600 dpi) bit-mapped images of each page are linked to a text file generated with optical character recognition software to enable searching. JSTOR does not publish current issues of the journals, which would put journal publishers' revenue stream at risk; instead, it publishes volumes when they are either three or five years old, depending on the journal. JSTOR now covers more than 117 key journal titles in 15 disciplines. Access to JSTOR is available through institutions such as university libraries that have site licenses.

The Federal Government's multi-agency Digital Library Initiative (<<http://www.dli2.nsf.gov/>>) is supporting projects at many universities around the country. These projects are designed to improve methods of collecting, storing, and organizing information in digital forms and to make information available for searching, retrieval, and processing via communication networks. These projects cover a broad range of topics in the sciences, social sciences, arts, and humanities. They cover information creation, access and use, and archiving and preservation for information as diverse as maps, videos, scientific simulations, and medical records. That diversity enriches the IT through these projects and the clientele for electronic information. It also differentiates digital library projects from preprint servers. The sidebar "Growth of the World Wide Web" provides additional information on libraries and the Web.

Effects of IT on Research

IT has had a major effect on research. It has facilitated new methods of research and development, new forms of research collaboration, and new fields of science. Computers have affected research from their beginnings, and scientific users historically have had the most advanced computing capability. Today, advances in the underlying technology make relatively advanced capabilities available more broadly, fueling the diffusion of IT from its historical stronghold in the physical sciences across the research community through other natural sciences, engineering, social sciences, and the humanities.

New Research Methods

High-end computing and software have had a fundamental impact on research in many areas of science and technology. 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). As information technologies have become increasingly powerful, they have facilitated continued advances in these areas of science and become increasingly vital to sciences such as biology that historically used IT less extensively.

Shared databases have become important resources in many fields of science and social sciences. Examples include Census Bureau databases, data from large scientific instruments such as the Hubble Space Telescope, genetic and protein databases (e.g., GenBank), and the NIH-funded human brain project, as well as many smaller and more specialized databases. 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.

Modeling and simulation have become powerful complements to theory and experimentation in advancing knowledge in many areas of science. Simulations allow researchers to run virtual experiments that, for either physical or practical reasons, they cannot run in reality. 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. Industry also uses simulations extensively to test the crashworthiness of cars and the flight performance of aircraft (DOE/NSF 1998) and to develop new financial instruments (e.g., derivatives).

The performance of computers continues to improve at a rapid rate. The Department of Energy'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 and is planning to operate a 100 teraops computer by 2004 (National Science and Technology Council 1999). Researchers funded by DARPA, NASA, and the National Security Agency (NSA) are evaluating the feasibility of constructing a computing system capable of a sustained rate of 10^{15} floating point operations per second (1 petaflop).

IT in Biology

IT is becoming increasingly important in biology. Genomics research, including efforts to completely map the human genome (which consists of 3 billion nucleotide base pairs) by 2005, depends on robots to process samples and computers to manage, store, compare, and retrieve the data (Varmus 1998). The databases that contain gene and protein sequence information have been growing at an enormous rate. GenBank, NIH's annotated collection of all publicly available DNA sequences, has been growing at an exponential rate: The number of nucleotide base pairs in its database has been doubling approximately every 14 months. As of August 1999, GenBank contained approximately 3. 4 billion base pairs, from 4.6 million sequence records. These base pairs were from 50,000 species; *Homo sapiens* accounted for 1.8 billion of the base pairs. (See figure 9-21.)

GenBank is part of a global collaboration; it exchanges data daily with European and Japanese gene banks. In addition to the publicly available sequences in GenBank, private companies are rapidly developing propriety genetic sequences.

To make use of data from the human genome project, 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

Growth of the World Wide Web

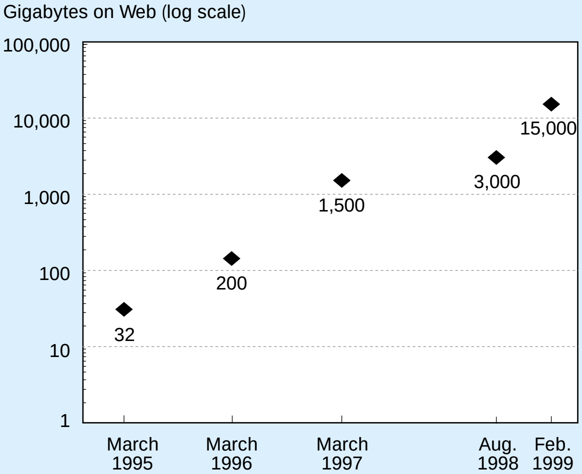
One indicator of the growth of digital information is the growth of the World Wide Web. The volume of information on the Web has grown enormously. (See figure 9-20.) Although scholarly information is only a small part of the Web, the amount of useful scholarly information is still large.

Lesk (1997a) notes that a book such as *Moby Dick* is approximately 1 megabyte in plain-text ASCII form, so 1 terabyte is the equivalent of 1 million substantial books. By this measure, the amount of text on the Web as of February 1999 was equivalent to 6 million books.

Lawrence and Giles (1999) estimate that there were 800 million pages on the publicly indexable Web as of February 1999—corresponding to 15 terabytes in HTML or 6 terabytes in text.* They also estimated that 3 terabytes of image data were available online. They found that about 6 percent of Web servers have scientific or educational content—defined as university, college, or research lab servers.

In addition to the World Wide Web, other online information providers such as Dialog and Lexis-Nexis make large amounts of information available. Dialog has approximately 9.2 terabytes and Lexis-Nexis has approximately 5.9 terabytes (Lesk 1997a). Many universities now have access to Lexis-Nexis (Young 1998).

Figure 9-20.
Growth in number of gigabytes on the Web



NOTE: The larger jump from 1998 to 1999 may be because Alexa counted actual pages it found and retrieved, whereas Lawrence and Giles used a sampling technique.

SOURCES: 1996, 1997, and 1998 data from Alexa <<www.alexa.com/company/inthenews/webfacts.html>>; 1999 data from Lawrence, S., and L. Giles, "Accessibiility of Information on the Web," *Nature* 400 (July 8): 107–109.

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By comparison, the largest library in the world, the Library of Congress, has 17 million books—equivalent to 17 terabytes of text. The Library of Congress also has 2 million recordings, 12 million photographs, 4 million maps, 500,000 films, and 50 million manuscripts. In all, it has 115 million items (Library of Congress 1999). Because these other types of collection would be very large in digital form, the collections in the Library of Congress might total 3,000 terabytes (Lesk 1997a).

Thus, the amount of information in network-accessible digital form is already very large and is approaching the volume of text in the largest libraries. It already exceeds the volume of text in libraries that are readily accessible to most people. It does not yet, however, match the total holdings of the largest libraries in sheer volume. On the other hand, the range of information available online is broader than that in most libraries, albeit in ways that do not necessarily make it more useful—as typical results of Web searches illustrate today. The amount of information available online is growing quickly and will likely grow even faster as more people obtain higher-bandwidth Internet connections and can more readily use the Internet for music, video, and multimedia information that they generate as well as consume.

Of course, there are great qualitative differences between material in libraries and material on the Web. Most material in libraries has been judged by editors and librarians to have some lasting value—it has been selected. Much of the material on the Web has not gone through such filters and has been generated for a wider variety of purposes (e.g., public relations or commercial information). In addition, for most of the material on the Web, there is no guarantee that the information will be accessible in the future. On the other hand, the Web is useful as a source for materials such as preprints and technical reports that may be difficult to find in libraries.

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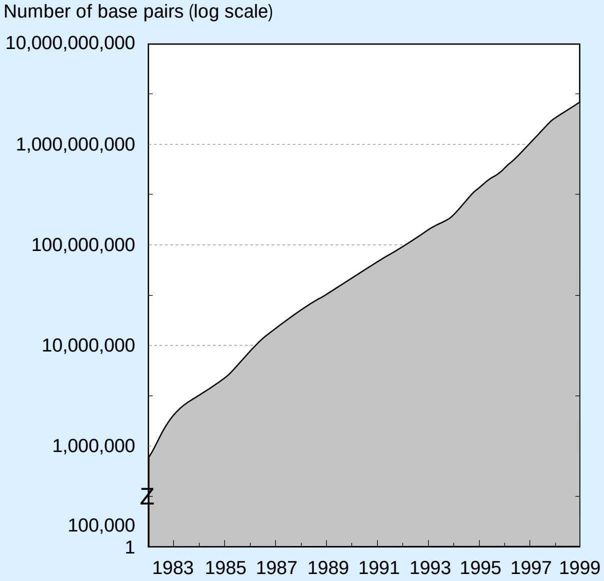
*Lawrence and Giles tested 3.6 million random Internet Protocol (IP) addresses to see if there was a server at that address. They found one server for every 269 requests. Because there are 4.3 billion possible IP addresses, this result led to an estimate of 16 million Web servers. After eliminating servers that were not publicly indexable (such as those behind firewalls or those with no content), they estimated the publicly indexable Web to comprise 2.8 million servers. Lawrence and Giles sampled 2,500 of these servers at random and found the average number of pages per server to be 289, leading to an estimate of 800 million Web pages. These pages averaged 18.7 kilobytes (7.3 kilobytes of text after HTML tags were removed). Lawrence and Giles also found 62.8 images per server, with a mean size of 15.2 kilobytes. Using a similar sampling method, the Online Computer Library Center (OCLC 1999) estimated that there were 288 million (± 35 percent) unique, publicly accessible Web pages in June 1999.

Figure 9-21.
Growth of Genbank



SOURCE: Genetic Sequence Data Bank, NCBI-GenBank Flat File Release 113.0 (15 August 1999): Distribution Release Notes. Available from <<ftp://ncbi.nlm.nih.gov/genbank/gbrel.txt>>.

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and the integrated function of thousands of genes. To model the folding of a protein—a capability that would dramatically aid the design of new drug therapies—takes the equivalent of months of Cray T3E computer time (DOE/NSF 1998). Researchers are also using pattern recognition and data mining software to help decipher the genetic information (Regalado 1999).

The importance of informatics for biology and medicine is difficult to overemphasize. Many scientists expect it to revolutionize biology in the coming decades, as scientists decode genetic information and figure out how it relates to the function of organisms. As NIH director Varmus (1999) stated, "All of biology is undergoing fundamental change as a result of new methods that permit the isolation, amplification, and detailed analysis of genes." Genomic information will be used to assess predisposition to disease, predict responses to environmental agents and drugs, design new medicines and vaccines, and detect infectious agents. New areas of biology—such as molecular epidemiology, functional genomics, and pharmacogenetics—rely on DNA data and benefit more generally from new, information-intensive approaches to research.

Research Collaboration

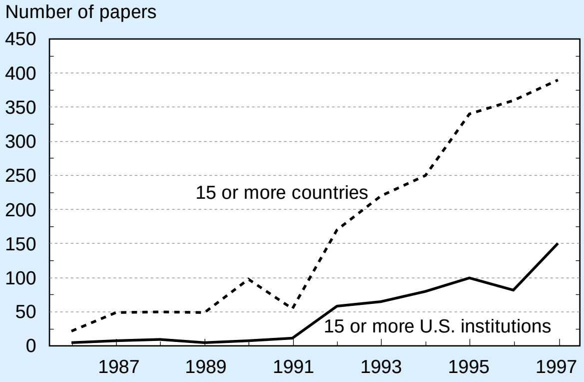
IT facilitates enhanced collaboration among scientists and engineers. E-mail, the World Wide Web, and digital libraries allow information to be accessed from anywhere and let geographically separated scientists (even if they are only a building away) work together better. Some companies with laboratories around the world pass off problems from one lab to another so researchers can work on the problems 24 hours a day.

Scientific collaboration—as measured by the increase in the percentage of papers with multiple authors—has been increasing steadily for decades. Much of this collaboration is probably the result of better telephone service and air travel, as well as the availability of fax machines and e-mail. Large-scale scientific collaborations may be especially enabled by new information technology. There has been a rapid increase in the number of papers with authors from many institutions that coincides with the rapid expansion of the Internet. (See figure 9-22.)

More advanced technologies to aid R&D collaboration are coming into use and are likely to migrate to broader usage in the next few years. (See sidebar, "Collaboratories.")

How the application of IT will affect the science and engineering enterprise in the long run is not clear. Although the potential for change is obvious, we do not know how much and what kind of change will endure. The availability of information from anywhere may reduce the need for researchers to be close to major research libraries. The ability to operate major scientific instruments over the Web may reduce the need for scientists to be located at major laboratories. If virtual laboratories can function effectively, there may be less need to assemble large multidisciplinary teams of scientists and engineers at a laboratory to work on complex problems at a common location. Most scientists, however, may still want extensive face-to-face interaction with their colleagues, and they may want hands-on participation in experiments.

Figure 9-22.
Number of papers with authors from 15 or more countries or 15 or more U.S. institutions: 1986–97



SOURCE: CHI Research, Inc.

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Collaboratories

In 1989, William Wulf (now president of the National Academy of Engineering but then at the National Science Foundation) coined the term "collaboratory" to describe the concept of using information technologies to make geographically separate research units function as a single laboratory. Wulf defined a "collaboratory" as a "...'center without walls' in which the nation's researchers can perform their research without regard to geographical location—interacting with colleagues, accessing instrumentation, sharing data and computational resources, and accessing information in digital libraries" (CSTB 1993).

In subsequent years, a number of programs began to develop tools for collaboratories and fund pilot projects. Among the earliest projects were:

- The NSF-sponsored Upper Atmosphere Research Collaboratory (UARC)—now the Space Physics and Aeronomy Research Collaboratory (SPARC)—which allows space physics researchers around the world to control and gather data from more than a dozen instruments located around and above the globe. SPARC is based at University of Michigan (<<http://www.crew.umich.edu/UARC/>>); it has collaborators from many institutions.
- The DOE-sponsored Materials MicroCharacterization Collaboratory (<<http://tpm.amc.anl.gov/MMC>>), which conducts research on the microstructure of advanced materials. This effort involves three DOE national laboratories, the National Institute for Standards and Technology (NIST), the University of Illinois, and several scientific instrument companies.
- The DOE-sponsored Diesel Combustion Collaboratory (<<http://www.collab.ca.sandia.gov/Diesel/ui/>>), which focuses on diesel engine emissions control and involves three DOE national laboratories, the University of Wisconsin, and several diesel engine manufacturers.

These collaboratories use a similar set of technologies for collaboration, including:

- Internet-based desktop video conferencing;
- Shared access to databases and computer simulation;
- Shared virtual workspaces, such as "white boards" on which researchers can sketch out ideas; and
- Shared electronic laboratory notebooks to capture the details of experiments.

One of the most important aspects of collaboratories is the ability to share scientific instruments over the Internet. This sharing may involve many users from different sites using a single major scientific instrument, such as a synchrotron at a national laboratory, or it may involve using a network of instruments, such as environmental sensors in geographically separate parts of the globe.

Many of the tools developed in these and other pilot projects are now being used in other research collaborations.*

Among the benefits of collaboratories (Ross-Flanigan 1998) are that:

- Scientists can avoid going to scientific instruments in remote locations.
- Many more universities, scientists, and students can participate in or observe experiments.
- By connecting computation to experiments, scientists can better and more quickly integrate experiments and theory. Theorists and experimentalists can work together in real time, greatly reducing the time required to analyze experiments.
- Scientists can put together quick video conferences to discuss the data.
- Students can participate in experimentation much earlier in their careers than before.

On the other hand, virtual communication has been found to be less successful than face-to-face communication in building trust between researchers. In addition, as a result of greater outside participation in the research, good researchers have more distractions. The early collaboratories also found that Internet congestion, the lack of reliability of some of the tools, and software changes slowed research.

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*See, for example, <<http://www.si.umich.edu/research/projects.htm#collabor>>; <<http://www.mcs.anl.gov/DOE2000/pilot.html>>; <<http://doe2k.lbl.gov/doe2k/index.html>>.

IT and the Citizen

IT in the Home

The breadth of information technologies in the home is considerable, ranging from televisions and telephones to smart house technology, microprocessors in coffeepots, personal computers (PCs), and the Internet.[8] The trends and developments presented here focus only on home computers and Internet linkages,[9] not on the full spectrum of home informatics or ways in which people can access the Internet outside of the office (such as in libraries, kiosks, or Internet cafes). In addition, the analysis concentrates on social impacts that occur within the home itself, such as changes in individuals, in family dynamics, or in household operations.

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[8] For a more extensive discussion of the diffusion and effects of information technologies in the home, see National Science Foundation, *The Applications and Implications of Information Technologies for the Home* (1999) (available at <<http://srsweb.nsf.gov/it_site/index.htm>>); National Technical Information Administration, *Falling Through the Net: Defining the Digital Divide* (1999) (available at <<http://www.ntia.doc.gov/ntiahome/digitaldivide/>>).

[9] Note that there is increasing diversity in technical access to the Internet—for example, through television (web TV^{TM}) and telephones. Such alternative mechanisms are not explicitly addressed in this study; most research reviewed here assumes that Internet access is achieved through a personal computer.

The broader social impacts of home-based computing—for example, on culture and values, democratic participation, and social cohesion—are not addressed; neither are the impacts of home-based businesses that are facilitated by PCs and Internet linkages.

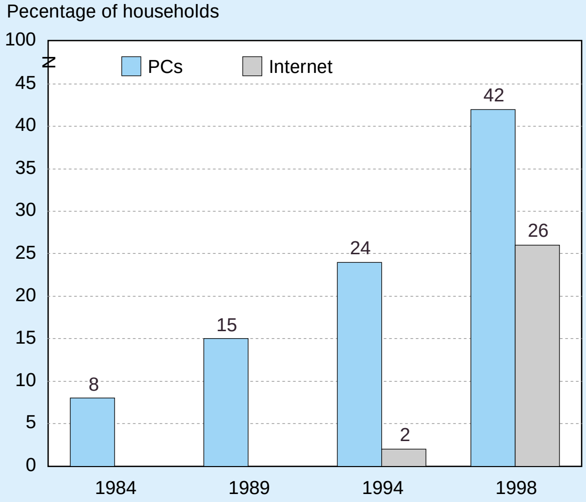
Two distinct eras characterize the diffusion of home computing in the United States. The first era is reflected in the steady growth in home ownership of personal computers throughout the 1980s (PCs were introduced commercially in the late 1970s); the second era is reflected in the accelerating adoption of home PCs and Internet use that began about five years ago. As the cost of home computers dropped to less than $1,000 and as Internet service providers shifted to flat-rate pricing, the rate of home PC diffusion and Internet access began to increase. In 1998, more than 42 percent of American homes had at least one personal computer, and 26 percent of American homes were connected to the Internet (NTIA 1999).

The growing access to home computing has not been evenly distributed, however. People with less than a high school education have less access to computers than people who have completed high school and much less than people who have completed college. (See "Use of Computers and Computer Technology in the United States" in chapter 8, figure 8-19, appendix tables 8-29 and 8-30.) Moreover, the National Telecommunications and Information Administration (NTIA) has repeatedly identified a "digital divide" in the United States, which it defined as a home computing gap between white or affluent Americans and those who are ethnic minorities or poor (NTIA 1995, 1998, 1999). Although disadvantaged groups have substantially increased their home access to computers and the Internet, the gap between these groups and white Americans is growing—at least temporarily.

Trends in PC and Internet Access

Personal computers were commercially introduced in the late 1970s, and home Internet access became widely available to the general public around 1992–93. The earliest reliable data on PCs in the home are from 1984; for Internet access, the earliest data are from 1994.[10] (See figure 9-23.) Rapid growth in home ownership of personal computers has occurred principally since 1994. During the four-year interval from 1994 to 1998, the percentage of households owning a home computer increased by 18 percentage points—double the 9 percentage point increase for the five-year period from 1989 to 1994 and far greater than the 7 percentage point growth from 1984 to 1989. Internet access has expanded phenomenally; the number of households connected to the Internet has grown from 2 percent of all households in 1994 to 26 percent in 1998.

Figure 9-23.
Percentage of U.S. households owning a home computer and percentage of U.S. households with access to the Internet



SOURCES: U.S. Census Bureau, except for 1994 data, which is from Clemente (1998).

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Inequities in Access. The recent rapid growth in home adoption of IT masks considerable disparities in access to IT by income levels, ethnic affiliation, and geographic location. Using data from the Current Population Survey conducted by the Census Bureau, the NTIA found that the "digital divide" is worsening among Americans (NTIA 1995, 1998, 1999). From 1994 to 1998, the gap in PC ownership between white and black or Hispanic households widened, as did the gap between rich and poor. Although ownership of home computers and Internet access increased in all income and ethnic categories during these five years, the disparity in ownership has widened. For example, in 1998, 46.6 percent of white Americans owned a home computer, compared to 23.2 percent of black Americans—a gap that increased by nearly 7 percentage points from 1994 (NTIA 1999). (See figure 9-24.) Notably, PC ownership is greatest for households with residents of Asian/Pacific Island heritage—55 percent of such homes own a PC.

Affluence alone does not account for these differences: Within every income category, blacks lag whites substantially in adopting home computers and linking to the Internet, although the gap is not as large at higher income levels. The NTIA reports that "the role of race or ethnic origin is highlighted when looking at similarly situated families. A white, two-parent household earning less than $35,000 is nearly three times as likely to have Internet access as a comparable black household and nearly four times as likely to have Internet access as a Hispanic household in the same income category" (NTIA 1999). Geographic location has an impact on household PC ownership and Internet access beyond that predicted

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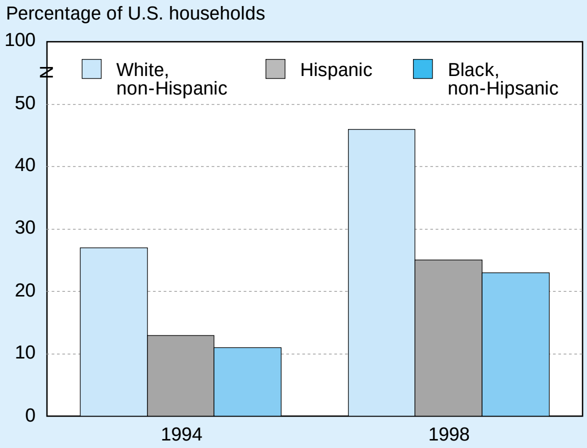
[10] Note that data on Internet access for households do not necessarily reflect constant subscription to the Internet. Households can sign up for the Internet and then drop or even switch Internet service providers (a process known as "churn"). As a consequence, survey data reflect "snapshots" of households connected to the Internet at the point in time at which the survey was administered.

Figure 9-24.
U.S. household ownership of personal computers, by race/ethnicity: 1994 and 1998



SOURCE: NTIA (1999). *Science & Engineering Indicators – 2000*

by income levels; households in rural areas are less likely to own PCs or be connected to the Internet even when income is held constant in statistical analyses (NTIA 1999). Certain groups thus appear to show consistently low levels of home IT access—particularly households that are low-income; persons who are black, Hispanic, or American Indian; less-educated Americans; single-female headed households; and households located in the South, in rural areas, or in central cities.

Determinants of Home IT Adoption. The research literature on technological diffusion shows that there is a distinctive socioeconomic (income, education, occupation) "early adoption" bias by individuals who are affluent, more highly educated, and from higher-status occupations compared to society as a whole.[11] This pattern holds across all kinds of household products, technologies, and innovations, and personal computers and Internet access are no exception.

Research conducted in the 1980s on home PC diffusion found that income and other socioeconomic factors were strong predictors of early PC adoption (Dickerson and Gentry 1983, McQuarrie 1989, Riccobono 1986); in a major review of the literature from 1980–87 on home IT diffusion and impacts, Dutton, Rogers, and Jun (1987) found that level of formal education was the "single variable most consistently associated with the adoption of computing." Research on the new wave of Internet access confirms the same trend in early PC adoption. The NTIA (1995, 1998, 1999) studies discussed above, as well as Clemente's (1998) findings on Internet households, substantiate the significant influence of income, education, and occupation on home Internet use.

Demographic variables do appear to play a role in home IT adoption behaviors. For example, Hoffman and Novak (1998) found complex relationships among home IT access, race, income, and levels of education. In their study, gaps in home IT access emerged for which neither level of income nor education could account. Hoffman and Novak found that differences in levels of home computer ownership between blacks and whites were statistically significant after controlling for level of education. In addition, Hoffman and Novak found that income could not account for extreme disparities between white and black students with respect to computer ownership: 73 percent of white high school and college students owned a home computer, whereas 33 percent of black students owned a home computer. The NTIA studies also identify persistent differences between whites, blacks, and Hispanics that level of income and education cannot explain.

Research suggests that a few other factors are important influences on IT adoption dynamics. Family structure (marital status of head of household, presence of children in the household, age of the head of household), for example, emerged in several studies as a differentiating factor for home PC and/or Internet access (Caron, Giroux, and Douzou 1989; Clemente 1998; Dutton, Rogers, and Jun 1987; NTIA 1998). In general, families with children and married parents are more likely to have personal computers or link to the Internet than single people, couples without children, single heads of household, or households headed by very young adults. (Note that income could be an intervening factor for these latter two family structures.) In addition, individuals with a positive attitude toward technology or computers are more inclined to adopt personal computers (Dickerson and Gentry 1983; Dutton, Rogers, and Jun 1987).

Patterns of Home IT Use

Research and data on patterns of IT usage fall into two distinct categories: research conducted in the mid-1980s on the use of home computers and research conducted in the mid-1990s on Internet use. Thus, there is a substantial gap in our understanding of how computers are used in the home. Not only do the studies on PCs essentially reflect early users—a group of people who are known to be atypical of the general population—but they tend to be studies that, because of their research design, cannot be generalized to the overall population. In addition, the software and user interfaces that we have today were designed primarily by and for white men, leading to more subtle psycho-cultural influences on adoption patterns (CSTB 1997). As a consequence, the findings for PC use should be regarded as suggestive (certainly not definitive): They identify areas of potential research interest and analytical need.

Home Use of PCs. Early adopters of home computers did not necessarily use their machines intensively. For example, Riccobono (1986) found that in a typical week, 40 percent of adults did not use their computer at all. In general, many households found that they were using the PC less than expected, and in Riccobono's national study, 43 percent of adult computer owners indicated that they used their computers much less than they expected at the time of purchase. These find-

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[11] "Early adopters" are individuals who purchase and use new technologies when they are introduced to the marketplace. See Dickerson and Gentry (1983) and McQuarrie (1989) for treatments of the literature on early adopter patterns in households.

ings are consistent with other "underutilization" findings reported in Caron, Giroux, and Douzou (1989); Dutton, Rogers, and Jun (1987); and Giacquinta, Bauer, and Levin (1993).

These patterns of use were variable across family members, however. In the Riccobono study, only 16–20 percent of children in the home ages 6–17 did not use the computer at all in a typical week, compared to 40 percent of the adults. Although 45 percent of the parents were non-users in the Giacquinta, Bauer, and Levin study, only 16 percent of the children were non-users. Fathers tended to dominate use of the computer in the home (Caron, Giroux, and Douzou 1989; Giacquinta, Bauer, and Levin 1993), and females tended to represent a higher proportion of non-users across all age groups (Giacquinta, Bauer, and Levin 1993, Riccobono 1986).

Evidence regarding the dominant content of PC use (for example, word processing, education, games, and so on) is mixed, and the research cannot be systematically summarized because of limited data, vastly different research designs, and different ways of presenting questions to survey respondents. The one theme that consistently emerges is the major role of education in early-adopter PC use; the importance of educational uses of the computer tends to be cited more often and in higher proportions by most studies than any other type of application (Dutton, Rogers, and Jun 1987, OECD 1998). Other salient uses appeared to be games, word processing, and work-related tasks, as well as programming and learning about the computer itself (Caron, Giroux, and Douzou 1989; Dutton, Rogers, and Jun 1987; Giacquinta, Bauer, and Levin 1993; OECD 1998; Riccobono 1985).

Home Use of the Internet. E-mail and World Wide Web (WWW) activity dominate home Internet use; in general, e-mail appears to be the more important activity. Kraut, Mukhopadhyay, et al. (1998) find from computer records that people use e-mail more frequently than the WWW and will use e-mail first in online sessions that include both e-mail and WWW activity. Indeed, people who used e-mail more than the WWW were more likely to continue using the Internet over the course of a year than people making greater use of the Web. Census data indicate that e-mail is used overwhelmingly to communicate with family and friends: More than 90 percent of all users report using e-mail at home for this type of communication, compared to only 33 percent (or less) who report using e-mail for work, hobbies, or educational activities (NTIA 1999).

Use of the Web is both idiosyncratic and generalizeable. For example, Kraut et al. (1996) find that the Web sites visited by family members in their study were unique to the individual. Of the roughly 10,000 unique addresses visited during the study, 55 percent were accessed by only one person, and less than 2 percent were visited by 20 percent or more of the individuals in the sample (these sites tended to be search engines and Web portals).

Usage is nonetheless patterned by broad categories. For example, in terms of general information searches, the American Internet User Survey reveals that health and medicine are the most popular Internet subjects. Thirty-six percent of all users and 47 percent of women report exploring this subject; other major areas of interest include entertainment, music, parenting/children, and lifestyles subjects.[12] NTIA (1999) finds distinctive patterns of Internet use in terms of the purpose for using the Internet at home. In general, individuals with higher income and higher education levels are far more likely to use the Internet for work-related activity, whereas minorities and unemployed individuals are enthusiastic users of the Internet for employment searches and taking educational courses.

Research and Findings on Effects of IT on the Home

Three categories of impact research are addressed here: time displacement studies, the impacts of teleworking on the home, and psychological well-being. The limited research on the impacts of IT shows this technology to be a bit of a mixed blessing: Although IT has the potential to improve the quality of life of the home and the individuals within it, IT also has the potential to be abused or lead to harmful consequences.

Time Displacement Studies. Time displacement studies assess the degree to which the introduction of a new technology in a household affects patterns of time use and allocation. Such studies have been carried out with respect to vacuum cleaners, automobiles, televisions, and microwave ovens, among other technologies. Three time displacement studies have been conducted with respect to home computing. Two focus on the impacts of home computing and the Internet on use of traditional news media (newspapers, TV, radio, books, and magazines); the other explores how individuals reallocate their time once home computers are brought into the household.

Robinson, Barth, and Kohut (1997) analyzed data from the Pew Research Center for the People and the Press on IT in the home. Curious about whether use of the Internet and home computers displaces use of traditional news media, the authors analyzed 1994 and 1995 survey data that reflect when and how often individuals use different kinds of media. Although they found a variety of correlations, few were statistically significant, of meaningful magnitude, or represented a clear pattern that could not be accounted for by socioeconomic factors. In general, however, the authors found that IT use in the home was associated with an increased use of traditional news media, not a decrease. Although they conclude that IT may therefore be media enhancing, home IT users also may be generally more "news seeking" than non-IT users.

Clemente (1998) analyzed data from the American Internet User Survey conducted by Cyber Dialogue and found patterns of media displacement that tend to support the Robinson, Barth, and Kohut findings. Clemente found that about one-third of all Internet user households reported that they watched less TV, although this displacement tended to be slightly higher for recent adopters than those who had been using the Internet

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[12] Data from the American Internet User Survey (<<http://www.cyberdialogue.com/free_data/index.html>>), accessed August 19, 1999.

for a year or more. The number of households that had been using the Internet for more than one year that reported declines in reading of newspapers, books, or magazines and listening to the radio ranged from 10 to 13 percent.

Vitalari, Venkatesh, and Gronhaug (1985) cast a broader eye on the time allocation impacts of home computing. In a study of 282 members of computer clubs in Orange County, California, the authors assessed the impact of computing on 10 household activities: watching TV, reading, leisure time spent with family, leisure time spent with friends, outdoor recreation, sports, hobbies, sleeping, time spent alone, and studying/doing homework. Notably, 96 percent of the respondents were men; this gender bias, as well as other factors (the majority of respondents had previous experience with computers and worked in technical professions) make this a particularly nonrepresentative group of respondents.[13] Nonetheless, the authors detected major time reallocation patterns; major shifts (e.g., more than 20 percent of the respondents reported the change) were detected with respect to decreased television watching, outdoor recreation, hobbies and sleeping, and major increases in time spent alone and studying were observed. (Note that these latter two activities are not mutually exclusive.) The greatest shifts in time allocation patterns were reported in families with children—suggesting that such households are particularly sensitive to the introduction and presence of a computer.

IT, Work, and the Home. Teleworking has long been hailed as one of the major social benefits of IT. By enabling individuals to stay home and work—whether by telecommuting to a parent office or establishing a home-based business—the relocation of work to the home is believed to offer multiple advantages to individuals and families. Flexible work hours, lower household costs, less stress from family—work conflicts, reduced commuting times, and so on are believed to be important payoffs to computer-based work at home.

The vast majority of research on teleworking addresses the economic benefits of these arrangements to parent companies. Traditional research on the impacts of telework focuses on such factors such as productivity, job satisfaction, work attitudes, job stress, overwork, and employee turnover. Little research has been conducted on teleworking in which the impact on home and family life are the focus. Habib and Cornford (1996) reviewed the research related to telework impacts on the home and identified key areas of concern: the effect on rules, norms, and roles in the household; the blurring of spatial boundaries between home and office; and the disruption of time patterns in family routines. Gurstein's (1991) research on 45 home workers echoes these concerns. Her research indicates that IT home workers express guilt over neglecting their families, discomfort with the loss of their home as a "refuge" from work, and a sense of isolation and being devalued by their office colleagues. Gurstein wonders exactly what flexibility advantages are created by telework and concludes that home-based computer work "results in role conflicts, inadequate workspaces, the blurring of the work/leisure time division, and the tendency for 'overwork' to occur" (Gurstein 1991, 177).

In contrast, Riley and McCloskey (1996) found that limited use of teleworking arrangements may have positive home impacts. Reporting on a pilot program in which GTE Corporation allowed managerial employees to work at home one day a week for six months, the authors found that "of the 120 participants in the telecommuting pilot study, 75 percent reported increased feelings of satisfaction with their home life, [and] 44 percent reported having more quality time with the family" (Riley and McCloskey 1996, 87).

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[13] In addition, because this study was most likely conducted in 1984, respondents are also "early adopters" of home computers. As others have shown (e.g., Dutton, Rogers, and Jun 1987), early adopters of home computers are atypical of the general population in a variety of ways.

IT and Disabilities

Information technologies have the potential to improve the lives of people with disabilities. IT can make work 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.

Information technologies do not automatically provide benefits to the disabled, however. Unless they are designed carefully, they can create new barriers. Web sites, for example, frequently convey information in a visual form that is inaccessible for people who are visually impaired.

The World Wide Web Consortium, a standards-setting organization for the World Wide Web, has developed guidelines to make Web sites more accessible (<<http://www.w3.org/TR/WAI-WEBCONTENT/>>). Among the guidelines are the following:

- There should be text equivalents for all nontext elements, including images, animations, audio, and video.
- There should be text summaries of graphs and charts.
- All information conveyed with color should also be available without color.
- The clearest and simplest language appropriate for a site's content should be used.

The Center for Applied Special Technology (<<http://www.cast.org>>) provides a free Web-based tool to analyze Web pages for their degree of accessibility to people with disabilities. Within the U.S. government, the Center for IT Accommodation (CITA; <<http://www.itpolicy.gsa.gov/cita/>>) in the General Services Administration's Office of Procurement Policy works to improve the accessibility of information technology.

These telework studies generally predate widespread access to the World Wide Web and major changes in distributed work arrangements in the private sector. As a consequence, they may not reflect the variety of household impacts that come from less insulated and "closed" work systems. Nonetheless, these studies are suggestive of a common theme in the theoretical and philosophical literature on IT—namely, the omnipresent duality of IT impacts. On one hand, teleworking can enhance people's ability to better balance work and family needs and reduce personal stress. On the other hand, home-based IT work can disrupt crucial family dynamics (roles, interpersonal relationships, and the sense of home as sanctuary) and create psychological isolation and low self-esteem. The extremely limited research described here suggests that there may be threshold effects associated with telework: The degree and intensity of telework's presence in the home may be damaging rather than telework per se.

Psychological Well-Being. As with so many other potential impacts of IT in the home, the influence of computing on the psychological well-being of individuals can be beneficial or harmful. Greater connectedness to a community, ease of communication with family and friends, and improved access to information can enhance self worth, feelings of satisfaction, a sense of community and kinship, and personal empowerment. Scholars express equal concern, however, for the dark side of computing: isolation; growing social insularity; and increasingly, "Internet addiction." A body of psycho-behavioral work exists with respect to computer-human interactions and computer-mediated communication; three empirical studies stand out, however, with respect to the psycho-behavioral impacts of Internet use. These studies relate to Internet addiction, social integration, and loneliness and depression.

Although the existence of Internet addiction as a clinical disorder remains in dispute, some professionals unequivocally assert that it is a real phenomenon.[14] Egger and Rauterberg (1996) explored whether heavy use of the Internet reflects addictive behavior; data were obtained from an online survey posted and advertised on the World Wide Web. Roughly 450 valid survey responses were received, largely from Swiss and American respondents.[15] Although the findings of the survey cannot be generalized outside the sample, the key findings are suggestive for future research. First, 10 percent of respondents perceived themselves as addicted to or dependent on the Internet, and objective measures of addiction, on the whole, were statistically significant for this group. Second, this small group of "Internet addicts" represented all walks of life. There were no statistically significant demographic differences between people who were considered Internet addicts and those who were not—this group was not differentiable by gender, age, nationality, or living situation.

Concerns that Internet users may be socially withdrawn from their communities are not substantiated in research reported by Katz and Aspden (1997). They found that after controlling for demographic differences between groups (age, gender, education, race, and income), there were no statistically significant differences in the degree to which Internet users were members of religious, leisure, or community organizations compared to non-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 spent with family and friends on the phone or through face-to-face contact. Interestingly, the data indicate that long-term Internet users belong to more community organizations than any other group (non-users, former users, and so forth).

In contrast, Kraut, Lundmark, et al. (1998) found evidence that greater use of the Internet was associated not only with increased social disconnectedness but with loneliness and depression as well. Using data from the HomeNet study, the authors found that greater use of the Internet was associated with "small but statistically significant declines" in social integration as reflected by family communication and the size of the individual's social network, self-reported loneliness, and increased depression. These correlations held even after the authors controlled for initial states of loneliness, social involvement, Internet use, depression, stress, and so forth. Although the authors' claim that their methods and findings indicate a causal relationship between increased Internet usage, declining social involvement, and worsening psychological states is an overstatement, the findings nonetheless show important statistical associations.[16]

IT at Home: Summary

Twenty years after the advent of the personal computer, we have a relatively clear picture of who has access to home computers and, more recently, the Internet. Patterns of IT diffusion and adoption clearly suggest that IT is still a resource acquired to a greater extent by more affluent and well-educated Americans. Although PCs have been diffusing rapidly in recent years, they have yet to make substantial inroads into poor and minority households, and research on PC and Internet adoption behaviors indicates that socioeconomic and demographic factors continue to be the primary predictors of home IT access. Very simply, income allows families to hurdle affordability barriers to adoption, and well-educated individuals are more likely to be aware of and appreciate the ways IT can be used in the home.

The picture is less clear with respect to usage patterns. The early adoption research suggests that the primary uses of home computing are for education, play, work, and basic word processing; findings generally suggest that children tend to use home PCs more often and for longer periods than adults. Sizeable proportions of early adopters found that they used the computer less than they initially expected.

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[14] See, for example, Kimberly S. Young, *Caught in the Net* (NY: John Wiley and Sons, 1998).

[15] The authors were from Switzerland, so most of the respondents were Swiss. The survey was posted in English and German, however.

[16] The models do not account for environmental conditions known to trigger social withdrawal and depression (such as loss of a job or marital conflict). Thus, they do not allow for intervening environmental variables or the possibility that greater Internet use could be a consequence of depression, loneliness, and social withdrawal caused by other factors.

Recent research on Internet use reinforces some of the impressions generated by the early computing studies: Children and male teenagers still tend to be the heaviest users of IT. The Internet has made a new form of interpersonal communication available to households, and several analyses suggest that e-mail and personal communication drive Internet use by individuals and households. Specific informational content derived from the World Wide Web is unique to each individual's interests and needs, although broad patterns of information use are emerging. Americans most often seek information related to health and leisure; affluent and educated individuals also use the Internet for work, whereas socioeconomically disadvantaged groups use the Internet to seek jobs and to take classes.

What we do not know about impacts is substantial. How do families and individuals use information gained from the World Wide Web, and with what consequence? What are the outcomes of the growing role of e-mail in some families' lives? Are families with e-mail any better off than families without e-mail? How does the presence of home computing affect family dynamics and relationships? Does it diminish or enhance quality of life, and under what circumstances? Are there pathologies associated with extensive Internet use? How does computer-based work at home affect the nature of the home itself?

Least understood is whether the socioeconomic inequities that exist in access to home information technologies matter, and how. The implicit assumption is that the absence of IT in the home perpetuates social and economic disadvantages. Childers (1975) creates a vivid portrait of how minorities, the underclass, and other groups in the United States tend to have fewer lines of access to information and less effective information networks than the rest of society. On the other hand, if the effects of computers on the home are mixed, the lack of home computers may not be as critical.

Information Technology, Government, and Citizens

Like businesses, government agencies have used IT in management information systems and in research for decades. With the advent of the Internet and especially the World Wide Web, however, IT has become a major means of communicating with citizens and stakeholders.

IT influences government in a variety of ways. The Internet is a very effective way to disseminate government-related information. Government agencies are placing information about their policies and programs, as well as information that they have developed or supported, on the Web. Examples of U.S. government information resources include STAT-USA (<<http://www.stat-usa.gov>>)—a service of the U.S. Department of Commerce that provides business, economic and trade related Federal Government information—and NSF's science statistics (<<http://www.nsf.gov/sbe/srs/stats.htm>>), including this volume. The National Technical Information Service (NTIS), which has been the distribution channel for government-sponsored technical reports, recently decided to close because agencies are offering their publications directly to the public over the Internet (for no charge). States and local governments are also using the Web to make information readily available to the public.

The Internet is also affecting political processes in the U.S. and around the world. Political candidates are establishing Web sites to communicate with voters, solicit funds, and organize volunteers. Interest groups are using e-mail and Web sites 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 the Congress on a timely issue. Other groups are experimenting with Internet voting. For example, the U.S. military is exploring using the Internet to provide a new mode of absentee voting for its overseas personnel.

Overseas, the Internet is providing a way around government controls on information. If a country allows its citizens to have access to the Internet, it is very difficult to prevent them from using it to gain access to information. For example, although China controls Internet service providers and blocks access to many Web sites, overseas Chinese send news via e-mail to large numbers of e-mail addresses, obtained from public lists, in China (Plafker 1998). The people who receive the e-mail can honestly tell authorities that they did not request the information.

As in the United States, governments around the world are using the World Wide Web to communicate with their constituencies. The Cyberspace Policy Research Group at the University of Arizona analyzes worldwide government use of the Web. Group members scan the Web for new agency sites, record the URLs, and analyze Web operations according to indices of transparency, interactivity, and openness. (See figure 9-25.)

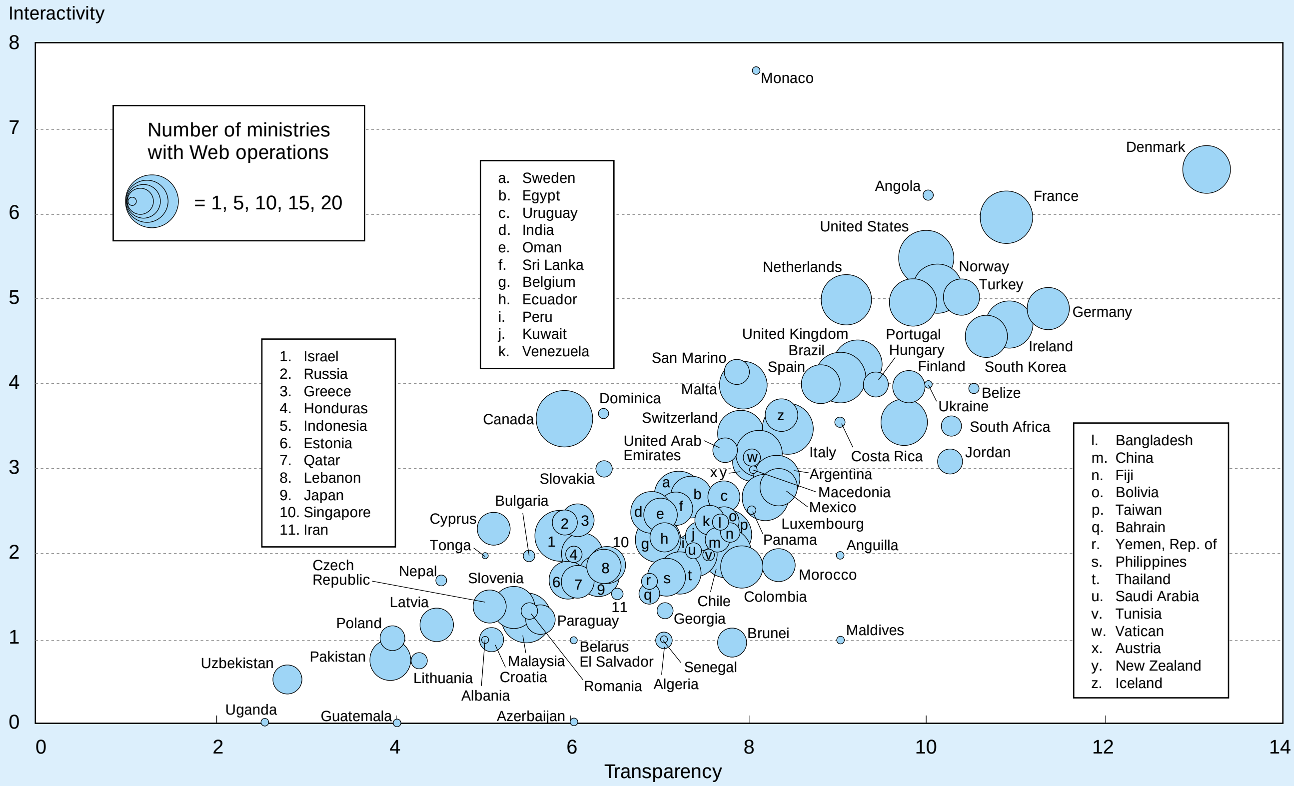
The transparency index measures the information an agency provides about itself and is based on measures of:

- ♦ how involved the agency is with the site;
- ♦ how easily the Web site visitor can contact people in the organization;
- ♦ how well information is provided about an organization's operations and relationships with other organizations;
- ♦ the extent to which the Web site helps citizens comply with regulations or take advantage of government programs, such as by making forms available; and
- ♦ how current an agency's information is.

The interactivity index measures the convenience with which information can be accessed. If information is theoretically available but practically difficult to obtain, the organization scores poorly on interactivity.

The size of each bubble in figure 9-25 indicates the number of top-level government agencies with Web sites for that country. The vertical axis shows the country's rating on interactivity, and the horizontal axis shows its rating on transparency. Countries in the upper right quadrants can be consid-

Figure 9-25.
Openness and its components: transparency, interactivity, and number of ministries



See appendix table 9-9.

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ered to use the Web to enhance the openness of government to a greater extent than countries in the lower left quadrant. A large number of national governments use the Web extensively. Almost 40 countries had Web sites for 70 percent or more of their agencies in 1998, and 17 countries had Web sites for all of their top-level agencies. (See appendix table 9-9.) There is also substantial variation in the measured transparency and interactivity of the countries, suggesting that countries vary in the extent to which they are currently taking advantage of the Web to interact with their citizens.

Conclusion

IT is having substantial effects on many domains of society, including the economy, education, research, and the home. In most areas, however, the effects of IT—and the choices that can be made to influence the effects—are not well understood. Moreover, significant new technologies are changing the nature of the effects as they are being researched. There is a large agenda for future research.

NSF sponsored a National Research Council (NRC) study of research needed on the economic and social effects of IT (CSTB 1998). Although the NRC panel did not attempt to provide a comprehensive research agenda, it highlighted an illustrative set of promising areas for research:

- **Interdisciplinary studies of information indicators.** Interdisciplinary study could help to identify and define a set of broadly accepted measures of access to, and the use and effect of, information and IT. (See sidebar, "Potential Information Technology Indices.")
- **Effects of IT on labor market structure.** To facilitate informed decisions on issues such as how to respond to increasing wage inequality, it is important to understand how and to what extent the use of computers might affect wage distribution.
- **IT, productivity, and its relationship to work practices and organizational structures.** Much evidence suggests that IT's effect on productivity depends on how it is used in organizations. Compilation of work that has already been done in this area is needed. Continued research also could illuminate how to better quantify the economic inputs and outputs associated with use of computers.
- **Intellectual property issues.** Policymakers considering revisions to intellectual property law or international agreements, as well as firms evaluating possible approaches to protecting intellectual property, would benefit from continued theoretical and empirical research.

- **Social issues addressed at the protocol level.** Widespread use of the Internet has far-reaching effects on intellectual property rights, privacy protection, and data filtering. Exploring how these concerns might be addressed at the protocol level—through policies, rules, and conventions for the exchange and use of information—could be a promising approach to addressing issues arising from the use of new computer and communications technology. Examples include the Platform for Internet Content Selection (PICS)—which implements a set of protocols for rating Web sites—and P3P, a project for specifying privacy practices.

The NRC panel also identified ways to improve the data needed to study the economic and social effects of IT, such as making data related to the social and economic effects of computing and communications available to the research community through a clearinghouse; exploring ways for researchers to obtain access to private-sector data; and establishing stronger ties with industry associations to facilitate collaborative research.

Potential Information Technology Indices

Interconnectivity index. This index would provide a measure of the facility of electronic communication and an evaluation of the development of this dimension of the information infrastructure.

Information quality of life index. Similar to an index produced by OECD, this index would attempt to evaluate the qualitative levels of communication available to individuals.

Leading information indicators. This index would attempt to predict the growth of the information infrastructure.

Home media index. This index of the state of penetration of communications technologies in the home might qualify as a leading index of the potential for future consumption of information.

Marginalization index. This index would measure the extent to which specific populations are excluded from participation in the information infrastructure.

SOURCE: CSTB (1998).

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Appendix B
Index

Table numbers in **boldface** refer to appendix tables contained in Volume 2 and available in both PDF and Excel formats on the attached CD-ROM (e.g., **AT2.58** is table 2-58 in Volume 2). Page numbers not in boldface refer to pages in Volume 1 and, when followed by an *italicized f* or *t*, refer to pages on which a figure or text table, respectively, appears in Volume 1.