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Needed: Reincarnation of National Defense Education Act of 1958

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This paper reviews the historical and current response of the United States to threats to its world leadership in scientific endeavors, with particular attention to the National Defense Education Act of 1958. The current status of the United States in mathematics, science, and engineering education is reviewed with respect to K-12 student achievement, K-12 teacher quality, numbers of degrees granted, and other indicators of international competitiveness. Concluding that we are a nation in peril, recommendations are made to enhance the likelihood that the United States will retain its preeminent position in science and technology and, therefore, provide for the national defense and economic wellbeing of citizens in an information age and global economy.

KEY WORDS: international comparisons; education policy; science and engineering workforce.

The purposes of this paper are (a) to analyze the status of mathematics, science and engineering education in the United States, and (b) to make recommendations that will enhance the likelihood that the United States can retain its preeminent position in science and technology and, therefore, provide for our national defense and economic wellbeing. Given the realities of the information age and global economy in which we live, we admit having two biases: (a) the United States must establish a world-class education system if it is to maintain its economic and military leadership role in the world; and (b) while all academic disciplines are important, mathematics, science, engineering, and technology play a special role in promoting the economic and national security of the United States. We limit our discussion to these disciplines.

To set the stage for our analysis, the first section briefly reviews four documents that have played or continue to play a major role in mathematics and science education in the United States (National Defense Education Act of 1958, *A Nation at Risk* (1983), and The National Goals of Education (1989) and a fourth document, *Road Map for National Security: Imperative for Change (2001)*, that offers a contemporary perspective. In this section, we also list some general findings from the National Assessment of Educational Progress (NAEP) and the Third International Mathematics and Science Study (TIMSS) data. The TIMSS and TIMSS-R data are relatively commonplace, having been analyzed in the media as well as professional journals, and therefore we do not attempt to explain the findings. However, these data are important in addressing whether we have achieved the National Education Goal in mathematics and science.

In the second section, we review the state of the American economy, using several National Science Foundation (NSF) indicators and National Center for Educational Statistics (NCES) data in answering the question of whether the United States is losing its competitive edge in mathematics and science. In the third section, we review the adequacy of the support and the qualifications of secondary mathematics and science teachers in the state of Texas and compare these findings with those from two other states. The fourth section focuses on mathematics and science programs in higher education and answers questions about the adequacy of the supply of graduates at the undergraduate and graduate levels. The fifth section

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analyzes the National Defense Education Act of 1958, suggesting modifications to meet the current crisis in mathematics and science education. Finally, the sixth section answers the question, "Are we a nation at risk or a nation in peril?"

FOUR DOCUMENTS

Document #1: National Defense Education Act of 1958 (NDEA)

Since World War II, few academic issues have dominated American education more than the need for improvement in science and mathematics. The launching of Sputnik by the Soviets in October 1957 shattered any notion of America's scientific dominance brought about by the Manhattan Project and other wartime technological innovations. Failure of the Naval Research Laboratory to launch a Vanguard rocket two months later raised additional questions about American prowess (*Historical importance of the NDEA and the establishment of NASA*, 1998). Viewed as an "educational emergency bill" by Congress, the National Defense Education Act was signed by President Eisenhower on September 2, 1958 and was followed by the establishment of the National Aeronautics and Space Administration (NASA) a month later.

Document #2: A Nation at Risk

Just 25 years later, in April 1983, the National Commission on Excellence in Education published *A Nation at Risk*, a scathing report on America's schools that still resonates in state legislatures across the nation. "Our nation is at risk," the report stated, and "Our once unchallenged preeminence in commerce, industry, science, and technological innovations is being overtaken by competitors throughout the world" (p. 1). *A Nation at Risk* pointed to declining test scores to make the point that:

> If an unfriendly foreign power had attempted to impose on America the mediocre educational performance that exists today, we might well have viewed it as an act of war. As it stands, we have allowed this to happen to ourselves. We have squandered the gains in student achievement made in the wake of the Sputnik challenge. Moreover, we have dismantled essential supports which helped make those gains possible. We have, in effect, been committing an act of unthinking, unilateral educational disarmament.
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> (p. 1)

The message was clear: If student achievement continued to decline as the United States moved from the industrial age into the information age, and *if* other nations produced better educated students, then the American economy would suffer. Indeed, *A Nation at Risk* catalyzed educational reform in K-12 and teacher education throughout the 1980s, 1990s and beyond. Education has remained at or near the top of the agendas of both political parties. This is no small achievement, given the fact that President Reagan vowed to abolish the Department of Education (Reagan, 1982).

Document #3: National Goals of Education (1989)

Charlottesville, VA, was the site of a conference of governors called by President George H. W. Bush in 1989 that produced six National Goals of Education, agreed upon by the 50 governors, and endorsed in the State of the Union Address (Bush, 1990). National Goal 4 is a major focus of this paper: "By the year 2000, American students will rank number one in the world in mathematics and science achievement" (U.S. Department of Education, 1994).

Has the United States achieved this goal? How well do our students perform in mathematics and science? Findings from several important sources address these questions.

NAEP data summary (*National Center for Education Statistics* (*NCES*), *2003*)

- Student performance in mathematics and science . . . has improved somewhat over the past three decades, but not consistently. Improvements have occurred over all ethnic/racial subgroups.
- Despite the improved performance overall, achievement gaps between various racial/ethnic subgroups persist and show no signs of narrowing since 1990.
- Gaps between males and females have largely disappeared, especially in mathematics.
- U.S. students are performing at or below the levels attained by students in other countries in the developed world.
- In international comparisons, U.S. student performance becomes increasingly weak at higher grade levels.

TIMSS (*1995*) *mathematics and science data summary* (*NCES*, *2001a*)

- U.S. 4th graders performed well in both mathematics and science.

- U.S. 8th graders performed near the international average in both.
- U.S. 12th graders scored below the international average and among the lowest of the TIMSS nations in mathematics and science general knowledge, as well as in physics and advanced mathematics.

TIMSS-R (1999) mathematics and science of eighth graders data (NCES, 2001b)

- U.S. eighth graders exceeded the international average of 38 nations in mathematics and science.
- In mathematics, U.S. eighth graders outperformed their peers in 17 nations, performed similarly to those in 6 nations, and performed lower than their peers in 14 nations.
- In science, U.S. eighth graders outperformed their peers in 18 nations, performed similarly to those in 5 nations, and performed lower than their peers in 14 nations.
- In the five mathematics content areas assessed, U.S. eighth graders performed higher than the international average in fractions and number sense; data representation, analysis, and probability; and algebra. They performed at the international average of the 38 TIMSS-R nations in measurement and geometry.
- In the six science content areas assessed, U.S. eighth graders performed higher than the international average in earth science; chemistry; life science; environmental and resource issues; and scientific inquiry and the nature of science. They performed at the international average of the 38 TIMSS-R nations in physics.
- The United States was one of 34 TIMSS-R nations in which eighth-grade boys and girls performed similarly in mathematics.
- The United States was one of 16 TIMSS-R nations in which eighth-grade boys outperformed eighth-grade girls in science.

Document #4: The Road Map for National Security: Imperative for Change

This document was developed by the U.S. Commission on National Security/21st Century (2001), whose 14 commissioners, including former Senators Hart and Rudman, concluded that "the U.S. need for the highest quality human capital in science, mathematics and engineering is not being met" (p. 30). To address this issue, the Commission made the following recommendations (pp. 32–46):

- The President should propose, and the Congress support, doubling the U.S. investment in science and technology research and development by 2010.
- The President should empower the Science Advisor to establish non-military R&D objectives that meet changing national needs and coordinate budget development within the relevant departments and agencies.
- The President should propose, and the Congress fund, the reorganization of the national laboratories, providing each with new mission goals that minimize overlap.
- The President should propose, and Congress pass, a National Security Science and Technology Education Act with four sections: (a) reduced-interest loans and scholarships for students to pursue degrees in science, mathematics, and engineering; (b) loan forgiveness and scholarships for those in these fields entering government or military service; (c) a National Security Teaching Program to foster science and mathematics teaching at the K-12 level; and (d) increased funding for professional development for science and mathematics teachers.
- The President should direct the Department of Education to work with the states to devise a comprehensive plan to avert a looming shortage of quality teachers.
- The President and Congress should devise a targeted program to strengthen the historically Black colleges and universities and particularly support those that emphasize science, mathematics and engineering.

Discussion

It is clear that U.S. students have improved their mathematics and science scores over the past two decades. It is equally clear, however, that students in other nations score well above U.S. students in both disciplines. Moreover, China and India, two of the largest countries in the world and two nations that have invested heavily in mathematics and science education, did not participate in TIMSS or TIMSS-R. Consequently, it seems fair to say that the United States has not met the National Education Goal of being first in the world in mathematics and science education. Although, as pointed out by Ravitch (2003, p. 8), the straight line drawn in *A Nation at Risk* between the quality of the schools and the health of the economy may be shaky, the two are interrelated. The U.S. Commission on National Security/21st Century was as unequivocal as *A Nation at Risk* in making this connection.

The next section examines selected indicators of the status of engineering, mathematics and science education in the world community.

IS THE UNITED STATES LOSING ITS COMPETITIVE EDGE?

This section opens with an overview of the shifts occurring in the world market place and the concomitant changes in science and engineering (S&E) demand and supply. To establish some baseline data, we examine the number of first university S&E degrees and doctoral degrees awarded in Asia, Europe, and North America in 2000. We then examine additional indicators: the number of foreign-born S&E workers in the United States; foreign investment in S&E education and R&D investments; U.S.-based authored publications and patent data; and, in the fourth section, the number of bachelor, master and doctoral degrees awarded in mathematics and science, as well as engineering and the information sciences, by American colleges/universities from 1970 to 2001.

Position of the United States in S&E

Following World War II, a rare combination of the factors of production—land, labor, capital, and entrepreneurs—aided and abetted by a cooperative government, a little "Yankee ingenuity" and an unequalled educational system—enabled the United States to emerge as the world's most powerful nation, both militarily and economically. Foreign students flocked to U.S. colleges and universities to learn the secrets of America's success. Control of the factors of production by a nation-state in the time of Adam Smith was believed to be fixed, but in the information age and global economy they were fluid and capable of being moved quickly to another nation. Over the next four decades, fewer and fewer "Made in America" products were available to U.S. consumers as American industries either moved overseas or outsourced the manufacturing of their products. Asian and European nations began investing heavily in S&E education. It is estimated that by 2005, one out of every 20 industrial technology jobs will shift to overseas, following several decades of the transfer of manufacturing jobs. This transfer of jobs—blue and white collar—threatens the U.S. manpower pool in the event of war.

Friedman (2004), in an article entitled 'Losing Our Edge?' sums up America's dilemma:

> Anyone who thinks that all the Indian and Chinese techies are doing is answering call-center phones or solving tech problems for Dell customers is sadly mistaken ... U.S. firms are moving serious research and development to India and China ... The bottom line: we are actually in the middle of two struggles right now. One is against the Islamist terrorists ... and the other is a competitiveness-and-innovation struggle against India, China, Japan and their neighbors.
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> (p. 27A)

Drucker (2004) sees significant changes in the world marketplace: "The dominance of the U.S. is already over. What is emerging is a world economy of blocs represented by NAFTA, the European Union, and ASEAN. There is no one center in this world economy." National Science Board chair, Warren M. Washington, believes that the days of U.S. benefit from lack of competition in the global S&E labor market are over. "The United States," he says, "is in a long-distance race to retain its essential global advantage in S&E human resources and sustain our world leadership in science and technology" (NSF, 2004, p. 1).

High-technology and knowledge-intensive service industries are driving economic growth in the United States and around the world. NSF's Johnson (2004) wrote: "For several decades, countries have strengthened their higher education systems in science and engineering fields as a strategy for development, based on the assumption that knowledge would bolster their economies." In 2001, U.S. high-tech industries accounted for 32% of the world output, and the United States was the leading provider of knowledge-intensive services, as well, providing approximately one-third of these services worldwide (National Science Board (NSB), 2003).

First University S&E Degrees

According to the NSF, more than 7.4 million students worldwide earned a first university degree, and about 2.8 million of the degrees were in S&E fields (NSB, 2004a, Chapter 2, p. 36). Asian

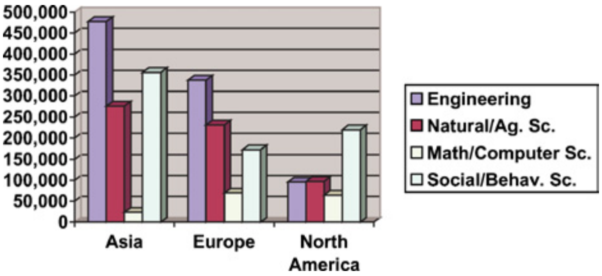

Fig. 1. First university S&E degrees in Asia, Europe, and North America, by field, 2000.

universities accounted for almost 1.2 million of the world's S&E degrees. Students in European universities earned more than 830,000 S&E degrees, and North American students earned more than 500,000 (NSB, 2004a, Chapter 2, p. 23). Historically, the United States has been a world leader in providing access to higher education, with roughly one-third of the college age cohort earning a degree. Today, at least nine other nations provide a college education to one-third of their college-age populations. Figure 1 shows the breakdown of S&E first degrees by major region in selected fields.

In the United States, S&E degrees account for about one-third of all bachelor degrees awarded. In 2001, China (59%), South Korea (46%), and Japan (66%) all exceeded that proportion. Compared with Asia and Europe, the United States has a relatively low percentage of its S&E degrees in engineering (NSB, 2004a, Chapter 2, p. 35).

Worldwide S&E Doctoral Degrees

According to NSF, 89,000 of the worldwide total of 114,000 S&E doctoral degrees were awarded outside the United States (NSB, 2004a, Chapter 2, pp. 26–27). Figure 2 shows the breakdown of S&E doctoral degrees by major region in selected fields. Europe leads both Asia and North America in the number of doctoral degrees awarded in natural/agricultural sciences. Europe and Asia both produce more doctoral degrees in engineering than North America. North American institutions produce more mathematics/computer science doctoral degrees than Asia, but not more than Europe. NSF staffer Johnson (2004) points out that Asian and European universities have increased their doctoral capacity in science and engineering, decreasing their dependence on the United States.

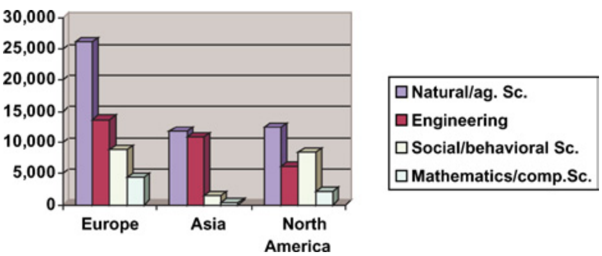

Fig. 2. S&E doctoral degrees in Europe, Asia, and North America, by field, 2000.

Non-citizen U.S. S&E Graduate Degrees

Non-citizens account for much of the growth in U.S. S&E graduate degrees over the past three decades. After graduation, these individuals add significantly to the workforce in whatever country they decide to take residence. In the period between 1977 and 2000, U.S. S&E master degrees awarded to foreign students increased from 7800 to 24,800, largely in computer science and engineering. In fact, in this same period, foreign students constituted 45% of the U.S. total of master degrees awarded in computer science and 38% of the master degrees awarded in engineering (NSB, 2004a, Chapter 2, p. 23).

Between 1985 and 2001, foreign students earned more than a third of S&E doctoral degrees awarded in the United States. In 2001, foreign students earned 49% of U.S. doctoral degrees in mathematics and computer science and 56% of the engineering degrees (NSB, 2004a, Chapter 2, p. 28).

R&D Investments in S&E

R&D expenditures are an investment in the future and, therefore, serve as an indicator of potential economic growth. The rapid growth sustained in the 1990s declined in 2001 and 2002, but R&D expenditures reached a new record of $276 billion in 2002 (NSB, 2004a, Chapter 4, pp. 4–5). In 2000, the United States spent more on R&D activities than all G-7 countries combined (NSB, 2004a, Chapter 4, p. 5).

The academic sector accounted for more than half (54%) of the R&D basic research conducted in the United States in 2002 and, although its share of funding has declined over the past three decades, the federal government continues to provide a substantial percentage of the total R&D support. In 1968, the federal government provided 68% of the funds for R&D performed in academic institutions; in 2001, it provided only 59% (NSB, 2004a, Chapter 5, p. 5). Between 1975 and 2001, significant shifts occurred in the share of funding for different disciplines from the federal government: engineering, life sciences, and computer sciences received increased funding, while funding declined for the physical sciences, the earth, atmospheric and ocean sciences, psychology, and the social sciences (NSB, 2004a, Chapter 5, p. 5). In most fields, the percentage of academic researchers with federal support was higher a decade earlier than it was in 2001 (NSB, 2004a, Chapter 5, p. 5).

Outputs of S&E: Research Articles and Patents

Although the output of scientific articles has grown substantially in Western Europe and several East Asian countries since 1992, American production has remained flat (NSB, 2004a, Chapter 5, p. 6). However, the United States still has the largest share of internationally authored papers and collaborates with the largest number of countries (NSB, 2004a, Chapter 5, p. 6).

In 2001, U.S. resident inventors received nearly 88,000 new patents, or about 53% of the total patents granted. Also, in 2001, U.S. academic institutions were awarded more than 3200 patents, a 10-fold increase since the 1970s (NSB, 2004a, Chapter 5, p. 6). As one might expect, the greatest number of patents were granted to a small number of research institutions and were highly concentrated in life sciences applications. Patenting in the United States by foreign investors shifted significantly in 2000 and 2001, when residents of Taiwan were first awarded more U.S. patents than residents of France or the United Kingdom (NSB, 2004a, Chapter 6, p. 4).

Discussion

Expert opinion and anecdotal data suggest that while the United States remains the most powerful nation in the world in economic and military strength, it is losing its competitive edge in science and technology. Europe and Asia are both awarding more undergraduate degrees in engineering and science than the United States. At the doctoral level, Europe is producing more graduates than the United States in both engineering and science, and Asia is producing more engineering graduates than the United States. The United States is producing more doctoral degrees in mathematics than Asia, but not more than Europe.

THE ACADEMIC PREPARATION OF MATHEMATICS AND SCIENCE TEACHERS

The quality of K-12 teachers is a critical factor in a nation's ability to compete in S&E. Although the United States seems to be moving toward a national system of education, responsibility for teacher quality currently rests with the states. Therefore, we look at teacher quality in Texas and compare it to two other states. Texas is of particular interest because of its influence on federal decisions of the Bush administration. In this section, we consider the adequacy of the number and quality of secondary mathematics and science teachers in Texas, the adequacy of the number and quality of the new teachers joining their ranks, and their possible effect on student achievement. We then look briefly at two other states of interest, California and Massachusetts.

K-12 Science and Mathematics Education

Numbers and Quality of Current Teachers

In 2002, the Texas high school teaching force included 11,552 teachers of mathematics and 9889 of science. Certification to teach 50% or more of the courses they were assigned to teach was held by 78% of the mathematics teachers. Of the remainder, 22% were not certified for most of their courses or not certified at the high school level, and 13% were not certified (Fuller and Alexander, 2002a). Students in seventh-grade mathematics were least likely to have qualified teachers, with 66.6% of their teachers qualified, followed by eighth-grade mathematics and Algebra I, where 73.1% of teachers were qualified (Fuller, 2002a). Also, less-qualified teachers were more likely to work in schools that served a majority of minority and/or economically disadvantaged students (Fuller, 2002b).

For high school science, the situation was worse. In 2002, only 64% of Texas high school science teachers were certified to teach 50% or more of the courses assigned. The remaining teachers were either teaching out-of-field (36%) or not certified (15%) (Fuller and Alexander, 2002a). Students of physics were least likely to have a qualified teacher, with only 55.1% of their teachers working in-field. In integrated physics and chemistry (IPC), 59% of the teachers were in-field (Fuller, 2002a). As with

Table I. Number of Texas Secondary Mathematics and Science Teachers Who Left the Profession

	1996	1997	1998	1999	2000	2001	2002
Mathematics	1907	2048	2280	2684	2786	3071	2900
Science	1536	1655	1805	2073	2253	2548	2304

Source: Fuller and Alexander (2002b), Texas State Board for Educator Certification.

mathematics, the socioeconomic level and ethnicity of the students served by the school were related to the qualifications of the teachers (Fuller, 2002b).

Large percentages of Texas teachers leave the profession annually. Table I shows the numbers of teachers of mathematics and science who quit each year since 1996. In 2002, the numbers of mathematics and science teachers who left constituted 25% of the state's teaching force in these disciplines.

Numbers and Quality of Entering Teachers

From 1993 to 2002, the number of high school mathematics and science teachers prepared annually by Texas educator preparation programs did not increase. Approximately 600 mathematics and 350 science teachers were prepared each year. In 2000, the numbers of science teacher program completers started to decline (Fuller, 2002c). However, completing a teacher education program is only one way to become certified in Texas. Already certified teachers may pass tests in new content areas, and teachers prepared in other states may be recruited. Table II shows the numbers of teachers of mathematics and science initially certified in Texas by all means in 1995, 1999, and 2002. These numbers do not approach the numbers of teachers exiting the profession in these fields.

In 2003, the work of alternative certification programs, which include school districts, regional education service centers, community colleges, and privately-owned businesses, in Texas, led to modest increases in the numbers of mathematics and science teachers produced. Alternative certification candidates hold baccalaureate degrees with mathematics or science majors and enter fast-track programs that provide on-the-job support. Research on alternative programs suggests that graduates are as able to teach as those from regular programs but their attrition rate is higher (Allen, 2003). High attrition is a concern because inexperienced teachers are often noticeably less effective than their more senior colleagues (Hanushek *et al.*, 1996).

Table II. Numbers of Texas Teachers Initially Certified by Field in Science and Mathematics in 1995, 1999 and 2002

	1995	1999	2002
Biology	513	604	631
Chemistry	61	61	87
Mathematics	1611	1606	1663
Physics	24	21	23
Physical science	65	41	53
Science composite	169	222	304

Source: Fuller (2002d), Texas State Board for Educator Certification.

Implementing the teacher quality provisions of No Child Left Behind, Texas has encouraged teacher preparation in composite science rather than in specific science disciplines. The composite certificate qualifies a teacher for any of the sciences. The college major associated with this broad-field credential consists of the introductory courses in each of the sciences, a questionable preparation for guiding students in critical thinking and inquiry.

Texas Student Performance

From 1992 to 2003, Texas logged steady increases in student performance in mathematics on the Texas Assessment of Academic Skills (TAAS) (Texas Education Agency, 2004). However, NAEP mathematics scores of Texas eighth graders in 2003 were not significantly different from the 2000 state mean, but did exceed the 1990 average (NCES, 2004). In 1990, 55% of Texas eighth graders scored below basic and 11% scored proficient on the NAEP, compared to 31% below basic and 21% proficient in 2003, with most of the increase occurring before 2000 (NCES, 2004). Sixteen states, including California, ranked lower than Texas in the percentage of eighth graders proficient in mathematics on the 2003 NAEP, and 34 states, including Massachusetts, ranked higher.

Longitudinal TAAS data on student performance in science is not available; science was added to the state tests in 2003. NAEP science scores of Texas eighth graders in 2000 were lower than average for the nation and did not differ significantly from state scores in 1996 (NCES, 2002a). The number of Texas students performing at the proficient level was also lower than the national average. Six states, including California, ranked significantly lower than Texas on the percentage of eighth graders proficient in science, and 24 states, including Massachusetts, ranked significantly higher (NCES, 2002a).

Efforts to improve the achievement of Texas students in mathematics, successful through 2000, appear to be stalled. Continued improvement of student scores in mathematics and science seems unlikely in view of the drain of experienced and qualified teachers from Texas classrooms. At the same time, science has been added to the state's high stakes testing battery, and a new default curriculum requires more mathematics and science courses of high school students.

The Situation in Other States

To address how Texas compares to other states, we looked at two, California, because of its similar demographic challenges, and Massachusetts, because of its reputation for leadership in higher education in S&E.

In 2001–2002, more than 6.1 million students were enrolled in California schools that employed 292,010 teachers (California Department of Education, 2004). According to Title II reports (Hickey, 2003), enrollment in California teacher education programs increased by 47%, to a total of 77,705, in 2001–2002. If demand for this many teachers exists, there is a 25% annual rate of teacher attrition. California has three routes to teacher licensure, with 79% of entering teachers prepared through a university-based program, and the remainder composed of out-of-state teachers and persons certified through district internships (Burke and Errett, 2003). Table III shows the numbers of mathematics and science teachers in California who qualified for initial certification under each option in 2001–2002. The number of emergency permits issued by the California Commission on Teacher Credentialing far exceeded the number of entering credentialed teachers in each of these content fields in 2001–2002, with 1716 emergency credentials issued in mathematics and 1189 in biological science (Burke and Errett, 2003, p. 24).

Table III. Numbers of Teachers Credentialed in California by Source of Preparation (2001–2002)

	University	Districts	Out of State	Total
Biology	385	23	262	670
Chemistry	91	4	110	205
Geoscience	41	2	35	78
General science	47	0	0	47
Mathematics	318	11	299	628
Physics	35	0	72	107

Sources: Hickey (2003) Title II State Report, California, 2003, university-prepared teachers, Burke and Errett (2003), Tables II and III, district recommended and out-of-state teachers.

On the NEAP, Texas surpassed California in the percentage of eighth graders proficient in mathematics and science. However, NAEP mathematics results for California eighth graders in 2003 were higher than in both 2000 and 1990 (NCES, 2004). In science in 2000, California eighth graders scored lower than the national average and lower that the state 1996 average (NCES, 2002a).

Since 1998, Massachusetts has committed funding through the Teacher Quality Enhancement Act to recruit and retain teachers (Massachusetts Department of Education (MDE), 2003). In 1999, there were 71,412 FTE teachers in the state, with 41% of them age 50 or older (MDE, 2003, p. 135). Annual attrition was less than 5%. In 1999, the state hired 7530 teachers, 452 of them in science, and 527, in mathematics (MDE, 2003, p. 138). Waivers were issued for 1185 teachers in fields for which certified teachers could not be found. Chemistry and physics were among the fields with large proportions of uncertified teachers (MDE, 2003, p. 150).

University-based programs are the major source of teachers in Massachusetts. The state Title II report (Murphy, 2003) showed 13,391 candidates enrolled in teacher education programs in 2001–2002. However, the following numbers of mathematics and science teachers were prepared in that year by university-based programs: biology, 59; chemistry, 0; earth science, 0; general science, 15; mathematics, 62; and physics, 0 (Murphy, 2003). Clearly, these numbers do not begin to approach the demand in these fields, assuming continued stability in attrition. At the same time, the state Teacher Quality Enhancement endowment failed to generate adequate interest, leading the Department of Education to request approval to spend the principal.

In terms of student performance on the NAEP, 2003 mathematics scores of Massachusetts eighth graders exceeded their averages in 2000 and 1992 and were higher than the national average. The percentage of eighth graders scoring proficient was 38%, higher than in earlier years (NCES, 2004). In the 2000 science tests, Massachusetts eighth graders scored above average for the nation but not significantly higher than the state 1996 mean. The percentage of eighth graders scoring proficient was 42%, above the national average (NCES, 2002a).

These state profiles show that California, with a severe shortage of qualified teachers, is lagging in student performance. Massachusetts students fare far better than those in either Texas or California. In spite of a strong record, there are clear signs that Massachusetts is not maintaining the quality of its mathematics and science teaching force.

Discussion

The extent to which teacher production statistics are reported in aggregate masks the alarmingly low numbers of mathematics and science teachers entering the profession by any means. None of the three states profiled is coming close to producing or retaining the teachers needed to enable strong mathematics and science learning by K-12 students. Some trends in teacher preparation, such as alternative certification and board-field credentials, may increase the supply of teachers but do not address the lack of college majors in the fields of need.

HIGHER EDUCATION PROGRAMS IN ENGINEERING, MATHEMATICS AND SCIENCE

According to NCES data, of the 1,244,000 bachelor degrees conferred in 2000–2001, the largest numbers were in the fields of business (266,000), social sciences (128,000), and education (106,000). At the master level, the largest fields were education (129,000) and business (116,000). The largest fields at the doctoral level were education (6700), engineering (5600), psychology (4700), and biological/life sciences (4600) (NCES, 2002b).

S&E Status in Higher Education by Discipline

Mathematics

As Table IV shows, American colleges/universities awarded fewer degrees in mathematics at all three levels in 2001 than in 1970; approximately 57% fewer bachelor degrees, 40% fewer master degrees, and 17% fewer doctoral degrees. In the

Table IV. Degrees Awarded by Degree Level and Gender of Recipient: 1970, 1990 and 2001

	Bachelor degrees			Master degrees			Doctoral degrees		
	Total	Men	Women	Total	Men	Women	Total	Men	Women
Mathematics									
1970	27, 442	17, 177	10, 265	5, 636	3, 966	1, 670	1, 236	1, 140	96
1990	15, 176	8, 236	6, 940	4, 146	2, 568	1, 578	966	794	172
2001	11, 674	6, 107	5, 567	3, 373	1, 962	1, 411	1, 024	729	295
Chemistry									
1970	11, 617	9, 501	2, 116	2, 146	1, 666	480	2, 238	2, 056	182
1990	8, 289	4, 965	3, 324	1, 711	1, 038	673	2, 100	1, 597	503
2001	9, 822	5, 047	4, 775	2, 009	1, 184	825	1, 980	1, 349	628
Physics									
1970	5, 333	5, 004	329	2, 205	2, 047	158	1, 544	1, 507	37
1990	4, 193	3, 514	679	1, 819	1, 523	296	1, 265	1, 135	130
2001	3, 362	2, 638	724	1, 244	1, 000	244	1, 204	1, 040	163
Biological sciences/life sciences									
1970	35, 743	25, 333	10, 410	5, 728	3, 805	1, 923	3, 645	3, 050	595
1990	39, 530	19, 412	20, 118	4, 765	2, 302	2, 463	4, 093	2, 577	1, 516
2001	60, 553	24, 549	36, 004	6, 344	2, 689	3, 655	4, 600	2, 572	2, 028
Engineering									
1970	44, 770	44, 433	337	15, 597	15, 428	169	3, 446	3, 430	16
1990	64, 705	54, 732	9, 973	23, 995	20, 726	3, 269	4, 894	4, 479	415
2001	59, 258	47, 344	11, 914	26, 523	20, 895	5, 628	5, 501	4, 565	927
Computer sciences/information sciences									
1970	2, 388	2, 064	324	1, 588	1, 424	164	128	125	3
1990	25, 083	17, 726	7, 357	9, 324	6, 563	2, 761	676	584	92
2001	41, 954	30, 347	11, 607	16, 038	10, 606	5, 432	768	632	136

Source: NSF, SRS (2004a).

Table V. Degrees Awarded by Racial/Ethnic Group in 1999–2000

	Total	White	Black	Hispanic	Asian/Pacific Islander	Indian	NR Alien
Mathematics							
Bachelor	11, 674	8, 657	874	673	983	54	433
Master	3, 373	1, 676	128	77	227	10	1, 255
Doctoral	1, 106	494	17	12	75	2	506
Physical science and science technology							
Bachelor	18, 385	14, 213	1, 189	654	1, 631	115	583
Master	4, 841	2, 983	132	95	276	19	1, 336
Doctoral	4, 018	2, 172	73	75	217	15	1, 466
Biological sciences/life sciences							
Bachelor	63, 532	45, 281	4, 878	3, 328	8, 284	391	1, 370
Master	6, 198	4, 336	232	250	615	27	738
Doctoral	4, 867	2, 915	109	145	439	8	1, 251
Engineering							
Bachelor	58, 427	40, 148	3, 161	3, 194	7, 059	336	4, 529
Master	25, 596	11, 705	700	770	2, 530	68	9, 823
Doctoral	5, 384	2, 061	97	91	402	5	2, 728
Computer sciences/information sciences							
Bachelor	36, 195	22, 234	3, 541	1, 836	5, 521	174	2, 869
Master	14, 264	4, 658	590	263	2, 172	29	6, 552
Doctoral	777	310	17	14	61	0	375

Source: NSF, SRS (2004b).

same time period, American colleges/universities awarded 839,730 bachelor degrees in 1969–1970 and 1,244,171 bachelor degrees in 2000–2001, an increase of nearly 33%. In other words, America's business and industry and public and private research facilities, as well as its public/private schools, community/junior colleges, and colleges/universities had a smaller number of mathematics majors available to them in 2001 than in 1970. With the overall increase in school enrollments, the increase in the number of students taking mathematics courses, and increases in required courses in mathematics, the supply of bachelor degrees in mathematics is clearly inadequate. The number of master degrees awarded is inadequate to meet the needs of community/junior colleges, as is the number of doctoral degrees for America's colleges/universities. Postsecondary institutions will soon experience many of the same staffing problems as the public schools.

In fall 2000, although high school mathematics requirements increased significantly in the 1990s, 71% of higher education institutions offered remedial mathematics courses, as did most public 2-year institutions (97%). Remedial courses were also more likely to be offered in public 4-year institutions (78%) than in private 4-year institutions (49%) (NSB, 2004b, pp. 1–2).

Over the past three decades the gap by gender of mathematics degree recipients is closing at all three levels (Table IV). Secondary school test scores corroborate this finding. Table V shows the huge gap that exists between White students and Black/Hispanic students earning degrees in mathematics at each of the levels. The paucity of Black/Hispanic students earning degrees in mathematics explains, in part, why institutions are unable to hire minority mathematics faculty.

Chemistry

As Table IV shows, American colleges/universities awarded fewer degrees in chemistry in 2001 than in 1970; more than 15% fewer bachelor degrees, 6% fewer master degree, and 11.5% fewer doctoral degrees. However, the decline in the number of chemistry degrees was not nearly as precipitous in the same time period as occurred in mathematics. Nonetheless, competing in a global economy and building a world-class educational system requires large numbers of chemists at all degree levels.

Improvement is noted in the number of women attracted to the field of chemistry. At the bachelor degree level, in 1970, only 18% of the degrees were awarded to women, but in 2001, women received

48.6%. Women received 8% of the doctorates in 1970 and 31.7% in 2001.

Physics

Although introductory courses and new programs in the physical sciences are likely to sustain departments of physics, physics, as a discipline, will be added to the Academic Endangered Species List within the next decade if enrollment trends continue. The one bright spot in the data over the past three decades is the increased number of women earning degrees in physics. In 1970, only 6% of bachelor, 7% of master, and slightly more than 2% of doctoral degree earners were women (Table IV). In 2001, 21% of the bachelor, nearly 20% of the master, and 13.5% of the doctoral degrees were awarded to women.

When one considers that there are approximately 15,000 school districts in the United States, it is obvious that very few schools are able to employ a certified teacher with an initial degree in physics. It is equally obvious that America's 1600 community/junior colleges and 3000 universities will experience similar shortages due to the paucity of advanced degrees in physics.

Given the importance of physics to S&E, the decline in graduates in this field is a problem of enormous proportions. It would not be an exaggeration to say that unless this problem is addressed immediately, the United States is unlikely to be able to compete effectively with Asia and Europe in either the information society or the global economy.

Table V shows the racial/ethnic breakdown of degrees conferred in the physical sciences and science technology programs in 1999–2000. At the baccalaureate level, the White cohort dominates the field (77%), with the Asian/Pacific Islander cohort in second (8%), and the Black cohort in third (6.5%) place. Fifty-four percent of the doctoral degrees in this field were awarded to Whites, 36.5% to Non-Resident Aliens, and 5% to Asian/Pacific Islanders. More Hispanics, as well as Blacks and other minorities, need to be brought into the physical sciences.

Biological Sciences/Life Sciences

Unlike the physical sciences, the biological sciences/life sciences (Table IV) have grown over the past three decades, especially at the baccalaureate level. In 2001, more than 60,500 degrees were awarded compared to about 36,000 in 1970. The increase at the master and doctoral level was not large, but the rapid increase in degree production at the undergraduate level bodes well for future graduate programs. Historically, more women have received degrees in the biological/life sciences than in the physical sciences and this condition continues.

Whites (Table V) received 71% of the bachelor degrees, nearly 70% of the master degrees and 60% of the doctoral degrees awarded by American universities in 1999–2000. Asian/Pacific Islanders received 13%, Blacks 7.7%, and Hispanics 5.0% of the bachelor degrees awarded. At the doctoral level, Whites earned nearly 60% of the degrees and Non-Resident Aliens were awarded 25.6%.

Engineering

After nearly two decades of expansion in the United States, the number of engineering doctoral programs in the United States declined for the first time in 1999. Between 1970 and 1990, the number of bachelor degrees and master degrees in engineering awarded by U.S. institutions increased significantly (Table IV). Doctoral degrees awarded in the same time period also increased, but not as dramatically. In 2001, fewer bachelor degrees were awarded than in 1990, but the number of master and doctoral degrees awarded increased modestly.

The most dramatic change was in the number of women receiving engineering degrees at all levels. The percentage increased from less than 1% of the total degrees awarded at all levels in 1970 to 20% of the bachelors, 21% of the master, and 17% of the doctorates in 2001.

Whites received more than 68% of the bachelor degrees awarded in 1999–2000; 46% of the master degree and 38% of the doctoral degrees (Table V). Non-Resident Aliens received 7% of the bachelor degrees, 38% of the master degrees, and slightly more than 50% of all doctoral degrees. Fewer than 100 Blacks and 100 Hispanics received doctoral degrees in engineering in 1999–2000. Asian/Pacific Islanders received 12% of the bachelor degrees awarded, nearly 10% of the master degrees, and 7% of the doctorates.

Computer Sciences/Information Sciences

Computer sciences/information sciences have experienced enormous growth in Asia, Europe, and the United States. Table IV shows this growth in the United States. In 2001, nearly 42,000 bachelor degrees were awarded in computer/information sciences compared to fewer than 2400 in 1970. The growth in the number of master degrees in the field also increased significantly, going from about 1600 in 1970 to over 16,000 in 2001. At the doctoral level, the increase in degrees jumped from 128 in 1970 to 768 in 2001.

Table IV also shows the gender of recipients of computer/information science degrees in 1970, 1990 and 2001. At the bachelor level, only 1% of the recipients were women in 1970, but that number changed to 21% in 1990 and to 27% in 2001, with increases at the advanced degree levels, also.

Table V provides data on the number of computer/information sciences degrees awarded in 1999–2000 by racial/ethnic groupings. In this field, 61.4% of the bachelor degrees were awarded to Whites, with 15% to Asian/Pacific Islanders, and nearly 8% to Non-Resident Aliens. The numbers shift dramatically at the master degree level with nearly 46% of the degrees awarded to Non-Resident Aliens, 32.7% to Whites, 15% to Asian/Pacific Islanders, and the remaining 5% to Black, Hispanic and American Indian candidates.

Discussion

The United States conferred fewer bachelor, master and doctoral degrees in mathematics, chemistry and physics in 2001 than it did in 1970. On the other hand, in the same time frame, more degrees, at all levels, were awarded by American universities in biological sciences/life sciences, computer sciences/information sciences and engineering. However, if the United States is to remain competitive with Asia and Europe in S&E, new ways must be found to encourage and support students and programs in mathematics, chemistry and physics in schools and universities. It is hard to understand how the United States can sustain its dominance in military and economic security without first-class S&E programs, especially when nations in Asia and Europe have given high priority to these programs, and are now out-producing us in S&E personnel. Moreover, current demand and supply of S&E personnel may be masked by outsourcing. States and universities lack the resources necessary to bolster their mathematics and science programs. The sine qua non of national security and the economy in the 21st century is S&E education.

Almost all persons with degrees in S&E disciplines seek employment in business/industry, and few with degrees in physics, chemistry, or mathematics seek teacher certification in any state. This lack of investment in K-12 education may explain, in part, why fewer and fewer college students are majoring in these fields. Career choice is an exceedingly complex phenomenon and many variables enter into the decision-making process. However, it is difficult to understand how teachers who lack academic competence in chemistry, mathematics and physics can transmit basic knowledge and skills to their students and motivate them to enter S&E fields. Several alternatives to the present S&E issues are suggested in the fifth section.

The number of women in S&E has increased significantly since 1970 but is still far from balanced, especially today, when more women than men attend college. No nation, in the information age and global economy, can afford to educate only its males in S&E disciplines.

Viewed from the perspective of race/ethnic grouping, Whites dominated all of the S&E fields in which bachelor degrees were awarded in the United States in 2001. At the advanced degree levels, the percentages begin to change due, in part, to the participation of Non-Resident Aliens in graduate programs. Higher education institutions are often chided for not hiring more African American and Hispanic faculty. In 2001, more than 3000 institutions competed for 17 African American and 12 Hispanic mathematics doctoral graduates who were also sought by business/industry. Blacks earned about 10% of the bachelor degrees granted in computer sciences/information sciences, the only field in which Blacks came close to earning degrees in proportion to their numbers in the general population. Hispanics did less well, obtaining about 5% of the bachelor degrees in each of the S&E fields, 2–3% of the master degrees, and 2–3% of the doctoral degrees.

THE NATIONAL DEFENSE EDUCATION ACT OF 1958

Historically, the United States has been able to maintain a strong S&E labor force by attracting foreign scientists and engineers who were trained in their respective nations, avoiding the costs of attracting and training native U.S. citizens in these fields. Beginning in the 1980s, other countries, especially those in Asia and Europe, began to increase investment in S&E education and the S&E workforce at rates higher than the United States. According to the NSF (NSB, 2004b), in the time period of 1993–1997, Organization for Economic Cooperation and Development (ORCD) countries increased their S&E research jobs by 23%, outpacing the United States increase of only 11%. With more foreign domestic jobs and a slowing of student and S&E worker visas into the Unites States for security reasons, many foreigners have opted to stay at home (NSB, 2004b). Concomitantly, NSF notes a "troubling decline in the number of U.S. citizens who are training to become scientists and engineers, whereas the number of jobs requiring science and engineering . . . training continues to grow" (NSB, 2004b, p. 1). These trends threaten not only the security of the United States, but its economic wellbeing. In 2001, the United States Commission on National Security/21st Century put it this way in their report (pp. 38–39):

> The capacity of America's educational system to create a 21st century workforce second to none in the world is a national security issue of the first order. As things stand, this country is forfeiting that capacity. The facts are stark:
>
> - The American educational system needs to produce significantly more scientists and engineers, including four times the current number of computer scientists, to meet anticipated demand.
> - To do this, more than 240,000 new and qualified science and mathematics teachers are needed in our K-12 classrooms over the next decade . . .
> - However, some 34% of public school mathematics teachers and nearly 40% of science teachers lack even an academic minor in their primary teaching field.
> - In 1997, Asia alone accounted for more than 43% of all S&E degrees granted worldwide, Europe 34%, and North America 23%. In that same year, China produced 148,800 engineers, the United States only 63,000

The major message in the NSF 2004 S&E Indicators (NSB, 2004b) is summarized in the report (p. 1–2).

> If the trends identified in Indicators 2004 continue undeterred, three things will happen. The number of jobs in the U.S. economy that require science and engineering training will grow, the number of U.S. citizens prepared for those jobs will, at best, be level; and the availability of people from other countries who have science and engineering training will decline, either because of limits to entry imposed by the U.S. national security restrictions or because of intense global competition for people with these skills.

The report also notes that if action were taken today, a reversal of these trends would be 15–20 years away because career choices to prepare for S&E degrees must begin in the middle school. Without action, we could reach 2020 and find that the ability of U.S. research and education to regenerate has been irreparably damaged.

The United States has faced S&E educational crises a number of times in the past, and the federal government has taken remedial action. For example, to meet the needs of the nation as it moved from an agricultural to an industrial base, Congress passed the Smith-Hughes Act of 1917 to provide support for the teaching of agriculture and home economics in public schools. The GI Bill was passed by Congress in 1945 to provide educational opportunities for returning veterans. In the aftermath of Sputnik, the National Defense Education Act of 1958 was passed by Congress to strengthen mathematics, science, engineering and foreign language education in the United States.

We recommend updating the National Defense Education Act of 1958 with the recommendations in the *Road Map for National Security: Imperative for Change*, the Phase III Report of The United States Commission on National Security/21st Century. These two documents provide an excellent blueprint for Congress and the Executive Branch to begin addressing issues related to S&E programs in our schools, colleges and universities. We endorse the six recommendations of the Commission as well as the major provisions of the NDEA of 1958 (*Summary of major provisions of NDEA*, 1958). Obviously, several provisions of the NDEA are obsolete and need to be removed.

The major provisions therefore would include but not be limited to the following:

- Establish education as a national security imperative.
- Significantly increase the U.S. government's investment in science, especially in the physical sciences, and technology R&D by 2010.
- Empower the President's Science Advisor to establish non-military R&D objectives that meet changing national needs and to accept responsibility for coordinating budget development within the relevant departments and agencies.
- Fund and reorganize national laboratories; establish new mission goals for individual laboratories that minimize overlap.
- Establish a National Defense Education Act with four major components: (a) reduced-interest loans and scholarships for students to pursue degrees in science, mathematics, engineering, and foreign languages; (b) loan

forgiveness and scholarships for those in these fields entering government or military service; (c) create at least four National Security Teaching Centers to foster science and mathematics teaching at the K-12 level, including on-line and DVD courses; (d) develop early admissions programs in science and mathematics in at least one university in each state, and promote a cooperative relationship between secondary schools and community/junior colleges, especially in S&E fields.

- Provide salary stipends for elementary and secondary mathematics and science teachers similar to the ones provided for agriculture and home economics teachers under the Smith-Hughes Act of 1917.
- Require each state to develop a comprehensive plan to avert shortages of quality teachers. Plans should emphasize raising teacher compensation, improving infrastructure support, reforming the certification process, and expanding existing programs targeted at districts with especially acute needs.
- Devise a targeted program to strengthen minority enrollments in S&E fields, especially in historically Black colleges and universities.

There are about 15,000 school districts in the United States. In 2001, colleges and universities produced fewer than 12,000 bachelor degrees in mathematics, less than 10,000 bachelor degrees in chemistry, and less than 4000 bachelor degrees in physics. Moreover, only a few of these graduates are certified to teach. In the foreseeable future, it is unlikely that the United States will be able to correct the present dearth of secondary teachers with degrees in mathematics, chemistry and physics. Therefore, we recommend that these academic disciplines be taught in high schools on-line and/or by DVD. Teacher education to support this technology mediated curriculum should be provided for all teachers with less than a bachelor degree in the subjects that they teach or with broad or composite certification that fails to require depth of content knowledge in science.

IS THE UNITED STATES A NATION AT RISK OR A NATION IN PERIL?

In 1983, the National Commission on Excellence in Education declared that America's preeminence in commerce, industry, science, and technological innovation had been squandered by an inept school system and that the nation was, indeed, at risk. NAEP, TIMSS and TIMSS-R data show that U.S. students have improved their mathematics and science scores over the past two decades. However, students in a number of nations score well above U.S. students. Moreover, China and India, two of the world's largest countries, are nations that have invested heavily in mathematics and science education but have not participated in TIMSS or TIMSS-R.

At the university level, since the 1980s, other countries, especially in Europe and Asia, have increased their commitment to S&E education and workforce at rates well above the United States. In 2001, S&E degrees accounted for about one-third of all bachelor degrees in the United States, 59% of all degrees in China, 46% of all degrees in South Korea, and 66% of all degrees in Japan. Compared with Asia and Europe, the United States has a relatively low percentage of its S&E degrees in engineering. In addition, according to NSF data, 89,000 of the worldwide total of 114,000 S&E doctoral degrees were awarded outside the United States.

In 2001, other indicators show that U.S. resident inventors received about 53% of the total patents granted. The United States has the largest share of internationally authored papers and collaborates with the largest number of countries, as well. Moreover, in 2000, the United States spent more on R&D activities than all G-7 countries combined.

According to a May, 2004 NSF Press Release, "The United States still leads in science and engineering, but uncertainties complicate the outlook" (p. 1). The window of opportunity is narrowing for the United States to retain its dominance in science and technology in the information age and global economy. Several European and Asian nations threaten U.S. leadership. NSB Chair Washington (NSF, 2004) sums up the current status of S&E education in the United States: "For many years we have benefited from minimal competition in the global S&E labor market, but attractive and competitive alternatives are now expanding around the world. We must develop more fully our native talent" (p. 1). Inaction by the President and Congress will result in the United States moving from being an "at risk nation" to a "nation in peril."

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