CHAPTER TWO

THE CONTEXT FOR INTERNATIONAL S&E ACTIVITIES

INCREASING GLOBALIZATION

The contributions of science and engineering research and education will continue to be key determinants of economic growth, quality of life, and the health and security of our planet in the 21st century. The environment in which these activities occur is becoming more global. Globalization—the worldwide integration of nations through trade, capital flows, diffusion of information, movements of people, and operational linkages among firms and other organizations—has been a key feature of the latter part of the 20th century and will become even more important during the 21st. Advances in transportation, information, and communication technologies have diminished the importance of international boundaries. Events in one country can now have major—sometimes instantaneous—effects in countries geographically far removed.

Both the volume of information and its rate of diffusion are expanding rapidly throughout the world. Flows of people, goods, services, and ideas are transcending national borders on an unprecedented scale. In the late 1990s, the ratio of U.S. trade (exports plus imports) to Gross National Product (GNP) approached 25 percent, its highest point in at least a century.[7] During the same time period, capital flows into and out of the United States peaked as a percent of U.S. GNP—the former at 8 percent, the latter around 5 percent.[8] This phenomenon is not occurring only in the United States. In 1999, foreign direct investment flows both in and out of Organization for Economic Cooperation and Development (OECD) countries reached record levels: more than 2.5 percent of their combined Gross Domestic Product (GDP) for inflows and 3.0 percent for outflows.[9] The ratios of world trade to world GDP increased from 25 percent in 1960 to its high of 45 percent in 1997. This indicator of increasing globalization grew even more rapidly in low-income countries, rising more than three-fold, from 14 percent to 43 percent during the same period.[10]

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[7] U.S. Council of Economic Advisers, *Annual Report of the Council of Economic Advisers, 2000*. p. 202, chart 6-2.
[8] *Annual Report of the Council of Economic Advisers, 2000*. p. 206, chart 6-4.
[9] U.S. Council of Economic Advisers, *Annual Report of the Council of Economic Advisers, 2001*. p. 151, box 4-1.
[10] The World Bank, World Development Indicators Data Base 2000.

The conduct of business is increasingly international, with firms establishing foreign subsidiaries, conducting research abroad, outsourcing production, and participating in international joint ventures or other types of international business arrangements. The role of the multinational company (MNC) has expanded. Worldwide, some 60,000 parent operations of MNCs and their 500,000 foreign affiliates account for roughly 25 percent of global output, one-third of it in host countries.[11] Dramatic advances in science and technology have both contributed to and arisen from this increasing integration of the global economy.

GROWING SIGNIFICANCE OF SCIENCE AND ENGINEERING IN THE GLOBAL CONTEXT

The scientific and engineering enterprise is itself increasingly global. The conduct of S&E research has become more international both through formal agreements and through more informal collaboration between individual researchers or groups of researchers. International boundaries have become considerably less important in structuring the conduct of research and development (R&D).[12]

"By its very nature, the science and engineering enterprise is global, often requiring access to geographically specific materials and phenomena and to dispersed expertise. It also requires the open and timely communication, sharing, and validation of findings. Certain issues and disciplines, for example, climate change and biocomplexity, are global in their very definition, and the proliferation of large, complex, and expensive projects and facilities has required participation and support from many nations."
NSB Strategic Plan, 1998

The proliferation of complex and expensive projects requiring large facilities and specialized instrumentation requires partnering among many nations to make the total cost affordable for those participating. Researchers' requirements for geographically specific materials and facilities transcend national boundaries. In addition, many research problems, both disciplinary and multidisciplinary, require scientists and engineers in different countries to work together. The global dimensions of the conduct of scientific activity are reflected in the patterns of citations to the literature. Internationally, close to 61 percent of all citations in 1999 were to foreign research, compared to 53 percent nine years earlier. These increases could be seen for most countries and most fields.[13] This growing globalization not only increases the international conduct of science but also advances the scientific process by providing opportunities for more open and timely communication, sharing, and validation of research findings.

Research collaboration internationally is on the rise in the industrial sector as well with a rising number of formal cooperative arrangements or alliances between firms, the growth of overseas R&D by way of both contracts and subsidiaries, and an increase in the number of industrial R&D laboratories abroad. The response to competitive factors has led to changing forms of cooperative activities. Most of the interregional alliances between firms sharing research and technology have been in two emerging areas—information technology and biotechnology.[14] A rising proportion of industrial R&D funding is also being

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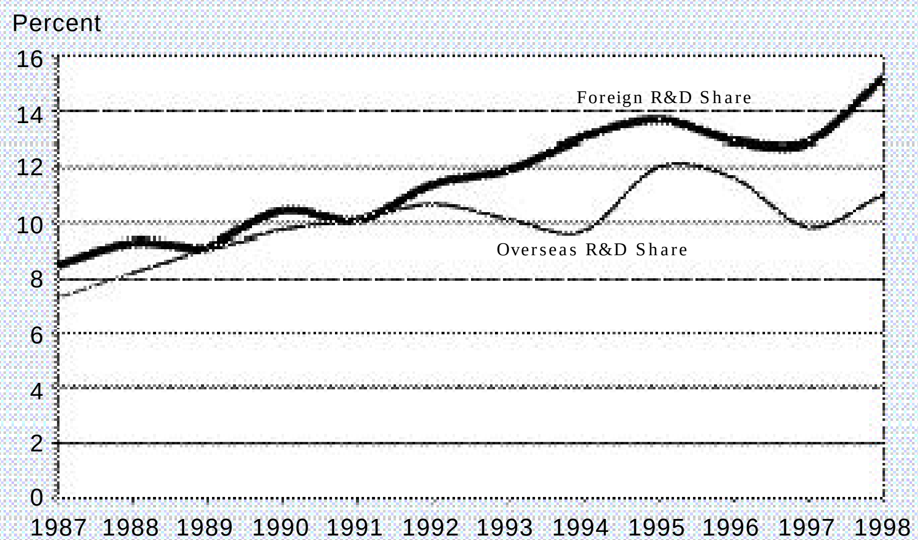
[11] *Annual Report of the Council of Economic Advisers, 2000*. p. 207, box 6-1.
[12] National Science Board, *Science & Engineering Indicators 2000 (S&EI 2000)*, p. 2-54.
[13] National Science Board, *Science & Engineering Indicators 2002 (S&EI 2002)*, figure 5-44.
[14] *S&EI 2000*, pp. 2-56, 2-57 and *S&EI 2002*, p. 4-39.

provided by foreign sources in a number of countries, reflecting increasing globalization of industrial R&D activities.[15] In fact, in 1998, foreign R&D spending in the United States as a proportion of company-funded industrial R&D in the United States reached a record 15 percent.[16] (See Figure 1.)

FIGURE 1. U.S. INDUSTRIAL R&D HAS BECOME MORE GLOBALIZED AS THE RATIO OF FOREIGN AND OVERSEAS R&D SPENDING TO COMPANY-FUNDED INDUSTRIAL R&D IN THE UNITED STATES HAS INCREASED DURING THE PAST DECADE.



NOTES: Foreign R&D refers to R&D performed in the United States by U.S. affiliates of foreign parent companies. Overseas R&D refers to R&D performed abroad by foreign affiliates of U.S. parent companies.

DATA SOURCE: Science & Engineering Indicators 2002.

In addition to benefiting scientists and engineers, international S&E collaboration and partnerships are increasingly viewed as ways to open and expand markets and increase opportunities for economic exchange internationally. Scientific and technological advances have not only improved the channels for expanded markets, they have also stimulated the growth of high-technology industries. These industries have generally been more successful exporters than other more traditional industries, not only in the United States and other industrial countries but also in newly industrialized economies, especially within Asia.

SHIFTING WORLD S&E CAPABILITIES

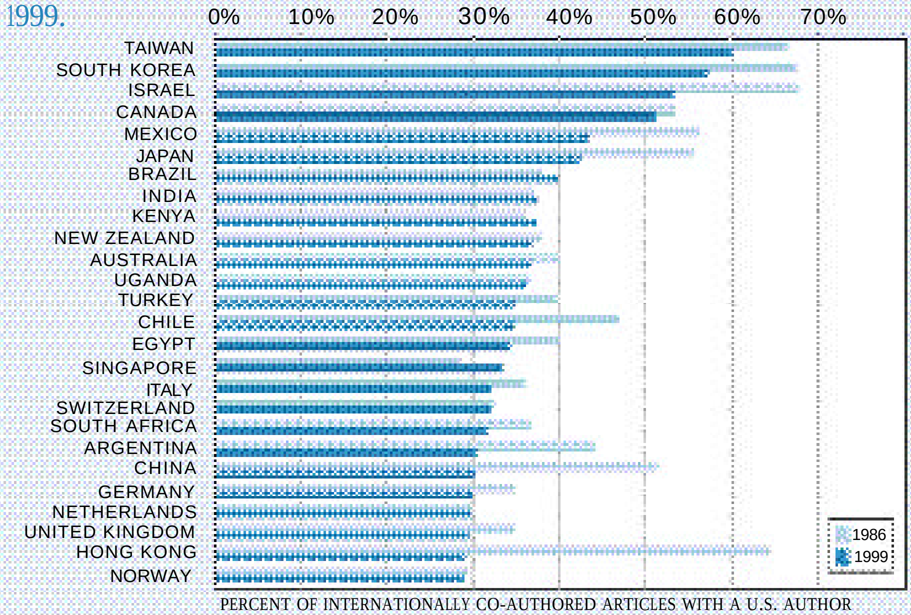
As opportunities for participation in international S&E partnerships increase, so does the urgency of taking advantage of them. Excellent science is no longer the domain of a small group of industrialized countries. In many OECD coun-

"The Internationalization of basic science and technology (S&T) activities, assets, and capabilities is accelerating, and current U.S. advantages in many critical fields are shrinking and may be eclipsed in the years ahead."
U.S. Commission on National Security/21st Century, Feb. 2001

[15] *S&EI 2002*, figure 4-35.
[16] *S&EI 2000*, p. 2-59 and figure 2-37.

tries the share of basic research in overall R&D is similar to the share in the United States, as is R&D as a percentage of GDP.[17] Other countries, including a number of newly industrializing economies are also beginning to spend percentages of their GDP on R&D similar to those of the OECD countries.[18] The balance of S&E expertise among countries is shifting, and new ideas and discoveries are emerging from all over the world. The U.S. share of internationally co-authored articles in other countries is declining overall and for most countries, indicating that new centers of activity and patterns of S&E collaboration are evolving.[19] (See Figure 2.)

Figure 2. The Percentage of Internationally Co-Authored Articles Involving One or More U.S. Authors has Declined for Many Contries/Economies Between 1986 and 1999.



NOTE: Countries/economies ranked by share in 1999.
DATA SOURCE: Science and Engineering Indicators 2002.

The development or strengthening of national scientific capabilities in several world regions is also indicated by continuation of a long-term decline in the U.S. share of total scientific publications. During the 1986-1999 period, the number of U.S. articles declined by 10 percent from its high earlier in the decade, while those of Western Europe and Asia rose by 30 and 80 percent, respectively.[20] Another indicator of the worldwide expansion in advanced S&E capabilities—particularly evident in Europe, Asia, and the Americas—is the expansion of S&E doctoral programs and graduate education reform to improve the quality of research and build national innovation capacity.[21] The importance of foreign science and technology to the United States is also shown by the fact that foreign-origin patents represent nearly half (45% in 1999) of all patents granted in the United States.[22]

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[17] *S&EI 2000*, figures 2-30 and 2-33 and *S&EI 2002*, p. 4-45.
[18] *S&EI 2000*, text table 2-14 and *S&EI 2002*, text table 4-13.
[19] *S&EI 2000*, pp. 6-49, 6-50 and *S&E I 2002*, text table 5-19.
[20] *S&EI 2002*, figure 5-32.
[21] *S&EI 2000*, p. 4-16 and *S&EI 2002*, p. 2-41.
[22] *S&EI 2000*, p. 7-21 and *S&EI 2002*, p. 6-21.

Collaborative activities and international partnerships are an increasingly important means of keeping abreast of important new insights and discoveries critical to maintaining the U.S. leadership position in key fields and contributing to U.S. economic growth. While the main emphasis in the U. S. Government's support of R&D is on health, defense, and medical sciences, other countries emphasize different activities. In Japan, for example, the emphasis is on energy related activities.[23] There are also differences in emphasis in the S&E literature across countries. Some emphasize the life sciences, others the physical sciences, engineering, and technology.[24] This differential emphasis across countries indicates that the U.S. S&E community can benefit by expanding its scientific knowledge base through international collaboration not only in fields where it plays a more dominant role, but also in fields where it is less dominant.

INTERNATIONAL EDUCATION AND MOBILITY OF SCIENTISTS AND ENGINEERS

The realization of the importance of science and engineering to quality of life and economic growth and the recognition that people are the main agents of knowledge transfer have led many countries to strengthen their higher education systems, particularly in S&E fields, to improve their S&E enterprises and meet the needs of the 21st century workforce. Recognition of the importance of a skilled workforce for economic growth has also led to international competition for workers and the evolution of a global and highly mobile S&E workforce. The continued international mobility of the S&E workforce relies on a policy of openness that, within a framework of appropriate national security considerations, encourages the free circulation of scientists and engineers across national borders. The U.S. science and engineering enterprise benefits from such international exchange and from the contributions of foreign-born scientists and engineers who migrate to the United States and work in our universities and research laboratories.[25]

"As the intrinsic nature of science is universal, its success depends on cooperation, interaction, and exchange, often beyond national boundaries. Therefore, ICSU strongly supports the principle that scientists must have free access to each other and to scientific data and information. It is only through such access that international scientific cooperation flourishes and science thus progresses."
from ICSU Statement on Freedom in the Conduct of Science (1995) in 2000 report

One indicator of mobility of S&E personnel in the world is the proportion of foreign born faculty in U.S. higher education. Of the 225,000 S&E faculty teaching in four-year institutions in 1997, 45,000 were foreign born.[26] Many firms have R&D sites outside their own countries that are often established to tap knowledge and skilled labor from competitors and universities around the globe, including direct employment of local talent.[27]

Many industrial countries attract a large number of foreign students to their universities. The United States, the United Kingdom (U.K.), Japan, and France all have a high percentage of foreign students in their doctoral S&E

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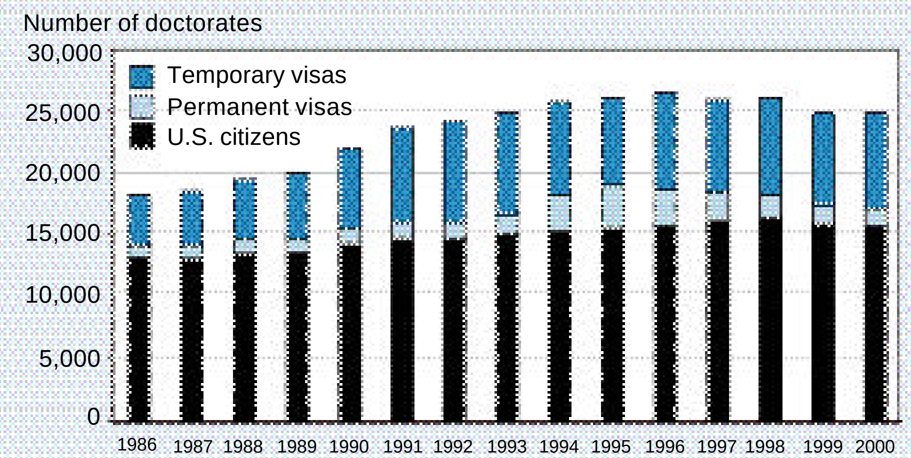
[23] *S&EI 2000*, p. 2-51.
[24] *S&EI 2000*, p. 6-47.
[25] National Science Board, "Statement on Open Communication and Access in Science and Engineering," May 4, 2000.
[26] *S&EI 2000*, p. 4-37 and text table 4-11.
[27] *S&EI 2000*, pp. 2-58, 2-59.

"In recent years, as scientific and technological research in other countries has increased, our nation's academic dominance has eroded in a growing number of fields. The likelihood that the quality of both research and instruction at colleges, universities, and research centers in Europe, Asia, and elsewhere will continue to improve reflects a central reality of our time: education and human capital have become the determinants of national power and well-being."
John A. Marcum, *Chronicle of Higher Education*, May 2001

programs. During the late 1990s, foreign students earned 44 percent of the doctoral engineering degrees in the U.K., 43 percent in Japan, 30 percent in France, and 49 percent in the U.S. Foreign students earned more than 31 percent of mathematics and computer science Ph.D.s in France, 38 percent in the U.K. and 47 percent in the U.S.[28] (See figure 3 for U.S. distribution of S&E Ph.D.s by citizenship.)

FIGURE 3. BETWEEN 1986 AND 2000, 30 TO 40 PERCENT OF U.S. DOCTORAL S&E DEGREES WERE EARNED BY FOREIGN CITIZENS.



DATA SOURCE: Science & Engineering Indicators 2002.

Many of the foreign students educated in these countries remain and many others go home. For example, about 53 percent of the foreign students who earned U.S. S&E doctorates in 1992 and 1993 were working in the United States in 1997. The stay rates were higher in the physical and life sciences and in engineering and lower in the social sciences. However, the stay rates tend to differ more by country of origin than by discipline. A much larger percentage of engineering doctoral recipients from India and China than from Korea were working in the United States in 1997.[29] The growth of increased opportunities in home countries, including the expansion of higher education in many developing countries, is likely to increase the number returning.

A number of countries are also making concerted efforts to encourage the return of their best and brightest scientists and engineers.[30] For instance, in the 1990s, the number of doctoral recipients from South Korea and Taiwan reporting plans to stay in the United States declined as these countries increased their capacities to absorb the majority of U.S.-trained doctoral scientists and engineers.[31] Their return is contributing to a rise in their countries' education and research capabilities in addition to providing both an opportunity and a rationale for continued international collaboration with U.S. scientists and engineers.

[28] Data for Japan are from 1997, for France from 1998, and for the United Kingdom and United States from 1999. *S&EI 2000*, pp. 4-33, 4-34, and text table 4-10 and *S&EI 2002*, figure 2-34.
[29] *S&EI 2000*, pp. 4-35, 4-36.
[30] James Glanz. "Trolling for Brains in International Waters." *The New York Times*, April 1, 2001. Geoffrey Maslin. "Australia Invites Leading Academics to Apply for Generous New Fellowships." *The Chronicle of Higher Education*. V47, Issue 34. May 2, 2001.
[31] *S&EI 2000*, pp. 4-34, 4-35.

21ST CENTURY PROBLEMS NEEDING GLOBAL S&E SOLUTIONS

For a growing array of issues that are global in nature, science and engineering are key to dealing with them effectively. These issues include climate change, genetically modified organisms, energy conservation and utilization, infectious diseases, disaster prevention and management, national security, population growth, immigration policy, sustainable development, intellectual property rights, and open exchanges of scientific information.

- Disagreements exist over the extent and significance of global warming and the costs and benefits of measures proposed to reduce it. Since the impacts of climate change are not limited to any one country or region, any effort to deal with it will have to be internationally coordinated. To be successful, it will also necessitate at least general agreement on the science underlying the various positions and the active participation of scientists and engineers familiar with the various and complex aspects of the issue.

- The safety of genetically modified organisms is another issue about which there is a great deal of controversy. There has been considerable international pressure for establishment of a biosafety protocol that regulates such organisms. However, there is disagreement about what requirements should go into such a protocol. Although safety is not the only factor being considered, an international scientific consensus on the safety of such organisms might contribute to more effective international negotiations on this issue.

- Protecting human health and reducing the spread of infectious diseases such as AIDS, tuberculosis, cholera, and ebola also require a concerted international effort and advances in science and engineering. The risks of both catching and dying from infectious diseases are especially high in many of the developing countries where extreme poverty and associated conditions are conducive to the rapid spread of such diseases. The increasing movement of people across national boundaries also makes it increasingly difficult to limit the spread of such diseases. Improved information and tracking systems as well as cooperative research efforts directed at understanding the biological mechanisms and epidemiological aspects of disease are needed to combat the spread of these diseases by facilitating more effective prevention and treatment.

- A concerted international effort is also needed to increase countries' preparedness for natural disasters. Natural disasters extract a heavy toll on both lives and property, with extensive human and financial losses. The increasing concentration of population in areas that are prone to such disasters magnifies the impacts of such events. International science and engineering cooperation can lead to both better predictive capabilities and strategies to reduce the impact of these disasters.

Most of these and other complex and systemic biological, economic, political, and ecological problems of the 21st century will demand more information, more participation by the scientific and engineering communities of all nations, and

"Issues like export control, nuclear safety and non proliferation, fuel and energy resources, infectious diseases, adequate and safe food and water supply, global warming, migration, drug trafficking, intellectual property rights — all these and more define the new, 21st Century international security environment. Our perception of what national security means needs to change, and our funding needs to change to reflect these concerns."
Senator Jeff Bingamon (March 2001)

"Intrinsic to science are two attributes integral to successful scientific efforts in this area [interacting with governments in mitigating conflicts]:
■ First, science is by nature international in its scope and its activities. Further, international cooperation has been normal in the scientific enterprise. Scientists maintain a transnational dialogue among themselves, exchanging information and ideas and reaching for consensus on various topics. The permanent intellectual communication framework used by scientists for mutual cooperation within science can also be useful for contact and cooperation between scientists on other matters of conflict.
■ Second, 'scientific culture' includes a group of shared attributes that can prove helpful when dealing with conflict situations. The culture includes a common language and a belief in the universality of truth. Other shared attributes are an 'organized skepticism' that expresses itself in a

suspension of judgment and the detached scrutiny of beliefs in terms of empirical and logical criteria. These shared attributes, combined with a rational approach to problem solving even amidst emotional conflicts, help scientists play an important, a possibly unique, role in mitigating international conflict."
Alexander Keynan
The Scientist, March 1999.

"The rapid rise in international cooperation has spawned activities that now account for 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. 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."
NSB *Science & Engineering Indicators 2000*

more cooperation between these communities and political decision-makers. These issues will not only affect U.S. national security but could also affect future global security. Increased international collaboration in S&E research and education will itself help expand the knowledge base for scientific consensus and will thus improve the international policy deliberations in many areas.

International S&E cooperation also helps build more stable relations among countries, communities, and individuals by creating a universal language and culture based on commonly accepted values of objectivity, sharing, integrity, and free inquiry. Acceptance of such values is critical to the resolution of many problems and issues being addressed in the international arena.

U.S. Governmental Collaborations in International S&E Research and Education

U.S. governmental collaboration in international S&E related activities is a growing phenomenon. A 1999 General Accounting Office (GAO) report shows that seven agencies—the Department of Energy (DOE), the National Aeronautics and Space Administration (NASA), the National Institutes of Health (NIH), the National Institutes of Standards and Technology (NIST), the National Oceanic and Atmospheric Administration (NOAA), NSF, and the Department of State—participated in 381 bilateral agreements between research agencies and their counterparts in foreign governments and international organizations and in 140 multilateral agreements to conduct international cooperative research, provide technical support, or share data or equipment.[32] 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. Overall, the United States collaborated with 57 countries, 8 international organizations, and 10 groups of organizations or countries. In terms of numbers, U.S. agencies had the greatest number of agreements with Japan (78). After Japan, U.S. science and technology (S&T) agreements were most commonly reported with Russia (38), China (30), and Canada (25).

Among the seven agencies that GAO reviewed, DOE participated in the largest number of official international S&T agreements (257). This total included almost 100 multilateral agreements with the International Energy Agency, 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).

The GAO accounting includes only official, formal agreements and therefore does not capture government-supported collaboration that frequently takes place between individual researchers or groups of researchers outside the framework of these formal agreements. Communications advances, particularly the Internet, have contributed to the growth of these more informal collaborations.[33]

[32] *S&EI 2000*, p.2-54.
[33] S. Teasley and S. Wolinsky. "Scientific Collaboration at a Distance." *Science*, Vol. 292, pp. 2254-55, 2001.

COORDINATION OF U.S. GOVERNMENT SUPPORTED INTERNATIONAL S&E ACTIVITIES

The increasing U.S. governmental collaboration in international S&E-related activities makes effective coordination and integration of such activities more important than ever. Unfortunately, even the formal international collaboration is frequently uncoordinated. It is not necessarily part of a coherent and integrated plan. Much of it is characterized by poor communication or insufficient data, so that little information is being shared.

The Office of Science and Technology Policy (OSTP) in the Executive Office of the President provides general oversight, integration, and direction of the U.S. Government's international S&E activities. Within OSTP, the National Science and Technology Council (NSTC) was established by the President to coordinate Federal science and technology policy and the diverse parts of the Federal R&D enterprise. The NSTC's Committee on International Science, Engineering, and Technology (CISET) is charged with providing interagency coordination in the international arena. CISET was established to address significant international policy, program, and budget matters that cut across agency boundaries. It provides a formal mechanism for interagency policy review, planning, and coordination, as well as exchanges of information regarding international science, engineering, and technology. In recent years, it has been co-chaired by OSTP's Associate Director for National Security and International Affairs and the Department of State's Undersecretary of State for Global Affairs.[34] Other NSTC committees address international issues directly in their purview (e.g., the Committee on Earth and Natural Resources). Also, there are a number of other entities within the White House with both an interest in and responsibility for various aspects of international S&E policy including the National Security Council and the National Economic Council. These overlapping and shared interests and responsibilities make coordination and management of international S&T activities even more complex and challenging.

"In the Executive Branch over many years, however, there has been a crazy-quilt of poorly defined responsibilities for science and technology in international affairs. Agencies have inconsistent strategies and inadequate resources. Programs are frequently knotted up with conflicting policies, erratic funding, and micromanagement. Only rarely are efforts properly knitted together, and then only by ad hoc mechanisms of coordination. The results have been poor, hardly befitting America's extraordinary assets in science and technology, and the consequences have been frustrating to Congress as well as to the President and the Secretary of State."

Rodney W. Nichols, Carnegie Commission on Science, Technology, and Government, 1993

The Department of State plays a leading role in a number of interagency international activities involving S&E research and education. It coordinates support for a number of vice-presidential-level bilateral commissions that accord considerable priority to S&E-related activities. It develops the concepts, frameworks, and details of umbrella intergovernmental S&E agreements and coordinates and negotiates them with its foreign counterparts. It also reviews and approves requests from other agencies for authorization for negotiating and signing memoranda of understanding and other agreements dealing with international S&E issues.[35]

It is clear that a number of government offices and agencies have key roles in developing and coordinating U.S. international S&E efforts. However, the current framework does not ensure effective communication and interaction and a close and continuing relationship among these organizations.

[34] Staff from the Department of State's Bureau of Oceans, Environment and International Affairs serve as nominal executive secretary of CISET.
[35] National Research Council, Office of International Affairs, *The Pervasive Role of Science, Technology, and Health in Foreign Policy: Imperatives for the Department of State*, Washington, DC. 1999. See pp. 64-67 for a broader and more detailed discussion of the role of the Department of State in interagency international S&E activities.