Chapter Three

Findings and Recommendations

The National Science Board's findings and recommendations focus on national workforce policies in five areas:

- Undergraduate education in science and engineering;
- Advanced education in science and engineering;
- Knowledge base on the science and engineering workforce;
- Precollege teaching workforce for mathematics, science and technology; and
- US engagement in the international science and engineering workforce.

Undergraduate Education in Science and Engineering

The global competitiveness of the US S&E workforce and domestic competitiveness of S&E careers will depend ultimately on how schools, colleges, universities, and other education providers develop and refine human resources. The Federal Government has long supported graduate S&E education through fellowships, traineeships, and research grants. At the undergraduate level, however, the responsibility for development of the S&E workforce has been shouldered primarily by States and localities through public institutions of higher education and an array of private institutions. The Federal Government has a stake in the workforce of the Nation as a whole, especially the S&E workforce needed to serve Federal missions.[26] It cannot rely solely on the aggregated State and institutional efforts at the baccalaureate level to ensure that there will be an adequate complement nationwide of high-quality teachers and practitioners in S&E fields and a sufficient pool of students prepared for graduate studies to meet the needs of the workforce for advanced S&E skills. The States and institutions of higher education lack the resources and incentives to provide sufficient support for the S&E workforce that the Nation needs.

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[26] The United States Commission on National Security/21st Century, *Road Map for National Security*: Chapter II.

For the Nation to be successful in attracting students to S&E study, policymakers must understand the context in which students make career decisions and institutions make resource decisions. They must understand the trends in S&E bachelor's degree attainment documented in the previous section of this report. The Board has examined the current situation in undergraduate education and identified actions that must be taken to increase success in educating students from the largest possible pool of talent.

The context of S&E study for the student

From the vantage point of the talented high school graduate, the postsecondary educational marketplace offers a huge array of choices and ways to invest time and money. Careers in S&E hold promise of good lifetime earnings, expanding job opportunities, and interesting work. [27] But preparation for such careers poses challenges. Research shows that student success in attaining a degree correlates with rigorous academic preparation in high school, especially in mathematics, and with "traditional" paths in college – continuous, full-time enrollment to obtain the degree.[28]

The issue for students is not only the choice of S&E study, but continuation in a course of study. Surveys of freshmen intentions show high levels of interest in S&E, with approximately 25-30 percent intending to major in S&E.[29] However, the net movement of students over their undergraduate years is out of S&E and into other majors or out of college. As a result, less than half of those intending to major in S&E fields complete an S&E degree within 5 years. Underrepresented minorities drop out of S&E majors at a higher rate than other groups.[30]

The affordability of a college education can have a major impact on a student's persistence and ultimate success in attaining a degree. The cost has been rising. Our current system of higher education is experiencing a steady decline of state support, rising tuition, and increased reliance on debt-based financing. The majority of students are turning to loans to finance college, with 64 percent of graduating students in 2000 reporting student loan debt.[31] The average student loan debt has nearly doubled over the past eight years to $16,928. For low-income students, the percentage of the cost of attending a public four-year college covered by the maximum Pell Grant award has fallen over the past 25 years, from 84 percent in 1976 to 40 percent in 2001.[32]

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[27] Natural scientists and engineers fall within one of the highest wage categories from the Bureau of Labor Statistics http://www.bls.gov/ncs/ocs/sp/ncbl0539.pdf, although wages vary among fields. NSF reports that S&E degree holders enjoy rising salaries over the years after receiving their degrees (SEI-2002: 3-11) and relatively low unemployment rates. In 1999 the unemployment rates for S&Es were 1.5 percent for men and 1.8 for women, while the unemployment rate was 4.4 percent for all workers and 1.9 percent for professional specialty workers (SEI-2002: 3-8,9).
[28] Jane V. Wellman, "State Policy and Community-College-Baccalaureate Transfer," August 2002, National Center for Public Policy and Higher Education.
[29] SEI-2002: 2-4.
[30] SEI-2002: 2-4.
[31] The State PIRGs' Higher Education Project, "The Burden of Borrowing: A Report on Rising Rates of Student Debt," March 2002.
[32] State PIRGs' Higher Education Project: 1.

The rising cost of higher education has led to a decrease within the college student population in the number and share of "traditional" students – those who enroll full-time immediately after high school and depend on parents for financial support. Only 27 percent of today's undergraduates are traditional students. Nontraditional students are most likely to attend public two-year colleges. However, 37 percent of students at public four-year institutions and 35 percent at private, nonprofit institutions are nontraditional. [33]

The difficulties faced by students unable to pursue full-time study are severe for S&E majors because of curricula built on prerequisites, limited course offerings at accessible times and places, and the necessity of laboratory work. S&E curricula generally require the sequential acquisition of knowledge and skills along directed paths. Should the student step off the path to an S&E career, it is difficult to rejoin.

Institutional resources for S&E education

Increasing the number of scientists and engineers from among all domestic students depends on adequate capacity in high-quality degree programs in a range of institutions. The highest quality S&E degree programs are found in institutions that can provide laboratories and equipment, the quality of faculty that are typically engaged in research, and curricula that are up to date. A primary issue in building institutional capacity is the higher cost of education in S&E as compared with other subjects. This cost differential has favored S&E capacity in institutions that are wealthier, whether by virtue of endowment, high tuition, Federal research funds, or state support.[34] For many institutions where enrollments are increasing and the percentage of students graduating in S&E is low, the sources of revenue are essentially limited to tuition and state/local support – and the latter is under great stress. New and augmented revenue streams are needed to give these institutions the capacity to better serve the needs of the S&E workforce.

Community colleges represent a special opportunity for expanding the number of S&E majors. Community colleges enroll about 38 percent of all students and their student enrollments are growing at twice the rate as those of four-year institutions. Minority students in higher education are concentrated in community colleges – 46 percent of Asians/Pacific Islanders, 46 percent of African-Americans, 55 percent of Hispanics, and 55 percent of American Indians/Alaskan Natives.[35] Community colleges are also important feeders to more advanced studies. Fifty percent of students in the California State University system attended a community college before entering a bachelor's degree program at a four-year institution.[36] Seventy-five percent of upper division education majors in the California State University system

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[33] *The Chronicle of Higher Education: Daily News*, 6/4/2002:1, citing National Center for Education Statistics, US Department of Education.
[34] Research universities enroll only 19 percent of the students in higher education, but they play the largest role in S&E degree production. They produce most of the engineering degrees and a large proportion of the NS&E degrees. In 1998, the Nation's 127 research universities awarded more than 42 percent of all S&E bachelor's degrees and 52 percent of all S&E master's degrees. SEI-2002, Chapter 2.
[35] Data for 1997, SEI-2002.
[36] California Council on Science and Technology, Critical Path Analysis of California Science and Technology Education System. Presentation by Dr. Susan Hackwood, Executive Director, California Council on Science and Technology, to the NSB Task Force on National Workforce Policies for Science and Engineering, March 2002.

began their studies at community colleges. Community colleges are also highly important in educating members of the technology workforce and keeping them current in their fields.

It is important that all institutions focus greater attention on retention as a strategy for expanding participation in S&E careers. Research on reasons for able students persisting or switching out of S&E programs concludes that improvement in the yield of S&E majors will require modification of the educational environment, particularly better teaching and advising, for improved retention of not only underrepresented minorities and women but able students from all demographic groups.[37] More institutional resources must be directed to improving the quality of teaching, the nature of introductory classes, the design of facilities to support new teaching methods, and more effective academic support mechanisms, including more effective advising. Strategies that focus on the individual student, such as are often directed to minority students, are not enough. The challenge is to change the conditions that give rise to retention problems and thereby improve the quality of the undergraduate learning experience for all students.

Attracting more US students to science and engineering studies must be multifaceted, targeting both the individual student and the institutions serving undergraduates.

RECOMMENDATION:

The Federal Government must direct substantial new support to students and institutions in order to improve success in S&E study by American undergraduates from all demographic groups.

The Federal Government should:

- Ensure that scholarships and other forms of financial assistance are available to well-qualified students who otherwise would be unable to attend school full time to pursue an S&E major;
- Provide incentives to institutions to expand and improve the quality of their S&E programs in areas in which degree attainment nationwide is insufficient;
- Provide financial support to community colleges to increase the success of high-ability students in transferring to four-year S&E programs in colleges and universities; and
- Expand funding for programs that best succeed in graduating underrepresented minorities and women in S&E.

[37] Elaine Seymour, "Tracking the Process of Change in US Undergraduate Education in Science, Mathematics, Engineering, and Technology," reviewed by NSB/EHR Committee, March 2002 meeting. A four-year study by Seymour and Nancy Hewitt identified the most important factors that distinguish undergraduates who switch out of science, technology, engineering and mathematics from those who persist. The two groups did not differ significantly in performance, motivation, or study-related behavior, but those who persisted in S&E were more able than those who did not to overcome the difficulties from poor teaching and advising.

ADVANCED EDUCATION IN SCIENCE AND ENGINEERING

Although there has been considerable debate over the last decade about the overproduction of PhD scientists and engineers in certain fields, it is beyond dispute that society is – and will become even more – dependent on science and technology. Future progress and world leadership depend on a steady stream of scientific discoveries and developments that, in turn, depend on a cadre of individuals with a high level of scientific training and education.

Recent data on graduate enrollments of US citizens and permanent residents show a decline of 3 percent from 1999 to 2000.[38] Overall gain in graduate enrollment between 1999 and 2000 was more than accounted for by students with temporary visas, which increased 11 percent from 109,890 in 1999 to 121,827 in 2000. Nearly all growth in S&E PhDs awarded to US citizens is attributable to the rise in the number of women and minorities earning PhDs. The number of US white males earning S&E doctorates actually declined from 9,262 earned in 1980 to 8,138 in 1999.[39]

There is widespread concern that some subfields of the physical sciences, engineering, mathematics and computer science are not attracting domestic students in the numbers that will be required in the near future, in part because declining Federal support for research sends negative signals to interested students.[40] These individuals will be crucial to maintaining and advancing our technological infrastructure and our national security, as well as contributing to our economic well-being.

A number of factors will contribute to growth in the need for US personnel with advanced S&E degrees in the next few decades. These factors include accelerating retirements,[41] greater competition internationally for S&E talent, and national security concerns that may both affect access and attraction of foreign students and scholars to the United States and raise the demand for US citizens in national security-related areas.

The context for advanced S&E studies

Federal research and education policy to strengthen the domestic workforce of highly skilled professionals must recognize the competitive environment for talented students – both domestic and international. In the

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[38] NSF, "Growth Continued in 2000 in Graduate Enrollment in S&E Fields" (02-306) December 21, 2002.
[39] SEI-2002, Figure 0-7.
[40] For example, The President's Council of Advisors on Science and Technology (PCAST) report, *Assessing the US R&D Investment* (2002), found that "Federal support…for US graduate students in science and engineering has declined significantly". The report quotes IBM that "there is a dramatic shortage of people with the needed skills" in physical sciences for nanotechnology research. The 1998 House of Representatives National Science Policy Study, *Unlocking Our Future*, notes with concern the drop in enrollments by American students in physics, mathematics, computer science and engineering, and states that: "There appears to be a serious incongruity between the perceived utility of a degree in science and engineering by potential students and the present and future need for those with training in our society". Likewise the Council on Competitiveness reports that US national vulnerabilities include static or declining undergraduate and graduate degrees in engineering, the physical sciences, and math and computer sciences. For other nations, unlike the United States, the share of science and engineering degrees increased over the decade 1987-1997 (*US Competitiveness* 2001: 21).
[41] SEI-2002: 3-26.

US labor market, there are attractive, highly remunerative S&E and non-S&E career opportunities that do not require advanced S&E training. Opportunities for outstanding students are also growing in other nations, many of which have developed strategies to attract and retain scientists and engineers who might otherwise be drawn to US education and careers.

Attracting more US students to enroll in and complete graduate training depends in part on their expectations that investment in science or engineering education will be rewarded by careers employing the skills they acquire. It also depends on considerations including costs to the students in lost opportunities they might otherwise have pursued, the quality of life during the educational period, and the debt burden incurred while pursuing a degree. The opportunity and educational costs of graduate education in science and engineering fields can be high, especially for US students who, unlike many foreign students, are able to take advantage of a range of career opportunities open to high-ability baccalaureate S&E graduates.

Long-standing Federal policy has encouraged students to pursue advanced S&E degrees by subsidizing the cost of education through a number of mechanisms. Mechanisms to support graduate students used by both Federal and non-Federal sources include fellowships, traineeships, research assistantships, teaching assistantships, and other mechanisms such as work-study and employer financing.[42] Federal support for graduate education is predominantly through research assistantships. The Federal Government supports half of all research assistantships, about two-thirds of all traineeships and one-quarter of all fellowships. Teaching assistantships are the predominant mechanism for support from non-Federal funding sources.[43]

Since teaching assistantships and assistantships on research grants are the predominant mechanisms of support for graduate students, undergraduate teaching requirements and research funding to academic institutions directly affect the employee pool for jobs requiring advanced education.[44] Any mismatch between undergraduate enrollments and funded research, on the one hand, and the skill needs in the workforce, on the other, can result in problems of under- and over-production of human resources across diverse disciplinary and multidisciplinary areas.

In the mid-1960s the Federal Government funded most of the Nation's research, primarily to serve Federal missions. Therefore, at that time the education of scientists and engineers at the graduate level who gained research experience on Federal grants might have been expected to roughly parallel the emphasis of the national R&D portfolio. An expanding university system created many new academic faculty positions that absorbed PhD-level scientists and engineers into jobs that drew on skills obtained through traditional graduate education.[45]

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[42] SEI-2002, 2-32,33.
[43] The Federal Government has a dominant role in supporting graduate education in some fields and plays a less important role in others. It supports most research assistantships in the physical sciences, most traineeships in physical and biological sciences and chemical engineering, but is not a significant source of support in mathematics. Primary mechanisms of support differ widely by field, with physical sciences supported mainly through research assistants (42 percent) and teaching assistants (41 percent). Research assistants are also important in engineering (42 percent) and earth, atmospheric, and ocean sciences (41 percent). In mathematics, the primary source of support is teaching assistantships (57 percent).
[44] Charles A. Goldman and W. F. Massy. *The PhD Factory*. 2001.
[45] SEI-2002, 4-7, 8, 9.

Today industrial research dominates the US R&D enterprise – more than two-thirds of US R&D. The private, for-profit sector is by far the largest provider of S&E employment. In 1999, approximately 74 percent of scientists and engineers with bachelor's degrees and 62 percent with master's degrees were employed in private, for-profit companies. For those with doctorates, 48 percent were employed in academic institutions, but the majority of PhDs in the workforce were employed outside of the academic sector. Academic demand for PhD-level scientists and engineers has grown slowly during the last decade, particularly in research universities (about 1.7 percent for all academic institutions and 0.6 percent for research institutions). In comparison, the business sector experienced a 4.4 percent growth and the public sector 4.9 percent growth.[46]

The need for action

The Board has addressed graduate and postdoctoral education in two previous reports (see Boxes B and C). Other studies have offered suggestions to improve the alignment of PhD and postdoctoral education with workforce demand. Recommendations for graduate education include improving guidance and information for graduate students in their career choices, reducing reliance on research assistantships within grants to principal investigators in favor of research/training grants to institutions, voluntarily reducing graduate enrollments in oversupplied disciplines, and broadening students' experience during graduate training to prepare them for a range of careers.[47]

It is in the national interest as well as the interest of individual students and scholars that the Federal Government – with other stakeholders in the S&E workforce – take action to guide the advanced education of scientists and engineers to better align with expected national skill needs. Areas of national skill needs include:

- National priorities in emerging areas – e.g., nanoscale science and engineering;
- Interdisciplinary skills – e.g., bioinformatics;
- Traditional disciplines where enrollments are insufficient to maintain national infrastructure for S&E in the face of level or increasing demand projections – e.g., in computer sciences; and
- Federal mission-related fields where enrollments are falling and projected needs rising, e.g., nuclear physics and engineering.

[46] SEI-2002: 3-9 and text table 5-5.
[47] National Research Council, *Reshaping the Graduate Education of Scientists and Engineers, 1995; Trends in the Early Careers of Life Scientists*, 1998.

RECOMMENDATION:

Federal support for research and graduate and postdoctoral education should respond to the real economic needs of students and promote a wider range of educational options responsive to national skill needs.

Federal strategies should:

- Ensure that Federal stipends for graduate and postdoctoral students provide benefits[48] and are competitive with opportunities in other venues[49];
- Invest in innovative approaches to doctoral and master's education that prepare students for a broad range of disciplinary and cross-disciplinary careers in academia, government, and industry; and
- Provide consistent, long-term support for high-quality disciplinary and interdisciplinary doctoral training programs in S&E.

[48] Fringe benefits, especially for health care.
[49] Currently, NSF is recommending an annual stipend of $30,000 for its graduate fellowship and traineeship programs. NSF Summary of Budget Request to Congress/FY 2004.

Box B:

Report of the Task Force on Graduate and Postdoctoral Education (1996)

The Task Force recommends that limited studies be conducted on alternative modes of graduate support, with defined goals and assessment criteria. Among these might be programs for:

- Traineeships for programs and encouraging breadth and interdisciplinary studies, and including specific attention to ethics and the responsible conduct of research
- Fellowships for professional technical masters degrees
- Fellowships for interdisciplinary research for students who have advanced to Ph.D. candidacy in a traditional discipline
- Fellowships or other support modes permitting internships in industry, government agencies, and/or public schools as part of the graduate research experience
- Devising new means to provide incentives for attracting U.S. citizens (particularly from underrepresented groups) to graduate programs in science and engineering
- NSF, possibly through SRS and/or the SBE directorate, should support data collection and/or research on the effects of funding mechanisms on the number, retention, programmatic quality, time-to-degree, and demographic and institutional distribution of students being supported.

The task force has recommended limited studies because, despite extensive study, we find inadequate data to compel a recommendation of a major shift in funding mode among fellowship, research assistantships, teaching assistantships, and traineeships for supporting graduate education in science and engineering. We have found:

- Major institutional and disciplinary variation in time-to-degree
- Shorter time-to-degree for students who are supported than for those who are not
- Specific attention should be paid to the role of foreign students in the SME enterprise. This should include collection of data on the number, support mode, and placement of foreign students.

Box C:

The Federal Role in Science and Engineering Graduate and Postdoctoral Education (1997)

1. Federal Support to the Enterprise

- The Federal government should reward and recognize institutions that initiate model programs for the integration of research and education.
- Mission agencies funding agency-initiated research in academic institutions should recognize the intimate connection between research and graduate education in universities. They should adopt principles and practices exploiting that interconnection and insure that their funding reaps the dual benefits of simultaneously advancing both research and graduate education.
- The Federal government should contribute to promoting closer collaboration between faculty in non-research and research institutions. Such collaboration in research offers opportunities for greater exposure to a variety of career options for graduate students. It can also improve the transition from undergraduate to graduate programs across institutions. The improvement of that transition is especially important for reaching minority undergraduates. Federal investments, particularly in communications infrastructure, can expand the scope of these programs.

2. Breadth vs. Narrowness of Graduate Education

Recommends that:

- University programs and Federal support policies continue to encourage exceptionally talented students to pursue Ph.D. programs and to develop their capacities to advance knowledge in their chosen disciplines;
- The Federal partner recognize and reward institutions that, in addition to the core Ph.D. education, provide a range of educational and training options to graduate students, options tailored to the career interests of the individual Ph.D. candidate. These might include interdisciplinary emphasis, teamwork, business management skills, and information technologies;
- The Federal and university partners seek more effective ways of promoting diversity and full access to graduate education, guarding against strategies that inadvertently keep underrepresented groups from the mainstream of research and graduate education. Efforts should emphasize identification of high-ability students earlier in the educational experience, including the precollege level, and encouraging them to consider careers in science and engineering.

The Board recommends the attention of universities to the following areas:

- To assure access for high ability students, examine the current use and possible misuse of assessment tools for entry to, and financial support for, graduate education, e.g. the Graduate Record Examination scores (GREs); and

BOX C (CONTINUED):

- Recognize postdoctoral researchers as a significant component of the system of graduate research and education in some areas, and better integrate postdoctoral scholars into the university community.

The Board recommends that the Federal government:

- Support university-initiated efforts to insure in the science and engineering faculty reward systems an appropriate balance between recognition for excellence in research and excellence in teaching, mentoring, and other areas of faculty responsibility;
- Examine how it can prevent unnecessary and unintentional interruptions in academic research programs and in associated support to graduate students that may result from the vagaries of the Federal research funding environment;
- Review conflicting or confusing treatment of graduate students and postdoctoral researchers—as students or employees—in Federal regulations and policies. The review should entail consideration of both consistency across agencies and coherence between the purposes of regulations and administrative requirements and Federal objectives for supporting and integrating research and education in academic institutions.

The Board recommends that the following areas be explored:

- Strategies to attract and retain talented students from underrepresented groups. These strategies might include consideration, in some cases, of criteria for support on research grants;
- The respective Federal and university responsibilities for reducing the administrative burden on faculty researchers/teachers to increase time available for mentoring and other educational and service activities that enrich the learning environment. This reduction in administrative burden needs to be coupled with the alignment of faculty reward systems;
- Improved policy data to assess the effectiveness of current Federal support for graduate education including attention to attrition and time-to-degree, and to identify current and emerging national needs for the science and engineering workforce.

This exploration should include input from a broad range of stakeholders in graduate education and be attentive to maintaining the benefits of graduate and postdoctoral research and education in science and engineering for the Nation.

KNOWLEDGE BASE ON THE SCIENCE AND ENGINEERING WORKFORCE

The science and engineering workforce is a dynamic system, reflecting the aggregated educational and career choices of individuals, educational offerings of institutions of higher education, financial considerations in acquiring an education, guidance and career counseling to students and professionals, availability of jobs, and any number of other factors. Individual members of the workforce may enter and leave occupations several times during their working lives. Workforce needs for specific skills can rise and fall—sometimes rapidly.

Even within science and engineering professions and among individuals who have invested the most in their education in a given specialty, substantial changes in career paths over their lifetimes are common.[50] For example, emerging research areas attract not only newly minted PhDs, baccalaureates, technicians, and postdoctoral scholars just entering the job market, but also those who have built careers in other specialty areas. Science and engineering degree holders at all levels may go on to pursue careers in such areas as law, technical management, or university administration and move out of research and teaching. Nonetheless, they may still use the skills gained through their previous S&E education and employment.

The organizational structures and processes for educating, maintaining skills, and employing science and engineering talent in the workforce are diverse and their interrelationships complex and dynamic.[51] As a result, production and employment of scientists and engineers are not well understood as a system. Adding the international context for science and engineering to the domestic system multiplies its complexity.

Federal policies and strategies for interventions in the workforce must be sensitive not only to impacts on areas targeted for intervention, but also to other impacts on broader workforce capabilities. There is a need for a fuller understanding of the S&E workforce as part of the national economy. There is a further need to understand the variables and interrelationships that affect choices and opportunities of individuals in various science, technology, engineering and mathematics careers. Strategies to impact the system as a whole now tend to target individual components in efforts to address identified areas of weakness. Interventions are often employed without critical analysis of impacts on other aspects of the workforce.[52]

Federal policymakers need an adequate base of knowledge to be able to assess impacts of interventions to the system as a whole and to better

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[50] SEI-2002: 3-4 to 3-10.
[51] SEI-2002: 2-7 to 2-15.
[52] Academia is an example. Twenty percent of the average yearly job openings for college and university faculty are being filled by permanent residents and H-1B visa holders (Lowell report for NWP). The percentage is considerably higher in many fields of engineering, computer science, and physical science. Both the short-term and long-term impacts of this situation upon the educational experience of domestic undergraduate and graduate students are not understood.

understand the integration of this complex system.[53] Greater understanding of the system would help avoid policies and strategies that are ineffective in strengthening national capabilities or that unintentionally undermine the health of US science and engineering.[54]

Lacking reliable tools for policy and strategies affecting the future S&E workforce, the consensus strategy is to attract more talented undergraduates to science and engineering majors in areas of need and encourage them to continue on to graduate school – particularly undergraduates from groups who have been underrepresented in natural science and engineering.[55]

Over the long term, there is a need to develop a quantitative, dynamic model of the global S&E workforce with respect to skills, mobility, occupational and geographic migration and demographic characteristics, and to understand the impacts of the global workforce on US science and engineering, especially the impacts of temporary workers and international students in S&E fields. As an initial focus, increased financial support is needed for academic research to develop more adequate models of domestic supply and demand for science and engineering skills. A special focus is needed on doctorates and postdoctorates, due to the high level of investment by the individual and society required to produce scientists and engineers at these levels of education.

New approaches to graduate and postdoctoral education must address factors within the education system that contribute to making careers in science and engineering uncompetitive. An important area requiring attention is time-to-degree and duration of time in postdoctoral appointments in some fields. Research is needed to better understand the transition rates to independent careers for graduate students and new PhDs. Another area that should be a high priority for research is the effects of international students and temporary workers on the US domestic workforce and S&E capabilities.

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[53] Integration of data among Federal agency sources that measure and track factors relevant to the national S&E workforce, such as Bureau of Labor Statistics, National Science Foundation SESTAT, and the Census Bureau, would enable more productive research on S&E workforce dynamics. NSF's data system on the science and engineering labor force (SESTAT) is able to add data only once a decade on individuals with only foreign-school science and engineering degrees. This is done through an NSF follow-up survey on college-educated individuals identified through the decennial U.S. census. Thus anyone with foreign, but not U.S. S&E degrees who entered the United States after April 1990, will not be surveyed by NSF until October 2003. NSF's data are unique in having large samples of individuals with science and engineering degrees with information on both field of degree and occupation. Data from the Bureau of Citizenship and Immigration Services (BCIS, formerly the INS) include the occupation of those entering under many visa classes, but not degree level or field, and not the number currently in the United States at any point in time. The Bureau of Labor Statistics' monthly Current Population Survey will pick up individuals in S&E occupations, but there is no information on field of degree, and sample sizes (approximately 60,000 households) are not sufficient to make estimates of foreign-born scientists by occupation and degree.

[54] There are few methodological tools to support such action. For example, good models of supply and demand for doctoral scientists and engineers are lacking and notoriously difficult to construct (see *Forecasting Demand and Supply of Doctoral Scientists and Engineers,* National Academy Press, 2000). While data on PhDs in academia are good, data on career paths of PhDs in industry are lacking. Demand in specific fields can be subject to short-term fluctuations, while the supply of domestic degree holders is relatively inelastic in the short run due to the long lead time necessary to complete a PhD.

[55] See, for example, Building Engineering & Science Talent (BEST), *The Quiet Crisis/Falling Short in Producing American Scientific and Technical Talent*; National Science and Technology (NSTC), *Ensuring a Strong U.S. Scientific, Technical, and Engineering Workforce in the 21st Century*, April 2000; Educational Testing Service (ETS), *Meeting the Need for Scientists, Engineers, and an Educated Citizenry in a Technological Society*, May 2002.

As part of a multilevel, inclusive effort to attract more domestic students to S&E studies and careers, there is a need to provide better and more accessible information, career guidance, and early experience in S&E settings.[56] Students need to understand not only the opportunities offered by careers in science and engineering, but also the educational pathways to achieve such careers.[57]

Therefore, in addition to the long-term goal of understanding the dynamics of the S&E workforce, there is also an immediate need for a coordinated effort to develop a national clearinghouse of information to facilitate individual career decisions and publicize successful model programs. A centralized information resource should serve the needs of individuals, employers, guidance counselors, educational institutions and other stakeholders in the science and engineering workforce. It should enable the development and dissemination of effective strategies to attract and retain the best students in science and engineering studies and careers and also serve as a tool for career guidance for both students and science and engineering professionals already in the workforce.

RECOMMENDATION:

To support development of effective S&E workforce policies and strategies, the Federal Government must:

- **Substantially raise its investment in research that advances the state of knowledge on international S&E workforce dynamics;**

- **Lead a national effort to build a base of information on:**
  1. **The current status of the S&E workforce,**
  2. **National S&E skill needs and utilization and**
  3. **Strategies that attract high-ability students and professionals to S&E careers.**

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[56] At the program level, one successful example among many is NSF's Research Experience for Undergraduates (REU).
[57] NRC, *Reshaping the Graduate Education of Scientists and Engineers*, 1995.

PRECOLLEGE TEACHING WORKFORCE FOR MATHEMATICS, SCIENCE AND TECHNOLOGY

The workforce-related needs for science, mathematics and technology learning at the precollege level can be divided into two categories: first, the need for basic science and mathematics literacy of the entire workforce; and second, the need to provide the foundation for students to pursue college majors in science and engineering fields.[58] Recent "No Child Left Behind" legislation[59] explicitly addresses science and mathematics education at the precollege level and in effect establishes the expectation that public precollege education will produce adequate national literacy in science and mathematics, validated by regular student assessments in the K-12 system.

Reports over the last several decades (see Box D) have identified a quality precollege teaching workforce in mathematics, science and technology as key to achieving both science and mathematics literacy and to preparing students for advanced studies in science and engineering to meet workforce demands. Nonetheless, identified reasons for failure to attract and retain qualified individuals in precollege teaching remain inadequately addressed. These reasons include the low status of the teaching profession, an unsupportive working environment, frustration with low student interest, inadequate and poorly enforced training and certification standards for teachers, insufficient financial rewards, failure to provide long-term opportunities for advancement, and a non-enabling classroom environment.

In February 2001 The United States Commission on National Security/21st Century identified the condition of precollege education as a critical national security problem: "we do not now have, and will not have with current trends, nearly enough qualified teachers in our K-12 classrooms, particularly in science and mathematics...A continued shortage of the quantity and quality of teachers in science and math means that we will increasingly fail to produce sufficient numbers of high-caliber American students to advance to college and post-graduate levels in these areas."[60] Indeed, 1999 estimates by the Department of Education indicate the need for 240,000 middle and high school mathematics and science teachers over the next 10 years, 70 percent of whom will be new to the teaching profession.[61]

The Board recognizes that the precollege science, math and technology teaching workforce is a dynamic resource, drawing its members from a range of educational and occupational backgrounds. Recruitment and retention strategies must be creative and flexible, responsive to potential entrants and reentrants to the teaching workforce at different points in individual careers and from a variety of socioeconomic and ethnic backgrounds. Entering

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[58] See Box E: NSB report on *Preparing Our Children: Math and Science Education in the National Interest*, 1999, listing the recommendations of that report.
[59] HR-1, 2001.
[60] The United States Commission on National Security/21st Century, *Road Map for National Security*: 40.
[61] National Commission on Mathematics and Science Teaching for the 21st Century: 29.

teachers include new baccalaureate-level graduates with education, science, or engineering majors, as well as professionals at various stages of their careers and from all levels of science and engineering education – from baccalaureate to postdoctorate. They include S&E professionals and retirees from careers in industry, government or the military as well as from academia. A critical barrier to participation in precollege teaching by scientists, mathematicians and engineers is the separation between precollege teaching and other science and engineering professions.

Further, even if a sufficient number of students and professionals with strong backgrounds in their subject areas can be attracted to precollege teaching, additional efforts are needed to retain them in teaching. Job satisfaction for well-qualified teachers requires a supportive working environment.

RECOMMENDATION:

In partnership with other stakeholders[62], the Federal Government should act now to attract and retain an adequate cadre of well-qualified precollege teachers of mathematics, science, and technology.

To make precollege teaching more competitive with other career opportunities, resources must be provided to:

- Compensate teachers of mathematics, science and technology comparably to similarly trained S&E professionals in other sectors;
- Reinforce the profession of teaching as an important and rewarding career and include teachers as an integral part of the scientific and engineering professions;
- Support classroom training and expedite teacher certification of scientists and engineers from professions other than teaching;
- Support in-service training to enhance classroom skills and subject matter expertise; and
- Support programs in teacher preparation at institutions that succeed in integrating faculty and curricula of schools of engineering and science with schools of education.

To improve effectiveness of precollege teaching, stakeholders must collaborate to:

- Support outreach efforts to K-12 by science and engineering professionals to motivate high-quality curricular standards and expand content knowledge for classroom teachers; and
- Support research on learning that better informs K-12 mathematics and science curricula and pedagogy development.

[62] Stakeholders include teachers, parents, students, employers, and S&E professionals; local school districts and schools; higher education faculty and institutions for S&E and teacher education; national and State certification bodies; S&E and teacher professional organizations; textbook and instructional materials publishers; sponsors of educational research; State and local governments; and Federal policymakers and agencies.

BOX D:
SELECTED SOURCES IDENTIFYING ISSUES IN ATTRACTING AND RETAINING PRECOLLEGE SCIENCE AND MATHEMATICS TEACHERS

A range of organizations have explored the conditions that make precollege teaching of mathematics and science particularly unrewarding to well-qualified teachers. A reflection of the unrewarding environment and more attractive careers outside of teaching is the higher attrition rate for mathematics and science teachers, exceeding not only that of other occupations, but also of other teachers (16 percent versus 11 percent and 14.3 percent, respectively). Moreover 40 percent of mathematics and science teachers leave because of job dissatisfaction, compared with 29 percent of all teachers, according to The National Commission on Mathematics and Science Teaching for the 21st Century. The reports below discuss the long-term, well- recognized problems involved in attracting and retaining precollege mathematics and science teachers.

The United States Commission on National Security/21st Century. "Education as a National Security Imperative," *Road Map for National Security: Imperative for Change*. February 15, 2001: 38-46.

National Science Board. "Teacher Preparation," in *Preparing Our Children/Math and Science Education in the National Interest*. Arlington, VA: National Science Foundation, 1999.

______. *Science & Engineering Indicators 2002*, 1-37, 38.

National Science Board Commission on Precollege Education in Mathematics, Science, and Technology. *Educating Americans for the 21st Century*. September 1983.

National Commission on Mathematics and Science Teaching for the 21st Century. *Before It's Too Late*. September 2000.

National Research Council. "The Continuum of Teacher Education in Science, Mathematics, and Technology: Problems and Issues" in *Educating Teachers of Science, Mathematics and Technology/New Practices for the New Millennium*, Washington DC: National Academy of Sciences, 2001: 30-40.

Box E:

Preparing Our Children/Math And Science Education In The National Interest (1999)

The Board believes that stakeholders must develop a much-needed consensus on a common core of mathematics and science knowledge and skills to be embedded consistently in classroom teaching and learning.

Recommendation 1: To implement the core recommendation through instructional materials:

1. The NSB urges (a) broad adoption of the principle of citizen review; (b) active participation on citizen advisory boards by educators and practicing mathematicians and scientists, as well as parents and employers from knowledge-based industries; and (c) use of public forums to foster dialogue between textbook publishers and advisory boards in the review process.

2. Accompanying this process should be an ongoing national dialogue on appropriate measures for evaluation of textbooks and instructional materials for use in the classroom. The NSB urges professional associations in the science community to take a lead in stimulating this dialogue and in formulating checklists or content inventories that could be valuable to their members, and all stakeholders, in the evaluation process.

Recommendation 2: To implement the core recommendation through teacher preparation and professional development:

1. The NSB urges formation of three-pronged partnerships: institutions that graduate new teachers working in concert with national and state certification bodies, and local school districts. These partnerships should form around the highest possible standards of subject content knowledge for new teachers, and aim at aligning teacher education, certification requirements and processes, and hiring patterns.

2. Mechanisms for the support of teachers, such as sustained mentoring by individual university mathematics, science, and education faculty, as well as other teacher support mechanisms such as pay supplements for board certification, should be implemented through the three-pronged partnerships.

Recommendation 3: To implement the core recommendation through the college admissions process, the NSB urges:

1. institutions of higher education to form partnerships with local districts/schools that create a more seamless K-16 system, increasing the congruence between high school graduation requirements in math and science and undergraduate performance demands; and,

2. faculty and student incentives that motivate interactions to reveal linkages between classroom-based skills and experiences and the demands on thinking and learning in the workplace.

Recommendation 4: To implement the core recommendation through research:

1. The National Science Foundation and the Department of Education must spearhead the Federal contribution to SMET education research and evaluation.

2. Overall, the investment should increase—by the Federal government, private foundations, and other sponsors—in research on schooling, educational systems more generally, and teaching and learning of mathematics and science in particular. To focus and deepen the knowledge base, an interagency Education Research Initiative, led by NSF and the Department of Education, should be implemented. It should be distinguishable as a joint venture within the agencies' respective research missions, and cooperatively funded.

US ENGAGEMENT IN THE INTERNATIONAL SCIENCE AND ENGINEERING WORKFORCE

It is more essential than ever to think about workforce development in a global context. Progress in science and engineering relies on knowledge and skills found throughout an international community. With the rise in electronic communication, knowledge is flowing faster and farther, enabling more widespread participation and competition in research and development. The US needs the perspectives and talents of both the native-born and foreign-born for the best possible S&E workforce. And most importantly, US students must be prepared for involvement in the complex world of international science and engineering.

The Board has addressed issues of US involvement in international S&E in a recent report, *Toward a More Effective Role for the U.S. Government in International Science and Engineering.*[63] That report documents the global dimension of S&E. For example, collaborative activities and international partnerships are an increasingly important means of keeping abreast of important new insights and discoveries critical to maintaining US leadership in key fields. In the industrial sector, research collaboration internationally is on the rise with the growth of R&D activities located overseas and a rising number of cooperative arrangements among US and foreign firms.

While the United States faces strong challenges, it has many competitive advantages in the global S&E labor market as it looks to the future. The United States experience with integrating immigrants into society and the economy is a major national asset and competitive advantage. The US has a rich tradition as an internationally diverse S&E workforce. It also has experience in educating large numbers of foreign students and there is strong public support for international education.[64] As expressed in congressional testimony by Dr. Bruce Alberts, President of the National Academy of Sciences: "International science and technology cooperation is an extremely effective way to leverage one of the defining strengths of the United States. We benefit from an extraordinary set of personal, professional, and cultural relationships due to the many people from other countries who are working in the U.S. science and technology enterprise, and due to the large number of science and technology leaders in other countries who have been trained in the United States."[65] Moreover, the United States like other nations can gain substantial benefits for the national science and technology enterprise from citizens working and studying abroad who serve as vital resources for knowledge exchange and entrepreneurial partnering.

Continued leadership of US universities in international education is an important component of US strength in S&E, drawing the best students and scholars to study and work in the United States. Since September 11, 2001, however, security-motivated policies and requirements – such as tracking

[63] See Box F for the recommendations of that report.
[64] According to a survey by the American Council on Education, the American public recognizes the importance of global involvement of US students and professionals and supports more international education opportunities, including study and internships abroad, scholarly exchanges, and opportunities to interact with international students. "Beyond September 11: A Comprehensive National Policy on International Education", ACE, 2002.
[65] Testimony before the Committee on Science, US House of Representatives, March 25, 1998.

foreign students in the Student and Exchange Visitor Information System (SEVIS) – have changed the climate for foreign students who wish to come to the United States. Host institutions are facing growing complications as they seek to maintain a healthy flow of international graduate students, postdoctoral researchers, and visiting scholars.[66]

Impact on S&E of visa policies

The Board looked in depth at the kinds of visas for entry into the United States and how these various visa categories are used.[67] Broadly described, the system is a mixture of visas for permanent residence or for non-immigrant status (e.g., temporary residence visas, such as H-1B, and student and exchange visitor visas). For permanent residence status, policy favors reunification of families. A relatively small percentage of immigration opportunities are geared to high-skill workers.

The major vehicle by which foreign workers join the Nation's S&E labor force is the temporary residence visa in various forms. About two-thirds of those attaining permanent residence who are classified as scientists and engineers adjusted into permanent status from a prior non-immigrant status. Of the two-thirds, 11 percent had been academic students, 7 percent visitors for pleasure, 6 percent exchange visitors and, significantly, 56 percent had been H-1B specialty workers.[68] The H-1B visa is a limited-term visa designed to address immediate demand for skills in the job market, as identified by employers. Demand for H-1B visas is dependent upon business cycles. Having the Nation's future skilled workforce needs met through a visa process that relies on the short-term needs of industry is not an effective long-term strategy.

The student visa (non-immigrant F visa) is intended for temporary study, as applicants must certify that they plan to return to their home country. In reality, the F visa often provides entree to permanent resident status. The best estimate is that about one-fifth of the foreign students moved both directly from F visas and indirectly through H-1B visas to achieve a permanent status in FY 1996.[69]

In summary, there are various pathways by which high-skill immigrants navigate from temporary to permanent status, but these pathways are undertaken at the initiative of individuals, not promoted by the design of immigration law. In light of growing international competition for high-skill students and professionals in S&E, the United States needs visa and immigration policies that provide a clearly understood and straightforward set of options for foreign S&E students and workers.

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[66] Willie Schatz, "Congressional committee hears tales of ongoing problems with visas and SEVIS," *The Scientist*, March 27, 2003.
[67] Report commissioned by the NSB: "State of Knowledge on the Flow of Foreign Science and Technology Workers to the United States," B. Lindsay Lowell, Institute for the Study of International Migration, Georgetown University (see Appendix V).
[68] Ibid:11.
[69] Ibid: 8.

RECOMMENDATION:

During the current reexamination of visa and other policies concerning the mobility of scientists and engineers, it is essential that future US policies:

- **Strengthen the capacity of US research universities to sustain their leadership role in increasingly competitive international S&E education;**
- **Strongly support opportunities for American students and faculty to participate in international S&E education and research; and**
- **While enhancing our homeland and national security, maintain the ability of the United States to attract internationally competitive researchers, faculty and students.**

Box F:
Toward a More Effective Role for the U.S. Government in International Science and Engineering (2001)

In February 1999, the NSB established a Task Force on International Issues in Science and Engineering, charged to develop recommendations for strengthening the Federal institutional framework of policies and agency relations that support S&E research and education in an international setting and for an effective leadership role for the National Science Foundation (NSF) in international science and engineering in the 21st century. Based on the task force study, the Board recommended:

The U.S. Government should move expeditiously to ensure the development of a more effective, coordinated framework for its international S&E research and education activities. This framework should integrate science and engineering more explicitly into deliberations on broader global issues and should support cooperative strategies that will ensure our access to worldwide talent, ideas, information, S&E infrastructure, and partnerships;

and recommended the following specific actions:

1. The Office of Science and Technology Policy (OSTP) should strengthen its international focus to ensure an effective, integrated, visible, and sustained role in monitoring, coordinating, and managing U.S. international S&E research and education activities. As part of this effort, OSTP should actively encourage Federal agencies to identify and increase the visibility of their international S&E research and education activities, to provide an adequate level of funding for these activities, and to allocate adequate funding and resources for their coordination and management. The Office of Management and Budget should prepare an annual international S&E budget crosscut, similar to its annual research and development (R&D) budget crosscut, that includes international activities found outside specifically designated international program budgets.

Box F (continued):

2. OSTP should encourage agencies to develop more effective mechanisms for gathering and disseminating information about U.S. collaboration and partnerships in international S&E activities and similar activities in other countries, with emphasis on fundamental research and S&E education.

3. The United States Government should promote the development of international S&E policy aimed at facilitating international cooperation in research and education. The formulation and implementation of policies related to areas such as immigration, intellectual property rights, and the exchange of scientific information and personnel should include consideration of their impact on international cooperation in research and education.

4. Federal agencies should encourage and support policies and programs that provide incentives for expanding participation in international cooperative research and education activities by younger scientists and engineers.

5. Federal agencies should encourage development of human and physical infrastructure for science and engineering in developing countries through partnerships with international, multilateral, and private organizations providing support to developing countries for S&E research and education.

6. The U.S. Government, especially the Department of State, with its primary responsibility for U.S. foreign policy, should recognize and address the importance of science and engineering in achieving its objectives. Mechanisms should be identified to improve communication among science officers, other U.S. embassy personnel, and science and engineering staff of other Federal agencies, including those working abroad, to facilitate sharing of information critical to planning and decision making, and to improve the general flow of information on critical S&E issues.

7. The U.S. Government should strongly endorse the spirit of the recommendations of the 1999 NRC report to the State Department and ensure that responses to those recommendations are implemented expeditiously. Because developing an appropriate U.S. capability in this arena requires a long-term concerted effort, effective change will require a multi-year, multi-Administration, and bipartisan response, with appropriate levels of funding.