Statement of

Harold Salzman, Ph.D.
Senior Research Associate
The Urban Institute

Globalization of R&D and Innovation: Implications for U.S. STEM Workforce and Policy

Submitted to the

Subcommittee on Technology and Innovation of the
Committee on Science and Technology
U.S. House of Representatives

November 6, 2007

Mr. Chairman and members of the Committee, thank you for inviting me to speak on the topic of globalization, the offshoring of research and development (R&D), and the science, technology, engineering, and mathematics (STEM) workforce. My testimony will address questions about the impact of offshoring and whether the United States has enough scientists and engineers (STEM workers), whether they are getting the education they need, and whether STEM careers are attractive. My analysis draws on research conducted with my colleagues Leonard Lynn at Case Western Reserve University and Lindsay Lowell at Georgetown University and is funded by the Sloan Foundation and the National Science Foundation.[1]

We are examining how multinational firms are globalizing their engineering and innovation and changes in the science and engineering education pipeline. Science and engineering (S&E), high-end technology, and innovation work are being offshored as a result of firms' strategy and organization, global human capital development and flows, and the nature of innovation activity in emerging economies. There is no single cause of offshoring nor are many of the current policy recommendations likely to change the current course of offshoring. The question is what policies will enable the United States to prosper as the new global system develops.

The challenges facing the United States are immense and require new strategies for economic prosperity that do not depend on dominating science, technology, and innovation as the United States has done in the past. Although the depth and breadth of U.S. science, engineering, and innovation are not matched elsewhere in the world, the globalization of technology and innovation work by firms and the increasing globalization of U.S. universities are leading to the rise of centers of innovation across the globe. Within the next decade we should expect to see emerging economies become the location of significant leading-edge innovation even if no one country has the scope of innovation as in the United States. Some of the current policy approaches focus on the wrong responses (e.g., increasing the number of scientists and engineers, particularly through expanded immigration) while not developing approaches that address the current changes in the global landscape. Policies should focus on developing U.S. strengths that make it a key partner in developing global knowledge and innovation, thus enabling the U.S. to be the central node in a global innovation network.

Our findings about the changes in firm strategy, human capital flows, and innovation activity are the basis for analyzing which jobs in the United States are affected by the development of offshore work, skill and education requirements for STEM work in the United States, and STEM workforce supply, and for a set of policy recommendations.

---

[1] The projects are supported through grants from the Alfred P. Sloan Foundation and the National Science Foundation, (Human and Social Dynamics Program, #SES-0527584; Social Dimensions of Engineering, Science and Technology #0431755). Additional support was provided by the Ewing Marion Kauffman Foundation to study technology entrepreneurship and globalization. Research assistance was provided by Daniel Kuehn, Everett Henderson and Katie Vinopal.

The Urban Institute is a nonprofit, nonpartisan policy research and educational organization that examines the social, economic, and governance problems facing the nation. The views expressed are those of the author and should not be attributed to the Urban Institute, its trustees, or its funders.

Summary

The following findings and policy implications are developed from my research on the globalization of innovation and engineering, and the U.S. STEM workforce education and supply.

Which STEM Jobs Face the Greatest Competition from Offshore Sites?

- Nearly all STEM jobs in the United States are already or potentially in "competition" with offshore STEM jobs. The historical advantages of advanced industrial nations' S&E work will be short lived. Within the decade offshore science and engineering capabilities will rival those in the United States in many areas. The rising capabilities and experience of offshore workforces, changes in work process and communications, the potential transformation of product and service development and delivery, and innovation advantages in emerging economies are, in combination, creating strong innovation centers offshore.

- The prospects for the U.S. STEM workforce, for the most part, depend on whether there is global growth in demand and the share of that work that firms locate in the U.S. There will be some areas that the U.S. has clear advantage, and a great deal of work that will continue to be done in the United States because of the market demand here and the depth of resources and knowledge. The IT industry is one example of globalization that has led to stable employment levels in the U.S. but not growth commensurate with the global growth in the industry. This IT industry and employment trajectory will occur in an increasing number of STEM areas.

Supply and Demand for STEM Workers

- The available data indicate that the United States' education system produces a supply of qualified STEM graduates in much greater numbers than jobs available. If there are shortages, it is most likely a demand-side problem of STEM career opportunities that are less attractive than career opportunities in other fields. However, standard labor market indicators do not indicate any shortages.

- Although there have been steady increases in the numbers of U.S. citizens and permanent residents pursuing a STEM education at both the undergraduate and graduate levels, the number of graduate students on temporary visas has also grown. It is unknown whether this indicates students on temporary visas are filling a demand for graduate students that U.S. undergraduate colleges cannot meet (serving as a complement to the domestic supply) or whether universities and companies are substituting temporary visa students for academically qualified U.S. students. Most likely, it is some of both, and there is a need for further research to determine the extent to which different immigration flows are complements versus substitutes.

Implications for Science and Engineering Education

- The standard education measures indicate there are enough students with the requisite skills to succeed in science and engineering courses of study, and managers we have interviewed rarely if ever note a lack of technical skills among their STEM workers. At lower levels there are large educational deficits in all subject areas. Addressing these very real educational problems will improve overall efficiency and productivity in the economy. An exclusive emphasis on math and science and on the upper portion of the student population may come at the expense of improving education for the lower third of students.

- The skills STEM job applicants and workers lack are communication skills that enable employees to work across boundaries, coordinate and integrate technical activities, and navigate the multidisciplinary nature of today's technical work. While solid math, science, and technology education is necessary to form the foundation for skills required by STEM workers, globally competitive education must go far beyond training technically competent graduates. A broad education that incorporates a range of technical and social science and humanities knowledge is important for developing a globally competitive workforce. In this, the United States currently has an advantage over the emerging economies.

A new Framework for Economic Growth

It is necessary to develop a new framework for achieving economic growth and prosperity based on a "collaborative advantage" policy framework. In brief, it is an approach that builds strength through participating in the global supply of human capital and innovation in collaboration with other nations. In addition, rather than taking a zero-sum approach to innovation, economic growth, and prosperity, this approach is based on mutual-gain strategies in which the growth in global markets provides expanding economic and job opportunities in all countries.

The United States is currently the best positioned country, I would argue, to lead this effort to establish a "global commons" of mutually beneficial global innovation and STEM workforces because of its history of openness, diversity, and free flow of knowledge, and because it is home to companies that are now leaders in developing globally distributed innovation systems (Lynn and Salzman 2005). Learning how to maintain economic strength in this new world order, however, requires new policy approaches.

Background

Before examining these findings and policy implications in more detail, it is useful to understand the background to current globalization patterns. The important structural changes in the globalization of innovation involve changes in human capital flows and firms' organizational form, structure, and functioning. Additionally, there has been an "innovation shift" in which pioneering technology development is occurring in emerging economies. This leads us to

question the longstanding views about the inherent innovation advantages of advanced industrial nations and particular regions, such as Silicon Valley. Theories of "geographical stickiness" propose that some regions have a unique mix of firms, capital, culture, and talent that makes them spawning grounds for innovation. Although these regions are likely to remain strong, the emerging economies are developing regional innovation clusters and industries that, in some areas, will be on par with those in the advanced industrial nations.

Internationalization of the Workforce

U.S. graduate schools and the workforce have become internationalized over at least the past 20 years. Students on temporary visas (recent immigrants) have generally made up between 20 and 50 percent of graduates of science and engineering graduate programs (with a few exceptions, such as petroleum engineers, of whom over 75 percent are foreign student graduates[2]) since the late 1980s (see figure 1 for 1995 and 2005). Some programs, such as IT-related programs, experienced sharp spikes in the number of foreign student graduates in the late 1990s, but for most programs, there has been a slow increase or constant rate of foreign student enrollments over the past 20 years. Over this period, these graduates have entered U.S.-based firms and now make up a significant proportion of the science and engineering workforce, concentrated in particular occupations and industries (table 1). A number of these scientists and engineers have now moved into senior technical and middle- and upper-level management positions. These workers, now in decisionmaking positions within firms, have the experience, familiarity, and linkages to facilitate the location of science and engineering work globally.

De-integration of the Firm

Historically, firms tended toward ever-greater integration of all parts of their production and services systems. This led to growth in organizational size and the scope of activities and functions. Firms also were firmly rooted in their "home" geographies, which aligned a firm's economic performance with that of the nation in which it was based. Another structural shift that led to the current globalization of innovation began during the late 1980s. Outsourcing began as large firms started buying rather than making commodity parts in manufacturing enterprises. Firms then expanded the scope of outsourcing to the external acquisition of innovation and high value-added functions. This change in innovation strategy occurred throughout many industries and, in a remarkable shift, Wall Street now considers firms to be weak if they rely on strong internal R&D rather than external acquisitions of companies, innovations, or technologies (Lynn and Salzman, 2007). This change in organizational form is the foundation for the globalization of science and engineering work we are now witnessing. An international workforce facilitates this globalization by providing firms with the necessary cross-cultural experience and knowledge (it is argued that the more integrated organizational form and less international workforces of European and Japanese firms slowed their globalization, especially of high-level activities).

---

[2] Throughout this paper, "foreign students" refers to students on temporary visas (generally indicating students immigrating to attend school); "U.S. students" refers to both U.S. citizens and permanent residents. "Immigrant workers" is based on country of birth as identified in Census surveys.

Innovation Shift

The third structural change is in the nature of innovation activity. There are at least three types of innovation shifts that provide advantages to emerging economies. First, in such areas as IT products and services, the initial offshoring of low-level activity (e.g., Y2K remediation) led to offshore companies implementing highly structured and systematized methods of software development. As IT technologies mature, the innovation shifts from product development to process, which can lead to more reliable and secure software.

The second innovation change is in the types of innovation that come from the local context of the emerging economies. In previous stages of globalization, local innovation was confined to adapting existing products to local conditions. Now, the emergence of local innovation for local environments has not only global applications but can be a leading-edge innovation.

Third, innovation is occurring in both high-end and low-end technology. In the past, typically only high-end innovation pushed the technology frontier. Now, low-end innovation may provide opportunities for new technology development and high profit. For example, the high-end iPhone is predicted to capture something less than 1 percent of the global market (under 10 million units), whereas developing an innovative, cheap cell phone has potential sales in the hundreds of millions (China Telecom is already the largest cell phone company in the world with an estimated 300 million subscribers).

Importantly, innovation in emerging economy sites may be conducted in local or foreign-owned firms. Conversely, innovation developed in a company's home country in advanced industrial nations may be transferred to locations elsewhere in the world. Leading innovation in a U.S.-based company does not necessarily mean the innovation activity or its benefits will accrue to the United States—it doesn't mean that it won't, but the inherent or taken-for-granted advantage to the United States of U.S. company innovation is increasingly uncertain.

This analysis of the changes in the globalization of science and technology sets the background for considering the workforce implications.

Which STEM Jobs Face the Greatest Competition from Offshore Sites?

Little can be predicted about the inherent qualities of STEM jobs that make them more or less competitive vis-à-vis workers in low-cost countries. A number of analysts argue that certain types of work are unlikely to be offshored, such as very high-end science and engineering work or jobs that require face-to-face interaction. An analysis of the relative growth of industries and employment opportunities for the U.S. workforce may be more important than an analysis of which jobs are inherently limited to the United States. That is, overall market growth is more likely to sustain U.S. workforce growth than is an attempt to maintain an exclusive share of certain jobs. The current U.S. IT workforce, for example, is certainly smaller than if all the global IT work were being done here. Yet, the U.S. IT workforce is not appreciably smaller now than it was in the past because of the global growth in demand for software services. At the same time, large numbers of IT workers have been laid off or forced to change jobs as a result of global shifts in the location of different types of IT work.

Job Offshoring
As the supply of skilled workers develops across the globe, firms will not decide to locate work in the United States just because there is a large supply of skilled labor here. And, if the U.S. supply is adequate, as all indicators suggest, then simply increasing the supply will not make the United States more attractive to firms. What about the cost of STEM labor? Although cost is certainly important, especially in the initial phases of offshoring, over time it becomes less important, particularly for high-end work. The wage-cost differential is declining, and when we include the coordination costs of travel and communications, we estimate the *net* cost savings of offshore STEM work is well under 30 percent and shrinking. For the *highest* levels of work, firms are not likely to jeopardize their innovative capabilities for marginal cost savings on a comparatively small portion of their workforce and wage bill. Now this is not always true, and it is not true for lower-level S&E work, but for high-level work, cost often becomes a secondary factor, as I will explain.

In our research based on case studies at over 75 sites of 46 multinational and entrepreneurial firms, several technology and innovation patterns emerged (Lynn and Salzman 2007). First, firms typically begin by locating lower-level work in their offshore site, but as these sites develop their capacity—hiring and training more educated and skilled workers, attracting emigrants to return—they engage in "engineering creep," that is, the firms expand the range of work the offshore STEM workers do, sometimes as a complement to what is being done in the firm's home country sites, other times substituting for it. The progression up the "innovation value chain" is a new developing phenomenon, and we do not see any indication there are inherent limits to the level of activity that can occur in emerging countries. Human capital is becoming ever-more available, and financial capital is available as well. The large potential markets in China, India, Brazil, and elsewhere lead firms to justify investments even for expensive labs and development facilities in these countries.

Some argue that the path for the United States is to move to the top of the value chain with highly skilled work, or creative work, and to abandon low-skilled work (e.g., NCEE 2007). This seems an unrealistic scenario given the large numbers of current workers in lower skilled service jobs (e.g., restaurants, grocery stores, and department stores, combined employ over 15 million workers; see table 5a). Others identify jobs that can't be offshored as personal services work (jobs that require face-to-face interaction) (Blinder 2007). This proposition fails to account for the transformation that can occur in the structure of jobs requiring face-to-face interaction. For example, we visited a firm that does patent filings, legal and financial analyst work, and other types of highly skilled professional services. Their approach is to restructure high-end work so that only the bare minimum of face-to-face interaction is necessary. Thus, they claim many professional services can be reduced to 10 or 15 percent direct contact in the United States, while the vast bulk of the work is done offshore. Alternatively, the rise of medical vacations, for instance, transports the customer to the offshore site for personal service.

These examples illustrate that firms are examining a range of STEM jobs that can be globalized. Recall that fewer than ten years ago, the consensus was that software could not be developed by teams separated over long distances. Microsoft was known for consolidating nearly all

development in one physical location to facilitate knowledge transfer, typically transferring staff of acquired companies to their Redmond campus.[3] Even more recently, a number of high-tech executives said they wanted to keep their work located in the United States because “it helps to have a concentration of researchers in the same place, where they can interact over the water cooler and at the baseball game, as well as on the computer screen” (*Wall Street Journal* 2006).

Our research suggests that it is difficult to draw any firm conclusions about the types of STEM jobs or activities that will necessarily stay in the United States. Recent history in software services shows how rapidly an industry once thought to be safely ensconced in the United States can be transformed and geographically dispersed. Currently, multiple factors are driving the development of offshore capabilities, and the global strategies of firms go far beyond cost factors. Although some types of work may be difficult to conduct over long distances or asynchronous work shifts, firms respond to these limitations by restructuring how the work is done and by moving entire operational units to offshore sites.

However, our analysis does not indicate an imminent threat to higher-level S&E jobs: although globalization may limit the expansion of a firm’s U.S. workforce, firms are unlikely to immediately abandon their U.S. sites due to their workforce’s deep skill and experience. Firms’ large investments in facilities and people are not easily replicated elsewhere. Moreover, the United States still has knowledge and capacities within its universities and organizations that are not available in the emerging economies. At the same time, there are impending shortages of workers offshore with the necessary skills and experience, though we should expect emerging economies will develop these capabilities at levels approaching those of the United States in the not-too-distant future. As U.S. universities globalize, they provide the highest level knowledge, personnel, and experience to emerging economy universities. Although there may not be precipitous declines in U.S.-based S&E work, growth is likely to be faster offshore, and some types of work may have faster offshore growth in the short term, such as IT work.

For these reasons, current policy proposals that focus on skill development or increasing the size of the STEM workforce may be counterproductive. Without evidence of the corresponding demand for these workers, merely increasing the supply will potentially reduce the quality of jobs and discourage the next generation of students from pursuing STEM careers.

Supply and Demand for STEM workers

Common to many policy reports is a call for large increases in the STEM workforce, and improvement in K-12 math and science as the means of achieving this increase.[4] The data do not reflect the claim that U.S. students show declining interest in science and engineering fields, either in college or in entering the workforce. There was a one-time dramatic “Sputnik Spike” of

---

[3] In an analysis of Microsoft, Cusamano and Selby (1995, 12, 105, 244), found that co-location was necessary for the company’s strategy of “learning by doing” rather than having formal training programs to transfer knowledge. The industry’s model of tacit knowledge transfer let many at the time to conclude that software development required face-to-face interaction and was not amenable to being conducted over distance and teams in different time zones.

[4] The following sections draw on, and are excerpted from, an analysis by Lowell and Salzman (2007).

students entering STEM fields in the early 1960s, followed by a sharp decline and then a gradual increase beginning in the mid-1970s and continuing until today (see figure 3). The actual numbers of STEM college graduates has increased over the past three decades and held steady in recent years (figure 4). The "continuation rate" of S&E bachelor's graduates going on to graduate school, following the early 1960s spike and then decline, has also remained at a steady rate for the past two decades (figure 5). The major change since the 1960s, of course, has been the large increase in foreign-born students (on temporary visas) entering graduate school (figure 6) and the workforce (figure 2).

From 1993 to 2002, U.S. colleges produced on average about 380,000 STEM bachelor's degree graduates, over 70,000 master's degree graduates, and nearly 20,000 doctoral graduates. Is that enough? The answer is not straightforward. We need to know what the employment demand is, whether the overall supply of graduates interested in entering STEM employment is equal to or greater than the number of openings (demand), and whether individuals not entering STEM employment are pursuing other careers because they are not interested in a STEM career, or could not find a job, or are not qualified for the STEM jobs that are available.

Are There Enough S&E Graduates?

To begin, it is important to know whether the production of domestic STEM college students is anywhere near the apparent demand for STEM workers. Looking at graduates and workforce growth, we can estimate an order of magnitude but not a precise calculation. Net workforce growth does not account for replacement needs due to retirement or to workers changing careers, and the supply of college graduates doesn't account for workers entering the workforce without a college degree or without a STEM degree (e.g., in IT occupations, up to 40 percent of workers do not have a four-year college degree).

The overall STEM workforce totals about 4.8 million, which is less than a third of the 15.7 million workers who hold at least one STEM degree. STEM employment is also a fairly consistent one-third of STEM graduates each year. From 1985 to 2000, the United States graduated about 435,000 S&E students annually with bachelor's, master's, and doctoral degrees—that total includes only U.S. citizens and permanent residents (about 72 percent of STEM workers hold a bachelor's, 20 percent a master's, and 7 percent a doctorate degree). Over the same period, the net change in STEM occupational employment ran about 150,000 annually, such that the average ratio of all STEM graduates to net employment change was about three to one.[5] Of course, net employment growth is not a direct measure of employment demand or total job openings, since net growth does not include replacement for retirements or occupational quits, nor do these aggregate numbers indicate the types of workers sought (education level, experience, etc). It also does not account for non-STEM degree workers or immigrants entering STEM fields. Moreover, it does not address future changes in supply or demand. But it certainly is suggestive that plenty of STEM students have been graduating relative to employment growth in STEM occupations.[6]

---

[5] Calculations made by the authors based on data on graduates and S&E employment for every second year from 1985 through 2000; the ratio is based on three-year moving averages of net employment growth.

[6] This simple calculation appears not to square with a comparison of the annualized growth rate of STEM graduates and jobs from 1980 to 2000. That calculation finds that the annual growth rate of STEM graduates at all degree

Naturally, not all STEM graduates will enter a STEM job, whether because of a change in interest, because their qualifications are not adequate, or because they never intended to enter a STEM career in the first place. However, there is a surprisingly low rate of STEM retention for the 1993 to 2001 cohorts of STEM graduates. One to two years after graduation, 20 percent of STEM bachelor's are in school but not in STEM studies, while another 45 percent are working but in non-STEM employment (total attrition of 65 percent). One to two years after graduation, 7 percent of STEM master's graduates are enrolled in school but not in STEM studies, while another 31 percent are in non-STEM jobs (total attrition of 38 percent) (NSF 2006, table 3).

The STEM Job Market: What Is the Nature of the Demand?

The pathway from high school student to college graduate has a number of transition points that are the primary focus of current policy initiatives. The goal of these initiatives is to increase the flow into, and retention within, the STEM education pipeline. However, the data we have reviewed suggest that secondary and higher education systems are providing a more than adequate supply for industry's hiring needs. Of course, these are aggregate numbers, so there still could be shortages for particular occupations or industries. Also, targeted initiatives to increase the flow of underrepresented demographic and income groups are warranted to increase workforce opportunity and workforce diversity. But overall, addressing the presumed labor-market problems through a broad-based focus on the education system seems a misplaced effort. Whether increasing the supply of STEM-educated workforce entrants would have any significant impact on workforce supply (given a graduate pool already 50 percent larger than annual openings) is a question that requires a better understanding of the labor market for these graduates. Moreover, increasing the education supply with such low yields seems a highly inefficient approach without a better understanding of the factors involved in the transition rates at all points along the pathway.[7]

A few labor market studies, notably by Richard Freeman and colleagues (2004, 2006), have focused on the quality of STEM jobs. These studies conclude that the decline in the native STEM worker pool may reflect a weakening demand, a comparative decline in STEM wages, and labor-market signals to students about low relative wages in STEM occupations. Indeed,

---

levels is about a third of STEM employment growth (1.5 versus 4.2 percent annually). But the rate of growth argument is somewhat misleading, as the slower growth rate of STEM graduates is, as noted here, based on a far larger number than the smaller but more rapidly growing number of STEM jobs. At first blush, one might assume these sizable differences in growth rates bode poorly for the future, but projections at these rates of growth show that the number of graduates and jobs does not converge for about 20 years assuming current trends continue at the same rate (see Science and Engineering Indicators, Appendix Table 3-2, http://www.nsf.gov/statistics/seind06/pdf_v2.htm).

[7] There is little comprehensive, systematic research on how college students choose a STEM career, either on the process or the factors that influence those choices. Standard labor-market economics theory focuses on the marginal impact of wage rate differentials. Research on career counseling is focused on matching interests and occupations, based on the assumption that interests are more or less fixed. The science and engineering communities have launched education and outreach programs to high school students to increase interest in those fields. And some observers focus on the overall appeal of an occupation based on its job quality and content of work as important factors influencing its attraction to potential entrants. There is some research that sheds light on the role of these different factors in labor supply.

research finds that the real wages in STEM occupations declined over the past two decades and labor-market indicators suggest little shortage (Espenshade 1999). Some researchers see these demand-side market forces causing highly qualified students to pursue other careers. A well-accepted model of cyclical patterns of student and worker supply is the cobweb model (Freeman 1976). This research finds, in accordance with market mechanisms, that an increase in wages leads to an increase in job seekers but, in turn, a large supply of job seekers can depress wages. Declining wages will result in reduced student enrollments, although there is a lag in enrollment response. For example, research finds that a previous decline in mathematics enrollments through 1996 corresponded to this cycle (Davis 1997). For this reason, caution is needed in increasing the supply of STEM graduates, particularly at the graduate degree level, without considering the level of demand and impact on future supply.

Where's the Problem? Hiring Difficulties versus Labor Market Shortages and Perceptions about the Future of Science and Engineering

It is generally asserted, without much evidence, that education deficits are responsible for the difficulty employers experience in hiring. It is important to distinguish between the problems an employer may have hiring the people he or she wants and an actual shortage of workers or potential workers. Although there may, in fact, be a labor market shortage, all the evidence cited in various policy reports is entirely individual employer accounts of problems in hiring. The industries most vocal about labor market shortages and the need to import workers may be voicing unrealistic expectations of desired work experience more than deficiencies in the skills or education of a new hire, or just dissatisfaction with the cost of labor.

In previous research (Lynn and Salzman 2002), we found that managers in engineering and technology firms do not claim a shortage of applicants, nor do they complain about applicants with poor math and science skills or education. They do often note difficulty in finding workers with desired experience, specific technical skills, or a sufficient number of "brilliant" workers in the pool.[8] The complaint, quite often, appears to be one of unrealistic expectations, as unwittingly illustrated in a recent *BusinessWeek* (2007) article on labor shortages. In this article, a company president described the current labor shortage as follows: "There are certain professions where skills are in such demand that even average or below-average people can get hired." It is difficult to consider an inability to only hire above-average workers a labor market shortage. Complaints also reflect firms' dissatisfaction about the need to train new entrants; often at issue is whether firms or education institutions should shoulder the costs of training new hires.

Other than frustration at not having an applicant pool at the tail-end of the skill distribution, the skills deficits most likely to be mentioned are the "soft skills" of communication and their ease in working across organizational, cultural, and disciplinary boundaries (Lynn and Salzman 2002; Salzman 2000). In our interviews, science and engineering firms most often complain about schools failing to provide students with the nontechnical skills needed in today's firm.

[8] Employers may complain of difficulties in hiring experienced workers with specific skills, such as JAVA programmers with 10 years experience, but these "shortages" are not the result of insufficiencies in the education system.

It is also worth noting that, more generally, employers do not complain about the math and science skills of employees hired for professional positions. In a study of engineering skills, managers did not identify technical qualifications as a concern. Employers' complaints about math skills typically involve examples of retail workers who can't count change or clerical applicants who lack basic literacy. And even for these levels, the need is for a broad array of academic, social, and communication skills (Murnane and Levy 1996).

If, as we argue, there is a sufficient potential workforce and any shortages are due to the inability of firms to induce more of those who are STEM qualified into STEM careers, then it is important to examine other factors that influence career decisions and hiring difficulties. In addition to wages, there is also the impact of perceived career opportunities and uncertainty. The current heated debate about the offshoring of engineering and other high-skill work should be expected to affect students' career choices. Although some analyses find relatively small numbers of jobs lost to offshoring, the *perception* about *future* opportunity is likely to affect a student's career choices as much as, or more than, tallies of current jobs available. These perceptions are not just the result of inflamed media commentators; even the business community appears to be undecided about the future course of its job location decisions. For example, in a bid to increase visa caps, a number of high-tech CEOs discussed the demand their companies had for U.S.-based science and engineering workers to a *Wall Street Journal* reporter in June, 2006:

> Mr. McNealy says Sun does 75% to 80% of its research and development in the U.S. Craig Barrett, chairman of Intel Corp., says his company also employs most of its researchers in the U.S. and wants to keep it that way. The reasons? … "If engineering is happening here in the U.S., I think my children will have a richer work environment." (*Wall Street Journal* 2006)

However, college graduates might have been influenced by an announcement Sun made to Wall Street analysts in May 2005:

> Sun Microsystems Inc. has chosen four of its facilities around the world *to take the place of its Silicon Valley office as the research and development hub*…. "We are over-invested in high-cost geographies like the U.S., and underinvested in low-cost geographies like India," … the company's senior vice president of global engineering told reporters in Bangalore. [He] said the company will not lay off programmers in the U.S.—but won't hire many, either.… The company has reduced its staff to about 30,000, from roughly 43,000 four years ago. (Associated Press 2005; emphasis added)

One can imagine that companies who are offshoring would have hiring problems even with an adequate labor market supply in the United States. Similarly, IT executives calling for greatly increasing, or even completely removing, numerical caps on foreign worker visas (e.g. the H-1B) may be sending strong signals to students and current workers about diminished career opportunities. Human capital is a long-term investment and potential STEM students read all the tea leaves before investing. We have conducted interviews with current managers and engineers who believe that there is little future in entry-level engineering jobs in many industries, and IT in particular. Not only will it be difficult to fill mid-level and higher-level positions from an inexperienced workforce that never had an entry-level position, but several future generations of

workers, currently in school, are developing their work interests and career aspirations based on their perceptions about the future state of labor markets. A range of public policies, such as immigration policy and corporate practices such as offshoring R&D, affect the career choices of current workers and future generations as well.

Content of Engineering Work

There is also some evidence that the content of engineering work, and the overall working conditions are less appealing today than in the past. From our current study of engineering, we often heard engineers and managers noting the lack of motivating science and engineering "problems" or challenges, like those of the early days of IT, and the lack of national purpose that was evident during the heyday of the space program. Engineers and managers interviewed also pointed to changes in both the substance and process of engineering. Projects are larger, team efforts, and require more coordination and management (whether because of outsourcing, systems integration, or increased scale of the technology, such as large enterprise resource planning systems). Developing and building many types of technology may be more routinized and less challenging or interesting than before. As one colleague expressed it, "How many 'real' engineers does it take to build a bridge?"[9] These are attributes of both the intrinsic interest of the field and the cultural milieu, or zeitgeist, of science and engineering. Although these factors are difficult to measure, they were noted by interviewees as often as diminished job prospects in explaining why they would not enter the field today.

Some STEM graduates simply leave the field because they lose interest in the application of their training or, more prosaically yet, they find that the labor market pays more for them to take other jobs (e.g., Freeman 2006). It is thus important to examine the full spectrum of labor market signals that can influence student and worker career choices.

Finally, it is important to understand the different STEM labor markets by industry, occupation, geography, and demographic. The labor market studies examine market conditions that may influence career choice in the aggregate. Less often do these studies examine choices by different demographic groups on entering specific STEM occupations or industries. For example, some STEM occupations appear to attract large numbers of traditional STEM students—U.S. native white males—but in others females outnumber males, and other occupations are disproportionately filled by immigrants. It is important also to understand specific industry dynamics. The IT industry labor market may be different from that of biotechnology or mechanical engineering (e.g., 40 percent of the IT workforce does not have a four-year degree; biotechnology has one of the largest concentrations of Ph.D.'s in industry; engineers

[9] Michael Horrigan, an economist at the Bureau of Labor Statistics, suggests that between the advances in knowledge for many engineering undertakings and technology shifts, say in using more engineering software, the role of engineering has likely changed and it may be that fewer jobs involve the engineering challenge of yesteryear (Personal communication, January 13, 2006). In our studies of engineering, we find that outsourcing and offshoring lead to new engineering management layers and engineers comment that they now manage engineering projects rather than engage in "real" engineering. Others have commented that engineering is less central to "innovation" or at least product development than design, marketing, and other areas.

predominantly have only bachelor's degrees). Although the labor market analyses examine changes in relative wages for STEM jobs and non-STEM jobs with similar education requirements (e.g., other professional jobs), they have not so far determined what affects the industry and occupation decisions of today's young people who could potentially enter STEM careers.

Implications for Science and Engineering Education

This analysis of globalization has implications for both the specific educational needs of scientists and engineers and broader educational directions. First, I review the types of skills and education that businesses need as reported by managers in technology firms (Lynn and Salzman 2002). Second, I discuss the broader educational needs and goals implied by our analysis of global shifts in innovation and technology development and by an economic strategy based on collaborative advantage. Finally, I raise questions about the policy recommendations that the U.S. workforce skill and education efforts can or should be focused on "top of the value chain" jobs and the implications for the U.S. position in the global economy.

Skill Requirements
Over at least the past ten to fifteen years, organizational, technological, and business strategy changes have led to new skill requirements for engineers and other technical workers. The de-integration of technology activity requires engineers to work across organizational boundaries with suppliers. Products that incorporate or have tightly integrated technology of different types, such as electronic and mechanical technology, or different materials, require engineers to work across disciplines, both within and outside of engineering. Business strategy that places more emphasis on market-driven technology development also requires engineers to understand the business drivers as well as the technical drivers of product or service development.

These different boundary-spanning skills and abilities are increasingly important, especially in firms that are systems integrators or are at the higher value-added part of the development chain. Managers typically said that technical skills were fairly easy to find and not a distinguishing criterion between candidates. Setting good employees apart were their ability to communicate their ideas, to work with others on a team and with non-engineers, and other related social skills. These skills reflect the changes in the nature of engineering work, ranging from greater teamwork, working across disciplines, with customers, and interacting with customers and suppliers in developing and acquiring technology (Lynn and Salzman 2002).

More recently, the global distribution of engineering has added another layer of technically adept but non-technical positions. Increasingly the ability to span cultures and nations is a key attribute. In this respect, we found global engineers and managers were often not born in the U.S. though educated here. Their experience across cultures and mixed national identities allow them to move easily between, and manage across global sites of the company.

In summary, we consistently find employers in technology firms most valuing the boundary-spanning skills that require adroit communication and an ease at working outside of a narrow field of expertise or technical training. In nearly all cases managers found a plentiful supply of technically qualified applicants and hiring decisions were made on the basis of their non-technical skills. While many of these skills can be provided through broad-based, multi-disciplinary education, some of the skills appear to come from cross-national experiences. In most cases, although these people were educated in the United States they were not born here and had lived in more than one culture. Perhaps this can be taught, but it may also require educators to incorporate cross-national experiences as part of technical training.

Implications for Education Policy

Solid math, science, and technology education is necessary to form the foundation of skills required by STEM workers. However, globally competitive education must go far beyond training technically competent graduates. A broad education that incorporates a range of technical and social science and humanities knowledge is important for developing a globally competitive workforce (e.g., see Hill, 2007). In this, the United States may have an advantage over the emerging economies. Trying to compete on the basis of sheer numbers of technically competent scientists and engineers is untenable and probably not the basis for achieving sustainable economic growth. Further, it is unlikely that a deficit of technical skills in the U.S. is leading to global diffusion of S&E work and innovation.

Although small numbers of individuals are credited with creating breakthrough innovations, it may be a mistake to focus so keenly on education targeting the upper reaches of the technical workforce. Underestimated in many analyses is the role of lower-level workers in achieving high productivity and economic growth. For example, although innovating a better computer network server is important, it is the legions of network administrators and technicians that affect how much of the potential productivity gains are realized from the technology. Throughout many types of work, the skills and aptitudes of lower level workers have individually small but cumulatively large impacts on the economy. This requires better overall education, not just science and math, for lower-performing students and schools.

A common but mistaken view of future U.S. competitiveness focuses on maintaining a position at the “top of the value chain.” Some of these scenarios imply that in ten or so years most of the U.S. workforce will be employed in “creative work” with low-skilled jobs located in emerging economies or done by machine. This prescription errs in two respects. First, the workforce is unlikely to undergo a shift in its skill/job distribution of the magnitude implied by this model. The vast majority of the workforce currently are in jobs far from the level of “creative” and highly skilled work that is predicted to characterize the future U.S. economy. Wal-mart alone employs 1.2 million workers, with most earning less than $10 an hour. The combined workforce of just the restaurant and retail industries is more than twice the size of the entire core S&E workforce. Science and engineering jobs make up only 5 percent of all occupations, and even in highly

technology-based industries, such as electronics or aerospace, the S&E workforce is well under 50 percent. Only in computer systems design and architectural and engineering services does it exceed half of their total workforces (57 percent and 58 percent, respectively; see tables 2–4).

Secondly, this scenario assumes that the United States can dominate innovation and creative work globally. Every indication from our field work and review of current trends suggests it is highly unlikely that this work will be as geographically contained as it once was. As discussed above, firms have largely abandoned this old model and are globally distributing all types of work. It is not clear how the U.S. could achieve the dominance of global STEM work advocated in many policy reports when firms increasingly have “top of the value chain” work globally distributed.

The global position of the U.S. may be changing but the data do not suggest a precipitous decline in science, math, and engineering performance or an inability to educate large numbers of qualified scientists or engineers is the cause. At the same time, the large numbers of low academic performers *should* be a cause for concern and should be the focus of competitiveness policy.

Conclusion and Policy Discussion

Current policy is driven by the twin perceptions of a labor market shortage of scientists and engineers and of a pool of qualified students that is small in number and declining in quality. Math and science education are viewed as the primary policy levers to increase labor market supply, supplemented by increased immigration. But the data show little evidence to support those positions, and, in fact, indicate an ample supply of students whose preparation and performance has been increasing over the past decades. We are concerned that the consensus prescriptions are based on some misperceptions about efficient and sustainable strategies for economic and social prosperity.

Assessing the claims of labor market shortages is crucial. Purported labor market shortages for scientists and engineers are anecdotal and not supported by the available evidence. Little analysis has been conducted of firms’ hiring difficulties and the supply of workers. A particular employer’s or industry’s experiences in hiring could be the result of any number of factors. The assumption that difficulties in hiring are due just to supply can have counterproductive consequences: an increase in supply that leads to high unemployment, lowered wages, and a decline in working conditions will have the long-term effect of weakening future supply by discouraging current students. Moreover, by bringing immigrants directly into the STEM workforce but without the attachments immigrants develop through longer residency and schooling in the United States, there is likely to be greater geographical workforce mobility. As the physical infrastructure of emerging nations improves and they retain more of their skilled STEM workers, the location of innovation and R&D is likely to follow.

Investing in domestic human capital can provide longer-term benefits to the United States, and a collaborative approach with other countries will provide the United States greater benefits of their

human capital development then through trying to absorb talent through short-term immigration to address short-term hiring needs (Lynn and Salzman 2006, 2007). The characteristics of human capital development and employment are qualitatively different from that of prior periods, and we should not fall back on past approaches to policy. Instead, evidence-based policy is necessary for developing effective programs for the emerging global economy.

Policies to Strengthen U.S. Science and Engineering Capabilities

Our analysis suggests several education and policy recommendations that will strengthen U.S. science, technology, and innovation. This list includes several current initiatives that we find will be helpful in strengthening the U.S. workforce.

1. *Emphasize a broad education rather than a narrow technical education.* Math and science skills are not what employers report being in short supply among their professional and technical workforce. An overemphasis on math and science could lead to the exclusion of the skills employers report most needing among their STEM workers. At the same time, it is important to broaden the content and improve the pedagogy of science and math throughout the education system, at primary, secondary and college levels. There are a number of efforts under way to improve science, math, and engineering education; additional support and diffusion of new curricula would be beneficial, as would improving other educational areas. It is important to distinguish between improving the quality for all students from policies focused on increasing the quantity and/or focusing on the upper levels of the student population as a means of increasing the STEM workforce.

2. *Expand the opportunities to enter a STEM career to populations currently underrepresented.* A number of programs encourage underrepresented and minority high school and college students to enter STEM study and careers, such as those developed by the National Science Foundation. Improving the education of low-performing students and schools can expand the pool of qualified students motivated to enter a STEM career by tapping a pool of those with an intrinsic interest in these areas and for whom these fields offer attractive career opportunities. Increasing workforce diversity and equity also serve broader social and economic goals that strengthen the United States.

3. *Encourage complements rather than substitutes in the labor market through immigration policy.* The H-1B program is cited repeatedly by technology workers as a factor in their perceptions of diminished opportunity. Instead, visas offered after completing a U.S. graduate education would expand the STEM workforce with workers who are likely to have more attachment to the United States and stronger ties to U.S. colleagues even if they return home. By making the entry point higher education, this type of visa program could also serve as a means of attracting higher skilled and more academically talented workers.

4. *Evaluate the STEM supply and production by colleges.* Government funding of STEM graduate program (e.g., via fellowships and research assistantships) should be adjusted to reflect market demand. As some are currently proposing, perhaps larger fellowships for a smaller number of recipients would improve quality and not depress wages. It may be better to control supply at the point of graduate school entry than after graduation and after a great deal of public and private educational investment. Discouraged graduates send negative signals to students further down the pipeline. Increased competition for fewer graduate slots would increase the value of the degree. As long as the supply of workers is far in excess of demand, as it currently appears to be, reducing the number of STEM graduates will not create a shortage and will increase the desirability of these careers as well as the quality of the graduate pool. Since it is not just wages but also longer-term employment prospects that affect STEM career decisions, this is one means of improving career opportunities.

5. *Establish international labs, similar to the model of the U.S. national labs.* Taking the lead in developing the structure and terms of participation in the global commons will provide the United States continued access to innovation and knowledge around the globe. It will also create new and exciting opportunities for U.S. STEM workers as well as integrate global STEM workers into networks in which the United States participates. This is one means of benefiting from global human capital development without substituting it for domestic STEM workers. This model reflects the current strategies of many U.S. firms and universities and the current structure of globalization in which knowledge and innovation flow across national boundaries.

6. *Focus innovation and technology policies on pressing global problems and technology that meets global needs.* Understanding the dual innovation frontiers—not just high-end technology—and addressing global problems should be a key aspect of R&D policy. In particular, a focus on innovation under resource constraint, such as limited energy, will lead to innovations applicable to emerging markets. Many firms are doing this, but in other countries. Developing leading expertise in the U.S. will keep the United States engaged in global technology development.

7. *Develop policy frameworks based on collaborative advantage and participation in the global commons of innovation.* Trying to develop "dominance" or "supremacy," as called for in some policy reports, will not garner the support of other countries or the large segment of the U.S. STEM workforce that has some interest in seeing the development of their countries of origin. The proposals above contribute to a collaborative advantage approach by promoting U.S. national interest through mutual-gain policies. Part of this recommendation is for a change in rhetoric and focus which will then lead to more specific initiatives. The current focus on U.S. techno-nationalist policies leads us in the wrong direction and it alienates many of the foreign nationals on whom our companies and universities depend and who are a vital part of the U.S. innovation system.

References

American Electronics Association. 2005. *Losing the Competitive Advantage,* February.

Associated Press. 2005. “Sun Microsystems Expands Around Globe.” May 9.

Blinder, Alan. 2007. “How Many U.S. Jobs Might Be Offshorable?” CEPS working paper no. 142. Princeton, NJ: Center for Economic Policy Studies, Princeton University. http://www.princeton.edu/blinder/papers/07ceps142.pdf

Boe, Erling E., and Sujie Shin. 2005. “Is the United States Really Losing the International Horse Race in Academic Achievement?” *Phi Delta Kappan* 86(9): 688–95.

Business Roundtable. 2005. *Tapping America’s Potential,* July.

Business Week. 2007. “Where Are All the Workers?” April 7.

College Board. 2006. “College-Bound Seniors: Total Group Profile Report.” New York: The College Board. http://www.collegeboard.com.

———. 2007. “Number and Diversity of SAT Takers at All-Time High.” New York: The College Board. http://www.collegeboard.com/press/releases/185222.html.

Council on Competitiveness. 2004. *Innovate America*. Washington, DC: Council on Competitiveness.

Cusumano, Michael, and R. Selby. 1995. *Microsoft Secrets*. New York: Touchstone.

Davis, Geoff. 1997. “Mathematicians and the Market.” Hanover, NH: Dartmouth College.

Espenshade, Thomas J. 1999. “High-End Immigrants and the Shortage of Skilled Labor.” Working Paper No. 99-5. Princeton, NJ: Office of Population Research, Princeton, University.

Freeman, Richard B. 1976. *The Overeducated American.* New York: Academic Press.

———. 2006. “Does Globalization of the Scientific/Engineering Workforce Threaten U.S. Economic Leadership?” In *Innovation Policy and The Economy,* vol. 6. Cambridge, MA: NBER/MIT Press.

Freeman, Richard B., Emily Jin, and Chia-Yu Shen. 2004. “Where Do New U.S.-Trained Science-Engineering PhDs come from?” NBER Working Paper No. 10554. Cambridge, MA: National Bureau of Economic Research.

Hill, Christopher T. 2007. “The Post-Scientific Society.” *Issues in Science and Technology* Summer.

Hull, Jim. 2007. “More than a Horse Race: A Guide to International Tests of Student Achievement.” The Center for Public Education. http://www.centerforpubliceducation.org/site/c.kjJXJ5MPIwE/b.1460713/apps/s/content.asp?ct=3449109.

Lynn, Leonard, and Hal Salzman. 2002. “What Makes a Good Engineer? U.S., German, and Japanese Perspectives.” Presented at Proceedings. The European Applied Business Research Conference, in Rothenburg, Germany, June.

———. 2006. “Collaborative Advantage.” *Issues in Science and Technology* Winter.

———. 2007. “The Real Technology Challenge.” *Change: Magazine of Higher Learning* July/August.

Miller, D.C., A. Sen, and L. B. Malley. 2007. *Comparative Indicators of Education in the United States and Other G-8 Countries: 2006.* NCES 2007-006. Washington, DC: National Center for Education Statistics, Institute of Education Sciences, U.S. Department of Education.

Murnane, Richard J., and Frank Levy. 1996. *Teaching the New Basic Skills. Principles for Educating Children to Thrive in a Changing Economy.* New York: Free Press.

National Academy of Science. 2007. *Rising above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future.* Committee on Science, Engineering, and Public Policy.

National Association of Manufacturers. 2005. *The Looming Workforce Crisis*. Washington, DC: National Association of Manufacturers.

National Center for Education Statistics. 2006. “U.S. Student and Adult Performance on International Assessments of Educational Achievement” NCES 2006-073. Washington, DC: NCES.

National Science Foundation. 2006. *Science and Engineering Indicators 2006.* Appendix table 2-6. http://www.nsf.gov/statistics/seind06/pdf_v2.htm. Arlington, VA: National Science Foundation.

Organisation for Economic Co-operation and Development. 2003. “Problem Solving for Tomorrow’s World—First Measures of Cross-Curricular Competencies from PISA 2003.” Paris: OECD.

———. 2006. “Evolution of Student Interest in Science and Technology Studies: Policy Report.” http://www.oecd.org/dataoecd/16/30/36645825.pdf. Paris: OECD.

Ramirez, Francisco O., Xiaowei Luo, Evan Schofer, and John W. Meyer. 2006. “Student Achievement and National Economic Growth.” *American Journal of Education* 113 (November).

Salzman, Hal. 2000. “The Information Technology Industries and Workforces: Work Organization and Human Resource Issues.” Committee on Workforce Needs in Information Technology.

Schmidt, William H., Curtis C. McKnight, Richard T. Houang, and HsingChi Wang. 2001. *Why Schools Matter: A Cross-National Comparison of Curriculum and Learning.* San Francisco: Jossey-Bass.

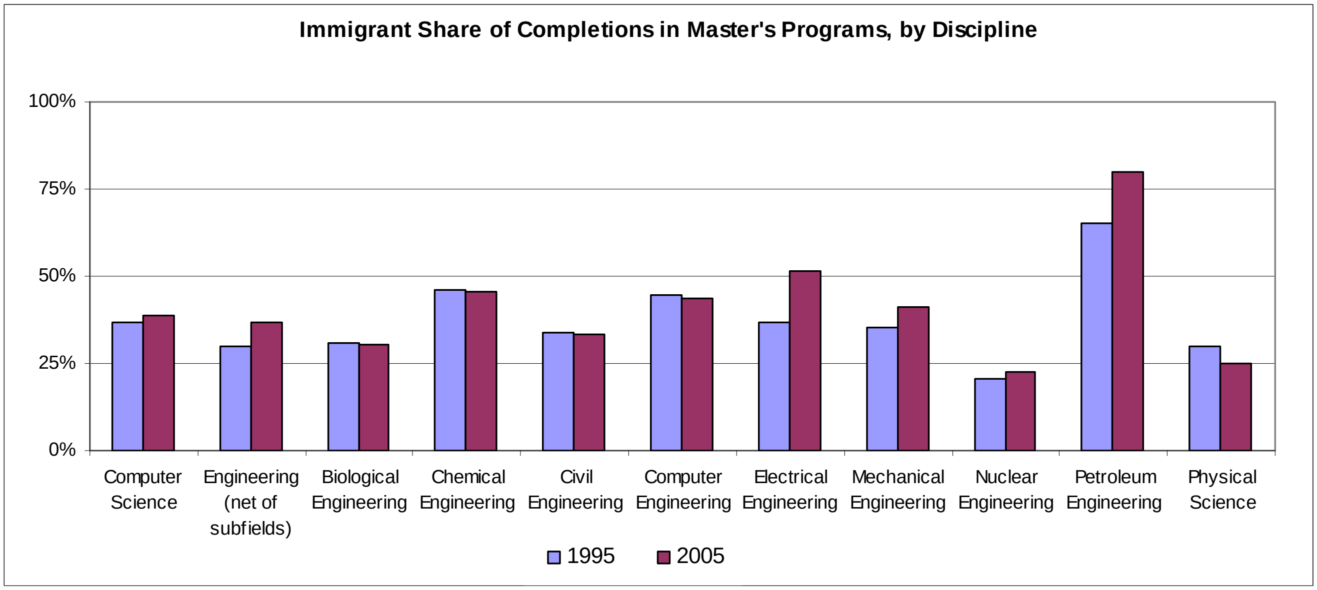
Seymour E., and N. M. Hewitt. 1997. *Talking about Leaving : Why Undergraduates Leave the Sciences.* Westview Press.

U.S. Census Bureau. 2007. Current Population Survey, 2006 Annual Social and Economic Supplement, table 2.

Wall Street Journal. 2006. “High-Tech Titans Unite on Lifting Visa Caps.” June 14, page A2.

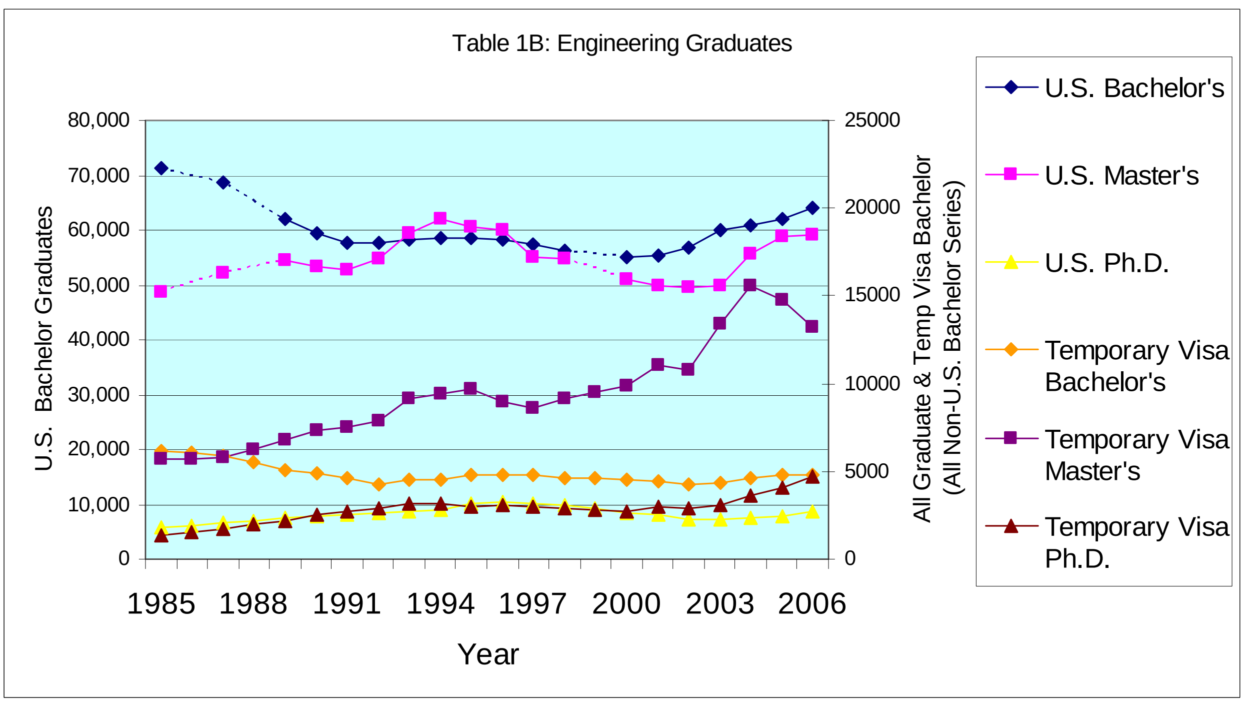
World Bank. 2007. “India Data Profile.” World Development Indicators database. http://devdata.worldbank.org/external/CPProfile.asp?PTYPE=CP&CCODE=IND.

Figure 1A. Students on Temporary Visas by Graduate Program



Sources: NSF, Indicators; IPEDS, tabulations by authors

Figures 1B–1E. Enrollment for Selected STEM Fields by U.S. and Temporary Visa Students



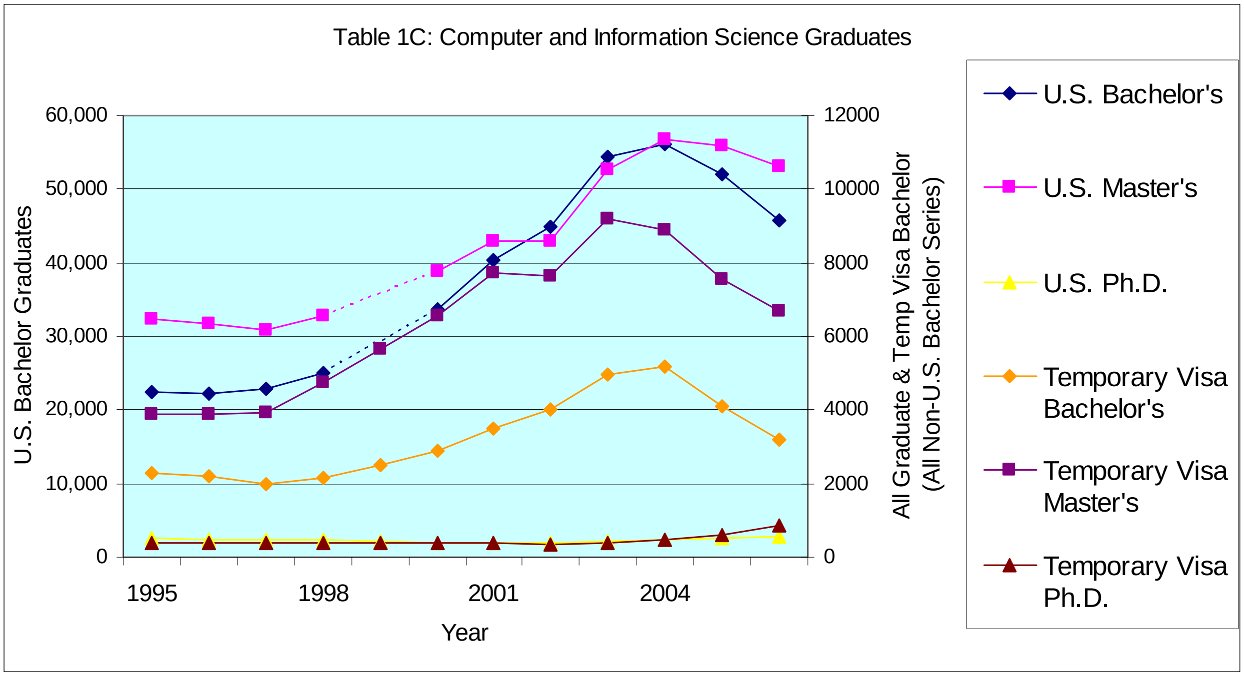


Table 1C: Computer and Information Science Graduates
U.S. Bachelor Graduates
60,000
50,000
40,000
30,000
20,000
10,000
0
1995
1998
2001
2004
Year
12000
10000
8000
6000
4000
2000
0
All Graduate & Temp Visa Bachelor (All Non-U.S. Bachelor Series)
U.S. Bachelor's
U.S. Master's
U.S. Ph.D.
Temporary Visa Bachelor's
Temporary Visa Master's
Temporary Visa Ph.D.

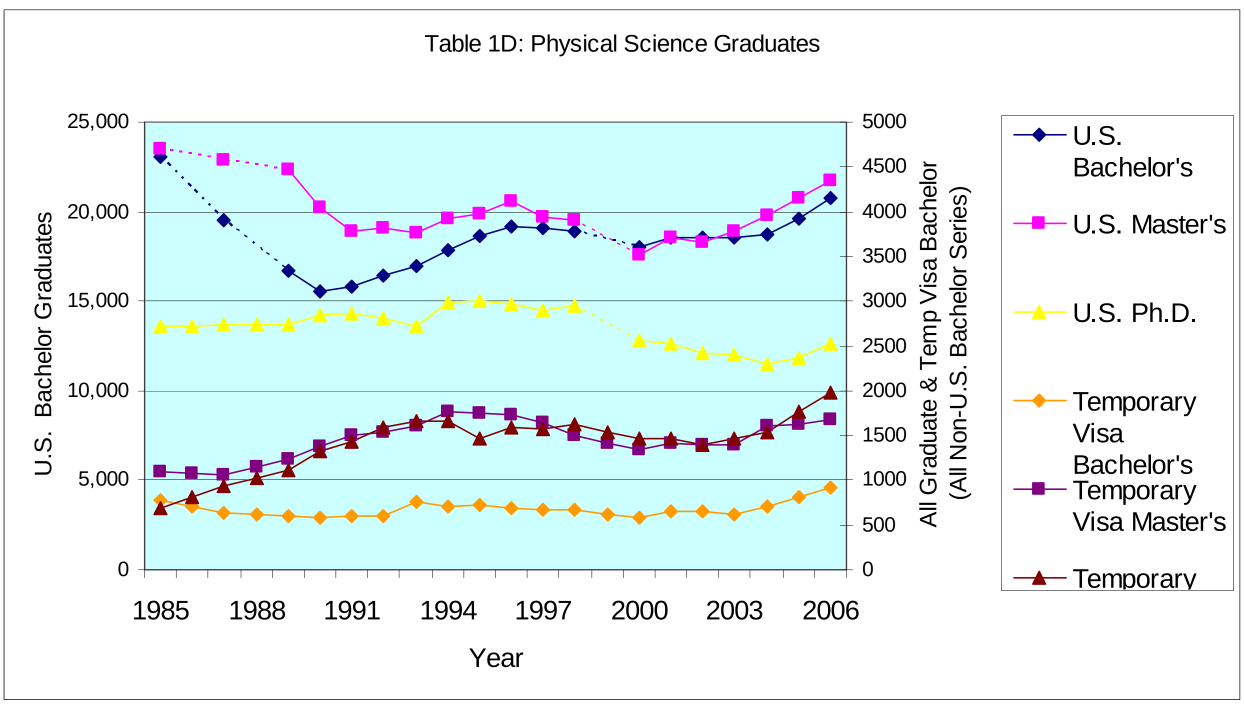


Table 1D: Physical Science Graduates
U.S. Bachelor Graduates
25,000
20,000
15,000
10,000
5,000
0
1985
1988
1991
1994
1997
2000
2003
2006
Year
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
All Graduate & Temp Visa Bachelor (All Non-U.S. Bachelor Series)
U.S. Bachelor's
U.S. Master's
U.S. Ph.D.
Temporary Visa Bachelor's
Temporary Visa Master's
Temporary

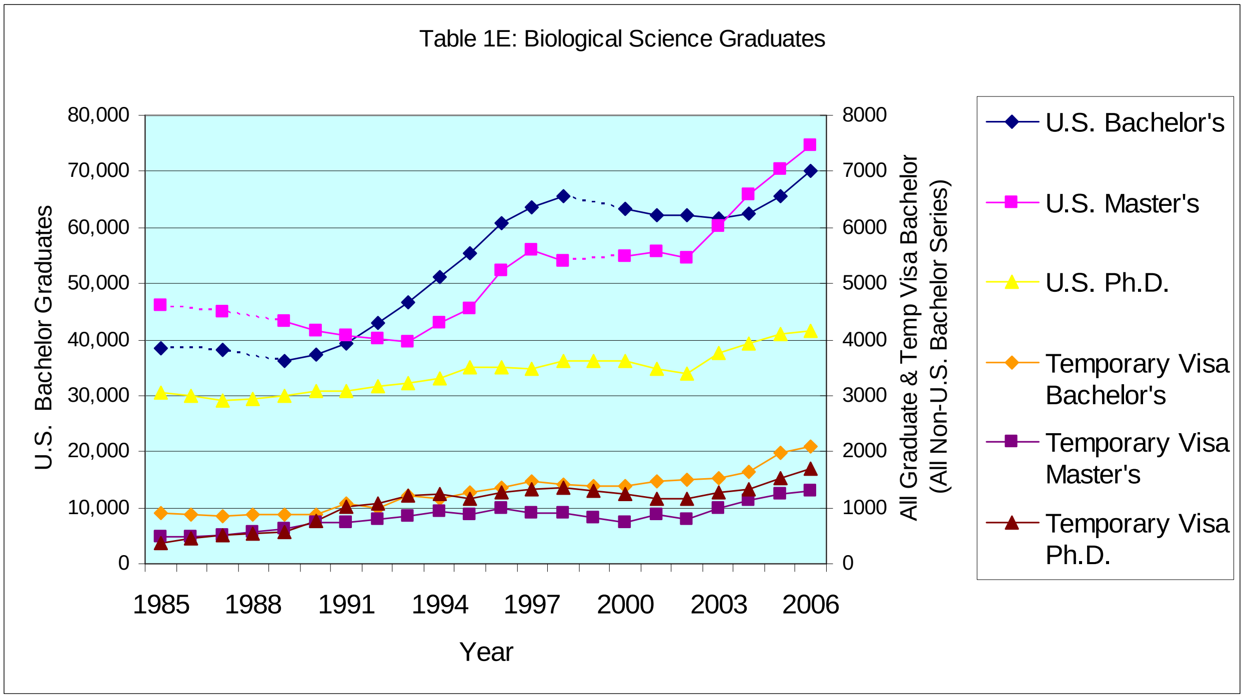


Table 1E: Biological Science Graduates
U.S. Bachelor Graduates
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
All Graduate & Temp Visa Bachelor (All Non-U.S. Bachelor Series)
8000
7000
6000
5000
4000
3000
2000
1000
0
1985
1988
1991
1994
1997
2000
2003
2006
Year
U.S. Bachelor's
U.S. Master's
U.S. Ph.D.
Temporary Visa Bachelor's
Temporary Visa Master's
Temporary Visa Ph.D.

Table 2. Immigrants in Workforce, Occupation by Industry (percent)

Selected Core S&E Occupations with Large Workforce and/or High Immigrant Percentage

Cells with above all industry mean (> 19%) immigrant percent	Computer scientists and systems analysts	Computer program-mers	Computer software engineers	Civil engineers	Computer hardware engineers	Electrical and electronics engineers	Industrial engineers, including health and safety	Mechanical engineers	Medical scientists	Astronomers and physicists	Chemists and materials scientists
Electric power generation, transmission, and distribution	--	23	20	--	--	--	--	--	--	--	--
Pharmaceutical and medicine manufacturing	22	35	24	--	--	20	--	--	40	--	32
Industrial and miscellaneous chemicals	--	19	--	--	--	--	--	--	--	32	20
Computer and peripheral equipment manufacturing	30	29	39	37	40	22	29	37	--	45	63
Communications, audio, and video equipment manufacturing	24	35	41	29	41	29	19	37	--	25	--
Navigational, measuring, electromedical, and control instr.	--	--	23	24	22	--	--	--	--	27	44
Electronic component and product manufacturing, n.e.c.	29	35	41	25	50	35	28	26	--	--	29
Aircraft and parts manufacturing	--	--	--	--	--	--	--	--	--	--	--
Aerospace product and parts manufacturing	--	--	--	--	31	--	--	--	--	23	--
Medical equipment and supplies manufacturing	--	24	31	--	63	--	--	19	24	24	32
Radio, TV, and computer stores	29	27	32	--	36	24	37	42	--	--	--
Wired telecommunications carriers	21	31	40	31	50	23	27	--	--	--	--
Other telecommunication services	19	35	43	--	64	34	34	25	--	--	--
Other information services	21	27	41	--	57	42	--	47	--	--	--

Data processing services	--	23	29	--	--	--	--	31	--	--	71
Banking and related activities	22	32	37	--	40	--	--	--	--	--	--
Securities, commodities, funds, trusts, and other financial	26	42	41	--	62	--	--	.	--	--	--
Architectural, engineering, and related services	--	19	19	--	22	20	21	20	--	21	--
Computer systems design and related services	28	30	39	33	37	30	35	29	74	--	--
Management, scientific, and technical consulting services	25	36	36	25	27	25	20	19	23	--	--
Scientific research and development services	--	25	25	--	--	21	--	--	49	29	25
Colleges and universities, including junior colleges	22	25	24	20	24	29	--	31	51	41	43

Source: 2000 U.S. Census; tabulations by authors

Figure 2.

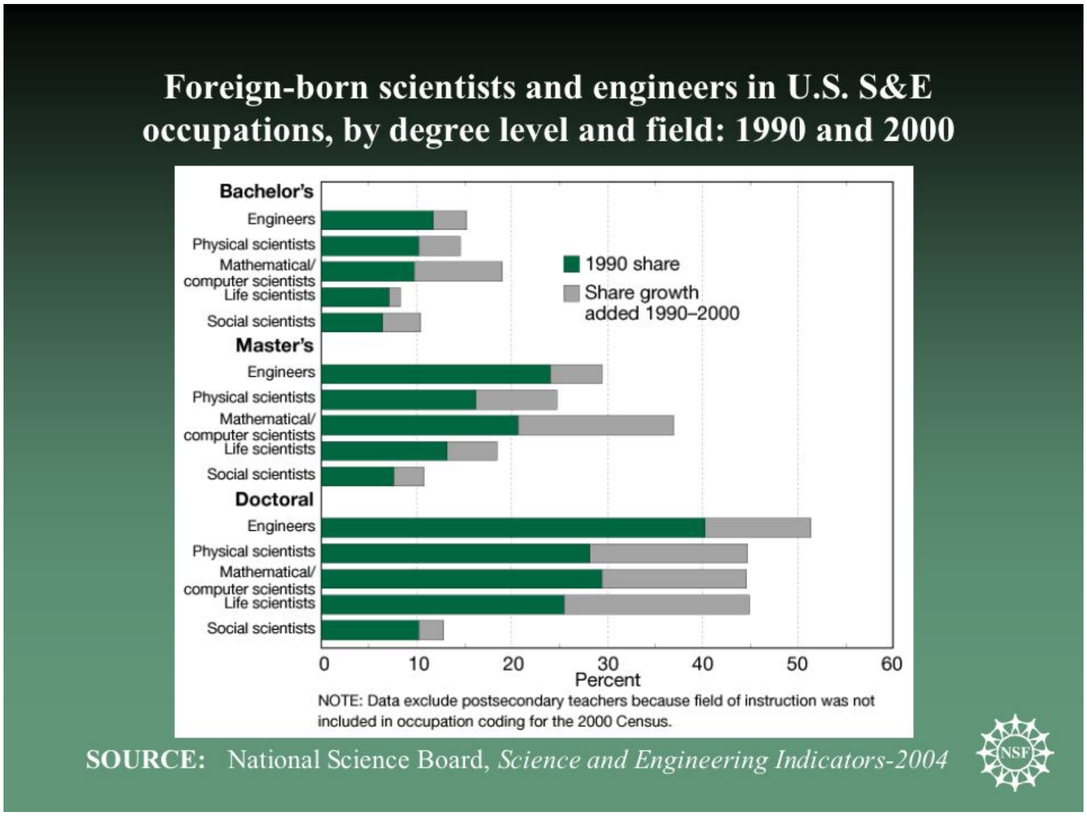
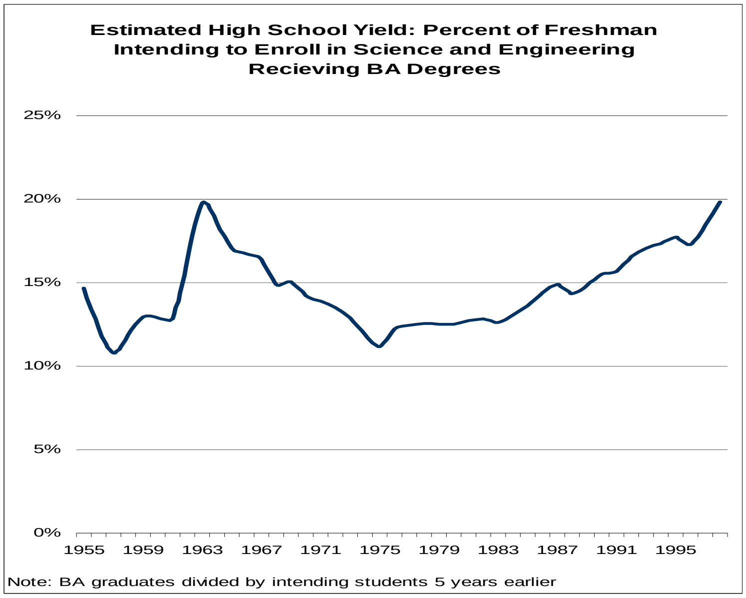
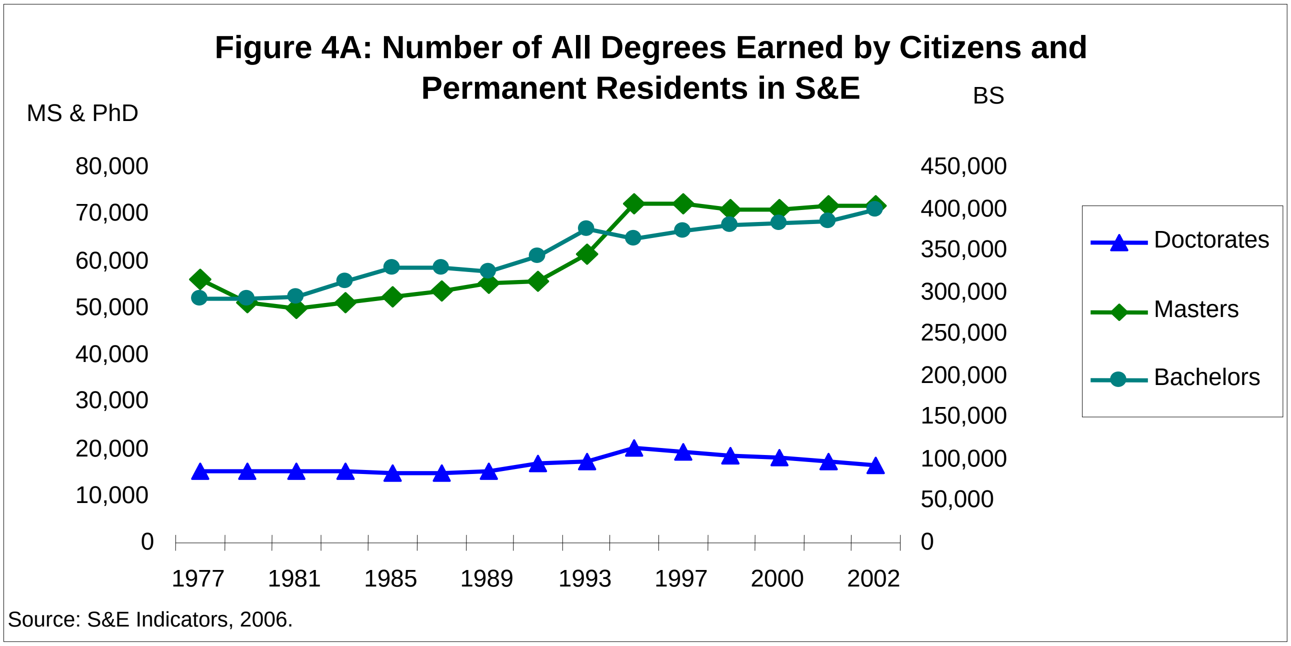
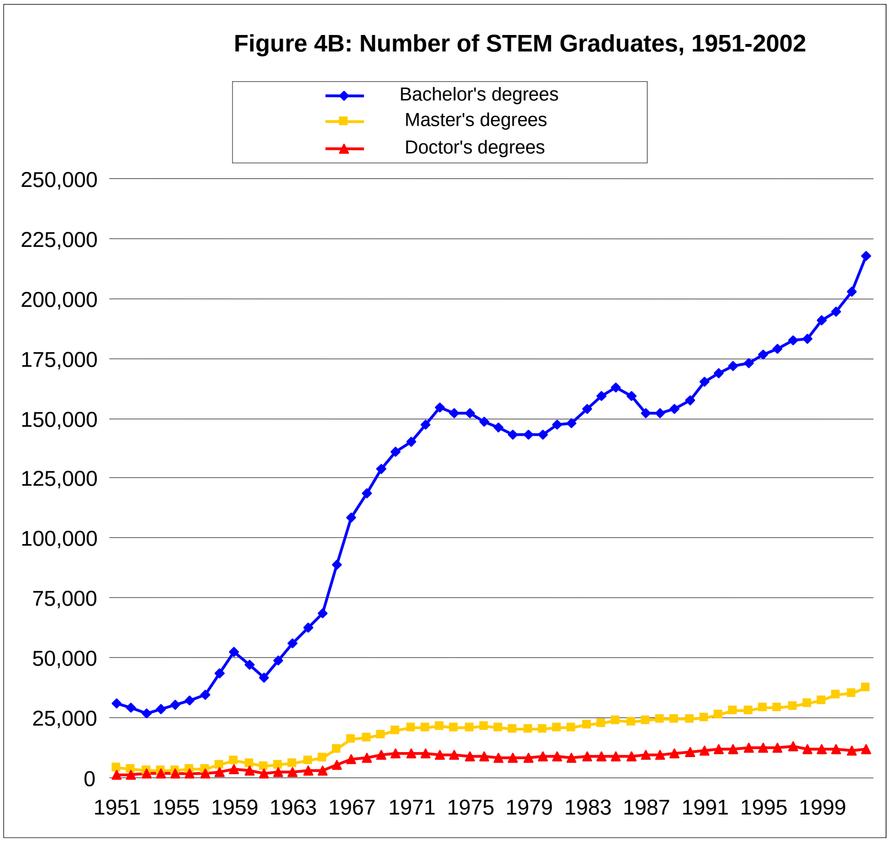


Figure 3. S&E College Entrants



Figures 4A–B. S&E College Grads





Figures 5A–5C. S&E Bachelor Graduate Matriculation to S&E Graduate School and the S&E Workforce

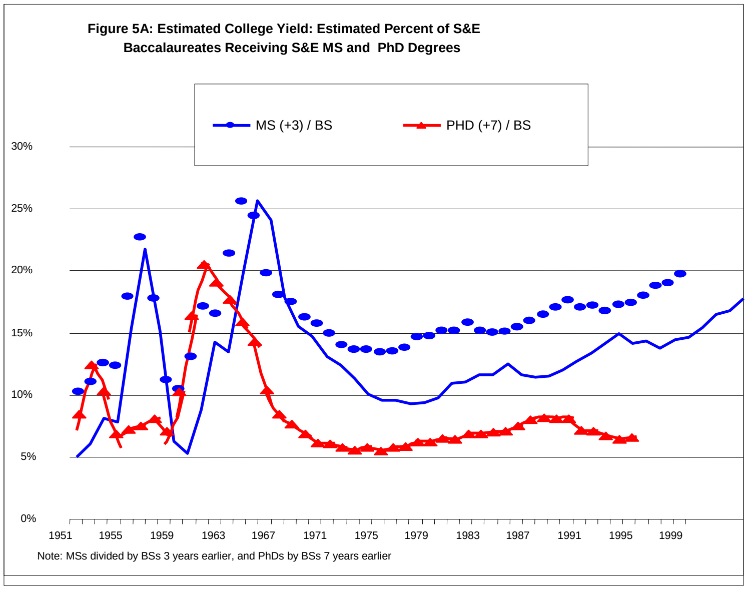


Figure 5A: Estimated College Yield: Estimated Percent of S&E Baccalaureates Receiving S&E MS and PhD Degrees

Note: MSs divided by BSs 3 years earlier, and PhDs by BSs 7 years earlier

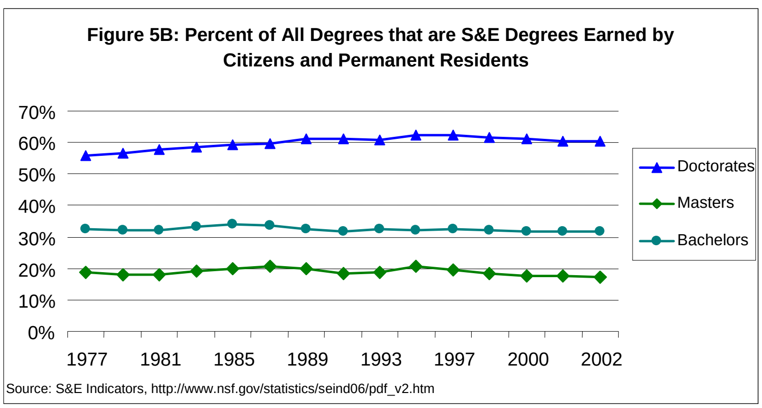


Figure 5B: Percent of All Degrees that are S&E Degrees Earned by Citizens and Permanent Residents

Source: S&E Indicators, http://www.nsf.gov/statistics/seind06/pdf_v2.htm

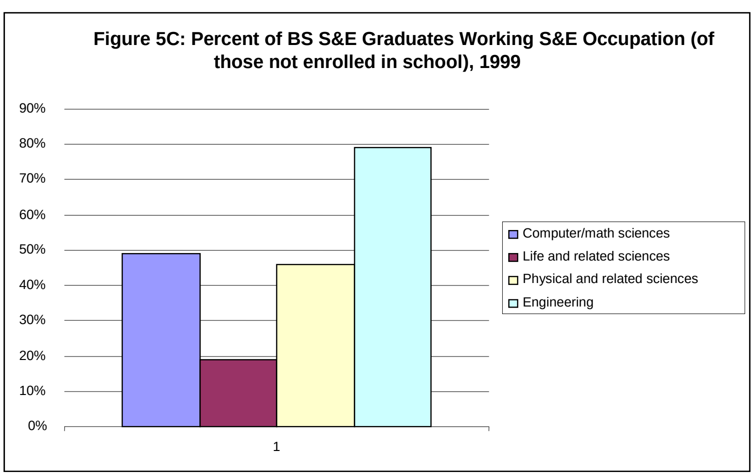


Figure 5C: Percent of BS S&E Graduates Working S&E Occupation (of those not enrolled in school), 1999

Figure 6. Temporary Visa Grad Students

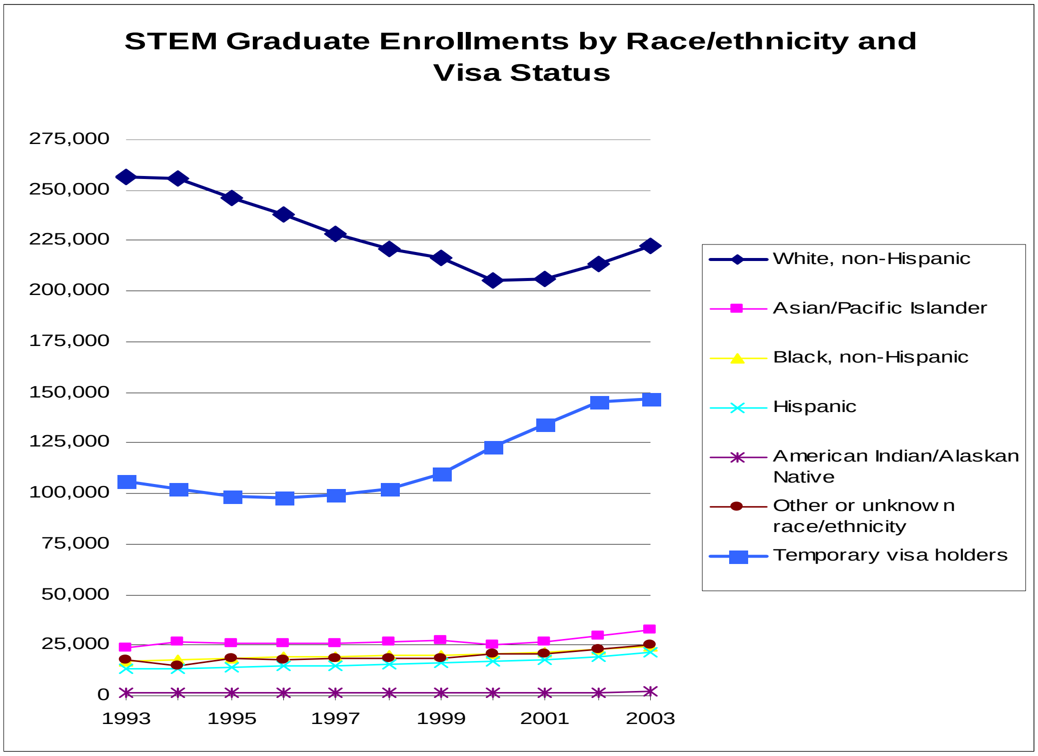


Table 2. Industry and S&E Employment by Size of Industry (> 750,000 Employees)

Code	Industry	Workforce Counts: Total Workforce	Workforce Counts: S&E Workforce, Total	Workforce Counts: S&E Workforce, Core S&E	S&E % of Total
	Totals / Average	167,996,851	8,102,712	5,113,526	5%
77	Construction	11,466,171	202,786	131,355	2%
786	Elementary and secondary schools	9,451,464	83,589	21,067	1%
868	Restaurants and other food services	9,351,427	7,833	4,306	0%
819	Hospitals	6,406,524	145,829	81,014	2%
497	Grocery stores	3,889,970	11,096	6,896	0%
787	Colleges and universities, including junior colleges	3,812,024	364,728	206,544	10%
538	Department stores	3,161,238	14,566	9,139	0%
947	Justice, public order, and safety activities	2,956,466	46,684	22,761	2%
699	Insurance carriers and related activities	2,924,894	164,195	122,387	6%
707	Real estate	2,473,782	22,443	10,319	1%
687	Banking and related activities	2,300,110	96,411	64,033	4%
859	Other amusement, gambling, and recreation industries	2,245,480	19,235	11,400	1%
847	Child day care services	2,163,328	1,897	637	0%
827	Nursing care facilities	2,122,146	4,139	1,759	0%
617	Truck transportation	2,110,791	9,997	7,197	0%
797	Offices of physicians	1,923,162	25,763	13,760	1%
866	Traveler accommodation	1,864,141	8,805	4,612	0%
357	Motor vehicles and motor vehicle equipment manufacturing	1,825,811	160,153	129,860	9%
727	Legal services	1,764,109	17,234	6,560	1%
877	Automotive repair and maintenance	1,672,318	2,727	1,221	0%
17	Crop production	1,518,346	6,500	2,974	0%
729	Architectural, engineering, and related services	1,429,041	835,095	433,909	58%
738	Computer systems design and related services	1,411,884	811,234	617,137	57%
467	Automobile dealers	1,393,185	3,525	1,541	0%
758	Employment services	1,341,742	34,975	18,738	3%
769	Services to buildings and dwellings	1,268,063	2,575	1,369	0%
697	Securities, commodities, funds, trusts, and other financial	1,267,650	82,396	55,829	6%
916	Religious organizations	1,263,280	5,997	2,396	0%
739	Management, scientific and technical consulting services	1,160,149	182,653	128,603	16%
339	Electronic component and product manufacturing, n.e.c.	1,155,562	287,082	197,320	25%
777	Landscaping services	1,142,979	17,518	6,175	2%
668	Wired telecommunications carriers	1,132,428	176,315	101,597	16%
939	Other general government and support	1,087,191	112,280	68,870	10%

637	Postal Service	1,080,002	12,977	3,460	1%
447	Groceries and related product wholesalers	1,074,737	10,588	6,263	1%
728	Accounting, tax preparation, bookkeeping and payroll service	1,056,771	23,745	15,223	2%
199	Printing and related support activities	1,053,559	24,380	14,879	2%
517	Clothing and accessories, except shoe stores	1,017,322	5,242	3,401	1%
689	Non-depository credit and related activities	1,012,234	49,234	32,156	5%
399	Not specified manufacturing industries	1,010,854	47,323	30,689	5%
898	Beauty salons	985,635	639	221	0%
487	Building material and supplies dealers	948,560	6,780	3,379	1%
479	Radio, TV, and computer stores	939,492	160,138	112,381	17%
507	Pharmacies and drug stores	869,676	6,204	3,906	1%
929	Private households	867,453	331	199	0%
818	Other health care services	864,344	34,630	22,536	4%
817	Home health care services	861,330	2,778	1,283	0%
917	Civic, social, advocacy organizations, and grantmaking and g	851,591	23,278	9,768	3%
837	Individual and family services	845,282	12,619	3,531	1%
389	Furniture and related products manufacturing	844,984	17,088	9,986	2%
798	Offices of dentists	819,974	1,120	680	0%
237	Plastics product manufacturing	810,652	37,451	21,558	5%
759	Business support services	810,092	24,063	12,443	3%
948	Administration of human resource programs	808,612	49,083	33,763	6%
856	Independent artists, performing arts, spectator sports, and	797,461	6,141	2,676	1%
607	Air transportation	782,879	16,335	11,944	2%
18	Animal production	780,289	3,761	1,311	0%
477	Furniture and home furnishings stores	779,128	3,080	1,581	0%
319	Machinery manufacturing, n.e.c.	774,521	79,649	56,387	10%
57	Electric power generation, transmission and distribution	772,758	116,756	83,205	15%
959	National security and international affairs	767,066	133,120	92,746	17%
629	Services incidental to transportation	751,034	18,442	11,829	2%

Table 3. Industry and S&E Employment by S&E Employment Size (> 25,000 S&E Employees)

Code	Industry	Workforce Counts: Total Workforce	S&E Workforce, Total	S&E Workforce, Core S&E	S&E % of Total
	Totals / Average	167,996,851	8,102,712	5,113,526	5%
729	Architectural, engineering, and related services	1,429,041	835,095	433,909	58%
738	Computer systems design and related services	1,411,884	811,234	617,137	57%
787	Colleges and universities, including junior colleges	3,812,024	364,728	206,544	10%
339	Electronic component and product manufacturing, n.e.c.	1,155,562	287,082	197,320	25%
746	Scientific research and development services	554,243	268,418	176,878	48%
77	Construction	11,466,171	202,786	131,355	2%
739	Management, scientific and technical consulting services	1,160,149	182,653	128,603	16%
668	Wired telecommunications carriers	1,132,428	176,315	101,597	16%
336	Computer and peripheral equipment manufacturing	510,732	168,502	133,118	33%
699	Insurance carriers and related activities	2,924,894	164,195	122,387	6%
357	Motor vehicles and motor vehicle equipment manufacturing	1,825,811	160,153	129,860	9%
479	Radio, TV, and computer stores	939,492	160,138	112,381	17%
819	Hospitals	6,406,524	145,829	81,014	2%
959	National security and international affairs	767,066	133,120	92,746	17%
358	Aircraft and parts manufacturing	536,821	122,688	102,428	23%
57	Electric power generation, transmission and distribution	772,758	116,756	83,205	15%
229	Industrial and miscellaneous chemicals	584,012	116,640	72,419	20%
957	Administration of economic programs and space research	733,908	115,144	77,652	16%
939	Other general government and support	1,087,191	112,280	68,870	10%
359	Aerospace product and parts manufacturing	283,463	109,780	94,542	39%
219	Pharmaceutical and medicine manufacturing	423,909	105,768	76,632	25%
949	Administration of environmental quality and housing programs	283,547	100,757	75,246	36%
678	Other information services	300,349	96,922	39,288	32%
687	Banking and related activities	2,300,110	96,411	64,033	4%

337	Communications, audio, and video equipment manufacturing	321,151	87,224	63,937	27%
669	Other telecommunication services	479,710	84,338	51,276	18%
786	Elementary and secondary schools	9,451,464	83,589	21,067	1%
697	Securities, commodities, funds, trusts, and other financial	1,267,650	82,396	55,829	6%
319	Machinery manufacturing, n.e.c.	774,521	79,649	56,387	10%
338	Navigational, measuring, electromedical, and control instrum	295,356	78,432	58,065	27%
808	Offices of other health practitioners	315,326	72,895	1,449	23%
679	Data processing services	246,177	70,538	43,929	29%
396	Medical equipment and supplies manufacturing	529,772	68,539	43,543	13%
349	Electrical lighting, equipment, and supplies manufacturing,	576,117	65,974	43,898	11%
667	Radio and television broadcasting and cable	699,813	51,432	25,565	7%
689	Non-depository credit and related activities	1,012,234	49,234	32,156	5%
948	Administration of human resource programs	808,612	49,083	33,763	6%
399	Not specified manufacturing industries	1,010,854	47,323	30,689	5%
947	Justice, public order, and safety activities	2,956,466	46,684	22,761	2%
417	Professional and commercial equipment and supplies	485,893	46,180	30,084	10%
749	Other professional, scientific and technical services	382,116	46,118	17,653	12%
937	Executive offices and legislative bodies	480,808	38,558	24,185	8%
237	Plastics product manufacturing	810,652	37,451	21,558	5%
758	Employment services	1,341,742	34,975	18,738	3%
818	Other health care services	864,344	34,630	22,536	4%
49	Support activities for mining	278,442	34,044	25,336	12%

Table 4. S&E Occupations and Employment

Occupation	Workforce, weighted count
Total	8,102,712
Computer Software Engineers	766,563
Computer Scientists and Systems Analysts	764,917
Computer Programmers	741,048
Engineering Technicians, Except Drafters	526,075
Computer Support Specialists	448,295
Miscellaneous Engineers, Including Agricultural and Biomedical	364,736
Network Systems and Data Communication Analysts	360,556
Electrical and Electronics Engineers	349,026
Civil Engineers	311,228
Mechanical Engineers	306,807
Drafters	270,016
Industrial Engineers, Including Health and Safety	218,132
Network and Computer Systems Administrators	217,879
Architects, Except Naval	216,867
Misc. Life, Physical, and Social Science Technicians, Including Social Science Research	199,625
Psychologists	186,635
Physical Scientists, All Other	166,891
Aerospace Engineers	130,329
Operations Research Analysts	120,390
Chemists and Materials Scientists	119,609
Market and Survey Researchers	105,804
Chemical Technicians	103,891
Surveying and Mapping Technicians	97,234
Biological Scientists	95,162
Environmental Scientists and Geoscientists	93,807
Medical Scientists	88,542
Database Administrators	85,114
Chemical Engineers	73,793
Computer Hardware Engineers	73,422
Miscellaneous Social Scientists, Including Sociologists	44,735
Materials Engineers	41,441
Surveyors, Cartographers, and Photogrammetrists	41,322
Environmental Engineers	38,759
Agricultural and Food Scientists	33,665
Miscellaneous Mathematical Science Occupations	33,378
Agricultural and Food Science Technicians	31,927
Conservation Scientists and Foresters	31,524
Economists	30,404
Petroleum, Mining and Geological Engineers, Including Mining	25,567
Biological Technicians	24,558
Urban and Regional Planners	24,455
Actuaries	23,214
Astronomers and Physicists	22,926
Geological and Petroleum Technicians	15,116
Marine Engineers	13,272
Atmospheric and Space Scientists	12,512
Nuclear Engineers	11,544

Urban Institute a nonpartisan economic and social policy research organization
2100 M Street NW
Washington, DC 20037

Hal Salzman, Ph.D.
HSalzman@ui.urban.org
978.929.9503~t/978.383.8020~f

Hal Salzman is a sociologist and Senior Research Associate at The Urban Institute, a national, nonprofit, nonpartisan, research and policy organization. Dr. Salzman's research focuses on labor markets, workplace restructuring, skill requirements, and globalization of innovation, engineering and technology design. He is currently Principal Investigator of a National Science Foundation-funded project on globalization, innovation, and human capital; this continues his research on "collaborative advantage" in globalization, engineering, technology entrepreneurship (research funded by the National Science Foundation and Kauffman Foundation, with Leonard Lynn of Case Western Reserve University and conducted with colleagues in the U.S., Germany, Japan, China, India, and Latin America). Dr. Salzman is also examining the science and engineering education and labor supply in research supported by the Sloan Foundation. He has conducted a number of studies of the IT industry, on both software design and work practices and on labor force issues in the IT industry. Currently he is completing, with colleagues, a project on corporate restructuring and the impact on jobs and training. His publications include *Software By Design: Shaping Technology and the Workplace* (Oxford University Press) and articles on issues of technology, skills, and the workplace, including "Collaborative Advantage" (in *Issues in Science and Technology)*, and forthcoming, *Technology Entrepreneurs in the Emerging Economies: The new shape of global innovation.*