U.S. SCIENCE AND ENGINEERING IN A CHANGING WORLD

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A View from the National Science Board

Technical Note Regarding Revisions to Historical Data Series on Research and Development

In keeping with the standard objective of economic and indicator reports to improve and update data series, the National Science Foundation (NSF) revised several data series presented in *Science & Engineering Indicators--1996* (*S&EI--96*) from those presented in the previous edition, *Science & Engineering Indicators--1993* (*S&EI--93*). The reader is advised to use the current edition for historical trends as well as for the most recent information.

There have been substantial revisions in the U.S. industry R&D data presented here. Since *S&EI-93*, NSF has instituted annual sampling of industrial firms and increased the sample size from about 14,000 to 24,000 firms in order to produce statistics that more adequately reflect the widening population of R&D performers among firms in the nonmanufacturing industries and small firms in all industries, and to better account for births/deaths of new firms, mergers and acquisitions. Complete details on the new survey methodology for industrial R&D are contained in NSF 95-324, and a summary can be found in NSF 94-317.

Another significant revision was in the data on Federal support for research and development. *S&EI--93* contained preliminary estimates of $65 billion and $68 billion in Federal R&D support for 1992 and 1993, respectively (see Appendix table 4-4, *S&EI--93*). The *S&EI--96* report presents revised estimates of $60 billion for both 1992 and 1993 (see Appendix table 4-4, *S&EI--96)*. The rest of this note summarizes the reasons for revising the estimates.

Sources of Data on Federal Support of R&D

The Office of Management (OMB) collects data on Federal agencies support for R&D and R&D plant as part of its annual budget preparation process. In gathering R&D budget authority and outlay data, OMB directs agencies to use the same definitions of R&D that are used for reporting obligation data to NSF's annual R&D surveys of Federal agencies (all defined on page 4-9, *S&EI--96*). Both the NSF and OMB collect data on past year and current year Federal R&D support and on outyear projections. The outyear estimates include budget proposals and amounts that reflect congressional appropriations, apportionment, and reprogramming decisions at the time of the survey, but are in advance of final data on authorizations, obligations, or outlays.

NSF collects data at a fine level of detail for both performers and funders of R&D, and encourages agencies and firms to report revisions in historical time series when appropriate. NSF reports both national and sectoral R&D expenditure data (e.g., Appendix table 4-4, *S&EI--96*) and Federal R&D obligations data (e.g., Appendix table 4-17, *S&EI--96*) because both of these series provide useful information at different levels of dissaggregation and periods in time.

There is no single survey of R&D activity in the United States. Rather, NSF sponsors a series of surveys to collect information on financial R&D resources in the various sectors of the U.S. economy--industry, Government, academia, and selected nonprofit organizations. These independent survey data are aggregated into R&D expenditure estimates (using survey data, and time series, analytical, and statistical models) so that the components of the R&D effort are placed in a national context, including data on: the national total of R&D expenditures; the sources of such funds; the sector performing the R&D.

NSF constructs national R&D expenditure totals primarily based on data reported by performers because they are in the best position to (i) indicate how much they spent in the actual conduct of R&D in a given year and (ii) identify the source of their funds. Performer reporting also reduces the possibility of double-counting and conforms to international standards and guidance. But before performer-reported survey data on Federal R&D expenditures are available from industry and academia, data collected by OMB and NSF from the funders of R&D are used to project R&D performance. When survey data from the performers subsequently are tabulated, these statistics replace the projections that were based on the funders' expectations. Details of the model, data sources, and estimating procedures are explained in NSF 92-330 and NSF 95-304.

Revisions in NSF Data

Data in *S&EI-93* reflected the best figures available in the summer/fall of 1993. Performers reported approximately $59 billion in Federal R&D support for 1991 (see Appendix table 4-4, *S&EI--93*). Preliminary and projected estimates for 1992 and 1993 were in part based on the Administration's 1993 budget proposal. Federal agencies reported to NSF and OMB 1992 R&D support levels of $61 billion to $66 billion--depending on when the estimates were supplied and whether authorizations, obligations, or outlays were being measured--and expected increases ranging between $2 billion and $9 billion.

Data in *S&EI-96* reflect the best figures available in the summer/fall of 1995. In contrast to the prospective growth reported by Federal funders of R&D, performers reported receiving and spending much lower amounts: approximately $60 billion in Federal R&D for each year, 1991, 1992, and 1993 (see Appendix table 4-4, *S&EI--96*). The Federal amount to be reported by performers is projected to increase to approximately $61 billion for 1994 and 1995. NSF currently is investigating the reasons for the recent divergence in data series reported by Federal agencies whose reported numbers continue to rise, and by the organizations that actually perform the R&D, whose reported numbers remain rather level.

The difference in the Federal R&D data totals appears to be concentrated in funding of industry by the Department of Defense (DOD). Industrial firms report, for calendar year 1993, $15 billion in R&D performance funded by contracts and grants from the DOD. This figure is almost $9 billion less than the R&D amount reported by DOD to have been obligated to industrial firms in fiscal year 1993 ($24 billion). The DOD-reported total includes industry funding from its full research, development, test, and evaluation budget. Performer-based and funder-based data have always differed somewhat. However, over the last few years, this difference has increased. NSF is continuing to work with DOD and the US Bureau of the Census (which conducts the survey of industrial R&D for NSF) to review these R&D data and estimates in order to verify and better understand the trends and changes that underlie them. Reports on these topics will be issued later in 1996.

The U.S. National R&D system is in a period of major transition. NSF continues to monitor the changes occurring in the Nation's R&D effort, and to examine ways to improve our data collection and analyses efforts. Reports on these topics will be issued in the future. The reader is invited to contact the NSF for recent data and reports at 703-306-1780, or at our world wide web address at http://www.nsf.gov/sbe/srs/stats.htm.

I. Introduction

The National Science Board is charged with focusing national attention on major issues of science and engineering (S&E) research and education. *Science and Engineering Indicators,* the Board's biennial report to the Congress submitted through the President, presents a quantitative overview of the condition of the U.S. science and technology (S&T) enterprise. To accompany *Science and Engineering Indicators–1996,* the Board offers this brief assessment of key policy issues facing the Nation as it seeks to sustain U.S. leadership in science and engineering.

II. Entering an Era of Change

During the Second World War, the United States turned to science and technology to ensure its security and defense. Since then, a consistent bipartisan policy of Federal investment in research and education for civilian needs has built a research and education enterprise of unparalleled scope and quality. This policy has directly contributed to the Nation's economic growth, the productive use and cultivation of its resources, and the health and well being of its people. U.S. investments in science and technology constitute a legacy that increases in value as the Nation faces the challenges and opportunities of the 21st century.

The research and education institutions comprising the U.S. S&E enterprise now must reassess and redefine their roles and objectives for a new era, one no longer driven by the defense imperatives that shaped their evolution. The challenge of the future is to adapt the programs and organizations that have nurtured scientists and engineers so successfully over the past 50 years in order to meet the Nation's new opportunities, needs, and goals.

This new environment will call for fresh approaches to setting priorities and responding to opportunities. Even in the best of circumstances, the exponential growth of scientific opportunities would require increased care in setting priorities. The limited resources imposed by the Federal budget constraints of the 1990s create an even stronger imperative to choose wisely and to weigh existing S&E activities, no matter how worthwhile, against the promise of new ideas and approaches.

Based on new data, the Board highlights three key S&T policy goals:

- Making research and development (R&D) priorities consistent with new scientific opportunities, post-Cold-War national goals, and unavoidable resource limitations;
- Addressing current and future needs for a well-trained U.S. workforce, from universal basic science and mathematics literacy to the steady renewal and upgrading of human resource capacities in S&E; and
- Strengthening the integration of research and education at the colleges and universities that have been the cornerstone of the U.S. S&T enterprise's success.

The remaining sections of this statement describe relevant trends presented in *Science and Engineering Indicators,* discuss the key policy issues, and recommend actions.

III. Priorities for Federal R&D Funding Consistent with New National Goals and Resource Constraints

Trends

As concerns about U.S. economic performance have overtaken Cold War considerations, Federal R&D priorities have shifted away from defense and toward the civilian sector. The shift reinforces the trend toward academic institutions assuming a greater role in the total U.S. R&D effort.[1] Academic institutions are highly dependent on Federal funds to finance their performance of research. Shifts in emphasis and performance have occurred in the context of worldwide financial resource constraints. Mirroring the funding slowdowns in other major R&D-performing countries, overall growth in U.S. support for R&D has not kept pace with inflation in the 1990s. Federal outlays, which constituted 36 percent of total U.S. R&D spending in 1995, have been falling in real terms each year since 1987.[2]

The academic sector has remained the Nation's largest performer of basic research. Between 1984 and 1994, average annual constant dollar increases in R&D performed at universities and colleges exceeded, by at least a factor of two, performance growth in all other settings. Growth in Federal obligations for academic R&D, however, slowed in the beginning of the 1990s to half the rate in the late 1980s. Three Federal agencies supported the bulk of academic R&D in 1995: the National Institutes of Health (NIH—53 percent), the National Science Foundation (NSF—15 percent), and the Department of Defense

[1]National Science Board, *Science and Engineering Indicators–1996,* NSB 96-21 (Washington, D.C.: Government Printing Office, 1996), Chapter 4 and Chapter 5.

[2]Ibid.; Chapter 4 and Chapter 5.

(DOD—12 percent). Since their support is concentrated in different academic fields, Federal financial constraints have different effects on education and research in various disciplines.[3]

Issues

Shifting national goals for science and technology and current Federal funding constraints will have important long-term effects on the U.S. R&D enterprise and on the continuous expansion of the S&E knowledge base needed to sustain national productivity and quality of life in the 21st century. The Federal response to these conditions will have special impact because of the Government's roles as major funder, user, and producer of R&D results. Current circumstances dictate reconsideration of Federal research priorities and decision rules on areas, levels, and directions of Federal funding.

New opportunities for domestic and international partnerships are creating a more robust and diversified base of support for S&E research. International collaboration opens the way to new research possibilities and promotes cost-sharing of expensive facilities. Recent domestic R&D partnerships among government, academia, and industry are also ripe for strengthening. The increasing importance of such partnerships underscores the need for more focused attention on such issues as when the Federal Government should initiate, lead, or follow in a research partnership and on how the government can protect both research openness and U.S. intellectual interests. Another prominent new issue is whether Federal goals for R&D investments should take into account the potential for creating jobs or enhancing U.S. industrial competitiveness.

Explicit consideration of the interdependence between, and the synergy among, the various elements of the U.S. R&D enterprise is of utmost importance. A reconsideration of research priorities could lead to significant Federal funding reallocations which, if made without regard to the impact on R&D, could be inefficient and even damaging. Experience suggests that the S&E knowledge base is best nurtured by long-term investment supported by reliable multiyear budgets. However, both are difficult to sustain in an environment that combines change and fiscal constraint. The National Science Board recommends three essential first steps toward creating an effective Federal R&D process for this new era.

[3]Ibid.; Chapter 4 and Chapter 5.

Recommendations

- *When establishing strategic goals for Federal research investments and principles for setting R&D funding priorities, Federal policymakers should strive for performance at a world-class level in all major areas of science and engineering and preeminence in a number of select fields.*
- *Policymakers should institute a new R&D budget-making process within the Executive Branch and Congress that enables them to (1) pay careful attention to the complex connections and mutual dependencies among U.S. R&D performers and users; (2) weigh the long-term consequences of specific funding decisions; and (3) coordinate Federal choices and trade-offs strategically within science and technology and across science and technology and other major budget categories.*
- *Federal policymakers should pursue international S&T cooperation to take advantage of valuable world resources, both material and human, in order to investigate global research questions and to share costs.*

IV. Needs of Current and Future Generations for a Well-Trained Workforce

Trends

In the 1990s, U.S. industry's use of advanced technologies continues to increase, creating greater demand for more educated employees and for a general workforce with greater technical knowledge and skill. Industry has continued to employ a majority of the graduates earning U.S. S&E baccalaureate or postbaccalaureate degrees, including Ph.Ds. Overall, the number of S&E jobs in industry increased by 2.5 percent between 1990 and 1993, with growth concentrated in occupations that required computer-related and mathematical skills. Hiring in other S&T fields declined.[4] In the 1990s, the service sector became the leading industrial employer of scientists in the United States and four of the other major member countries of the Organisation for Economic Co-operation and Development. More than half of U.S. scientists and engineers working in industry are now in nonmanufacturing businesses.

[4]Ibid.; Chapter 3.

Issues

To remain competitive in today's global marketplace, the United States will need workers and entrepreneurs who are educated in science, mathematics, and engineering and are able to understand and use S&E research results and technological capabilities. To gain new knowledge and exploit novel processes and products, the United States also will need a cadre of scientists and engineers prepared to use their education and skills in a wide variety of employment settings. Finally, to address important national and global challenges, all members of U.S. society will need a foundation in mathematics, science, and engineering that enables them to make informed decisions about complex issues involving science and technology.

For these reasons, Federal policymakers have an overriding interest in engendering and maintaining a basic understanding of, and baseline skills in, science, mathematics, and engineering in the United States. Historically, Government has supported S&E education, with a special focus on postbaccalaureate training, primarily in the context of Federal R&D mission goals. Future needs call for a Federal approach to human resource development in science and technology that goes beyond these mission goals for R&D, cuts across all levels of education, and includes all participants in the educational process.

The challenge for government policymakers and their partners is to implement this new approach through programs aimed at improving science, mathematics, engineering, and technology education and through decisions made in the R&D funding process. In this context, the National Science Board recommends three immediate actions.

Recommendations

- *National S&T policies must include a component that addresses the role of science and technology in the development of the Nation's human resource base. This must focus on revitalizing K–12 science and mathematics education at system-wide levels, emphasizing partnerships among diverse communities and all sectors of the economy and encompassing the education and training of S&E personnel in the context of excellence in science, mathematics, engineering, and technology for all Americans.*

- *Agencies' R&D funding decisions have an impact on human resource development. Federal S&T policies should require agencies to take these effects into account when making funding decisions. For example, funding constraints may adversely affect the new partnerships among Federal agencies and laboratories, industry, universities, and schools that emphasize science and mathematics standards in expanding system-wide K–12 education reforms. Likewise, funding decisions have an impact on undergraduate, graduate, and postdoctoral students, affecting both the extent of support to their educational programs and the nature of those programs.*

- *Federal S&T policies should promote the use of networking and information technologies, libraries, museums, community colleges, and S&T centers to increase public understanding of science and technology and to assist the workforce in adopting new skills.*

Establishing these policies will require an expanded information base on science and technology in the development of human resources. The National Science Board expects NSF, working with interested partners, to compile, analyze, and disseminate the information needed for all scientists and engineers to understand labor market conditions more fully. Future volumes of *Science and Engineering Indicators* ought to include this information. The Board also expects NSF to conduct experiments designed to develop the educational programs best suited to evolving employment conditions.

V. Integration of Research and Education at U.S. Colleges and Universities

Trends

The magnitude of the current U.S. higher education enterprise is unmatched, internationally or historically. In 1993, more than 3,600 U.S. institutions of higher education enrolled almost 15 million students, more than double the number enrolled in 1967. These institutions awarded 2 million degrees, one-quarter of which were in S&E fields.[5] Federal support of basic research has had a significant effect on both graduate S&E education and academic employment. For example, many doctoral students in S&E programs have received their primary financial support from research assistantships. Also, the 3-percent annual employment growth of doctoral scientists and engineers on U.S. campuses during the 1980s has slowed and is confined largely to nonfaculty positions, many in research areas supported by the Federal government.[6]

Most faculty who make substantial time investments in research also have teaching responsibilities.[7] In fact, teaching and research can reinforce

[5]Ibid.; Chapter 2.
[6]Ibid.; Chapter 5.
[7]Ibid.; Chapter 5.

each other. Great teaching is a form of synthesis and scholarship. At the precollege level, however, many mathematics and science teachers have very little training in mathematics and science. In 1993, less than 4 percent of elementary mathematics and science teachers had majored in mathematics, mathematics education, science, or science education. At the high school level, the picture is better: More than 60 percent of the math teachers and more than 70 percent of the science teachers had in-field majors in 1993.[8]

Individuals who have completed more years of formal schooling and more courses in science and mathematics are significantly more likely than other U.S. citizens to understand the nature of scientific inquiry and the research process. Nevertheless, only about one-quarter of U.S. adults understand the nature of scientific inquiry well enough to make informed judgments about results reported in the media.[9]

Issues

The U.S. research enterprise has been enormously successful, inspiring imitation throughout the world. A key component of this success is the investment of Federal research dollars, through NSF and other agencies, in institutions of higher learning, simultaneously supporting investigation and education. Research universities are the primary vehicles for current U.S. investments in fundamental S&E research and the locus of public investments in the technologically sophisticated and scientifically trained populace.

A major challenge facing Federal policymakers is to preserve and strengthen this integration of research and education at U.S. colleges and universities. In so doing, policymakers will promote public understanding of scientific inquiry and reinforce public confidence in the value and quality of the research and educational process. For the overall S&E enterprise to flourish, the pieces need to be strong individually, and their interactions need to be enhanced.

Science, mathematics, and engineering need to be integrated from K–12 science education all the way through research at the frontiers. An educated public and future scientists and engineers are both important goals of this integration. Many U.S. colleges and universities make research experience a regular part of undergraduate education in science. For example, with support from NSF, K–12 teachers and high school and undergraduate students are able to work with faculty as assistants on research projects, experiencing discovery and coming to understand the true nature of science.

NSF information suggests that some schools are exceptional at preparing select groups of students to understand particular areas of science and engineering. While there is no single model for how best to integrate research and education, the Nation needs to explore the possibilities.

Recommendations

- *Integration of research and education is in the national interest and should be a national objective. To advance this goal, Federal S&E policies should strengthen efforts to promote the integration of research and education at all levels and should support innovative experiments in this area.*
- *Confidence that academic research enriches the educational process at U.S. colleges and universities underpins public support for science and engineering. Federal S&E policies should promote public awareness of model higher education institutions and programs that have demonstrated leadership in strengthening the synergy between research and education.*

VI. Conclusions

The U.S. S&T enterprise serves as a wellspring of creativity and discovery as the Nation faces the next millennium. In order to preserve the integrity and vitality of this enterprise and U.S. leadership in science and engineering, the National Science Board recommends new approaches to setting Federal R&D priorities and developing coherent budget strategies. The Nation must put absolute priority on educating and training all members of society in mathematics, science, and engineering so they may be productively employed in an increasingly sophisticated global economy. This educational process is a lifelong endeavor, an opportunity that U.S. colleges and universities can revitalize, in cooperation with Federal agencies, by promoting the integration of research and education at all levels. A reinvigorated S&T enterprise, in which all components appreciate and reinforce their own and one another's essential role, will enable U.S. society to meet successfully the technological challenges of the 21st century.

[8]Ibid.; Chapter 1.
[9]Ibid.; Chapter 7.

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