Science and Technology Intellectual Capital

A Critical US Asset

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The potential for losing intellectual dominance in science and technology is a major threat to the ability of the United States to maintain national security and economic superiority. The United States must ensure it exercises the best possible options to grow, attract, and maintain enough qualified individuals to stay ahead of all adversaries. In addition to expanding the base of technology-educated individuals, the United States must counter threats to the intellectual capital base to secure its ability to deter the actions of adversaries. The primary measure of intellectual capital development is the number of undergraduate and graduate degrees earned in science, technology, engineering, and mathematics (STEM). The United States must focus now on doing what is necessary to maintain educational excellence and post-education opportunities to ensure that the US knowledge base in science and technology will remain the strongest in the world.

The following discussion examines many variables influencing the future of US intellectual capital. I first review the strategic importance of growing, attracting, and retaining graduate-level STEM professionals. This includes the first-, second-, and third-order effects of having, or conversely losing, US intellectual capacity. I next address current trends and, specifically, the importance of benefiting from foreign-born students and workers. This analysis includes statistics regarding graduate degrees granted in the United States to both citizens and noncitizens. Subsequently, I review initiatives to ensure that the United States will have a robust technology-educated core in future years. Finally, the discussion lays out potential impacts of developing technology on deterrence. I specifically focus on the United States' ability to stay at the cutting edge of innovation and the correlation of maintaining STEM intellectual capacity to countering or deterring technically advanced threats.

The exponential growth of technology combined with rapid globalization points to a future that requires the United States to have an advantage in science and technology intellectual capital. Without this

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resource, the United States will be at a disadvantage in many areas, including national security and economic stability. To best prepare for future threats, the United States needs to prioritize growing, attracting, and maintaining graduate-level technical capacity.

The Importance of STEM Intellectual Capital

A loss of leadership in S&T [science and technology] could hurt the U.S. economy, living standards, and national security.

—Titus Galama and James Hosek
Perspectives on U.S. Competitiveness in Science and Technology

The United States earned and has maintained the preeminent place on the world's science and technology stage because of a robust higher education system and a pervasive culture of innovation. This advantage contributed to successes in all sectors and is a perishable resource worthy of attention and preservation. Exponential growth in technological change combined with rapid globalization increases the criticality of creating, recruiting, and maintaining science and technology intellectual capital.

STEM intellectual capital is the group of individuals with education and prowess in science and technology who use those talents to benefit the nation. This definition includes both American-born individuals and immigrants. Historically, the technological and scientific knowledge needed for US national security has not been a function of only domestic scientific talent.[1] While the Manhattan Project was overseen by a general and a chief scientist who were both US born and educated, over half the key scientists involved were foreign born.[2] The two scientists most responsible for the hydrogen bomb were born and educated abroad, one in Hungary and the other in what is now the Ukraine.[3] Similarly, when the "space race" began with the Soviet Union launching *Sputnik I*, the United States responded by recruiting Wernher von Braun, born in Poland. He became known as the "father of the U.S. space program."[4] These examples illustrate that throughout American history, when faced with a threat, the United States found the requisite talent wherever available. This has been, in breadth and depth, a uniquely American approach, one that has created diversity and strength in many fields. To maintain and increase intellectual capital, the United States must continue to seek, recruit, and retain foreign immigrants with science and engineering (S&E) capabilities.

Retaining or increasing the advantage of dominant intellectual capacity in science and technology is critical to the United States' staying

at the forefront of innovation and has potential second- and third-order economic, political, military, and social effects. Potential first-order effects include producing new forms of energy, responding to diseases, protecting the environment, stimulating further interest and excitement in students to study science and technology, sparking the next technological revolution, and enhancing security.[5] Currently, the United States is the leader in many of these areas, and a change in that position could alter the world's economic, social, and security balance. Possible second-order effects of STEM capability include innovation, economic growth, military superiority, and the ability to detect and counter threats. All these elements support the broad US national strategy of promoting peace and prosperity. Third-order effects could include global social changes which alter the balance of power. These effects are amplified by globalization.

As an example, the National Academy of Engineering published an in-depth analysis of the impact of globalization on technical advancement. In part, it stated that "the United States must develop the necessary human, financial, physical, regulatory and institutional infrastructures to compare more advantageously with other nations in attracting the technical, managerial, and financial resources of globally active private corporations or individuals."[6] In a globalized world, additional opportunities exist for individuals worldwide to gain expertise and use it in many locations for a variety of motivations. Where a person earns a degree may have less influence on where he or she will work in the future. Likewise, in a globalized world, where a highly educated worker lives will put less of a limit on whose interest he or she supports. This illustrates the importance of growing and recruiting individual intellectual capital working specifically in the interest of the United States.

One second-order effect of intellectual capital superiority is the national security activity of deterrence—influencing adversary leadership decisions away from actions deleterious to the United States. This endeavor requires an understanding of the actions an adversary is capable of taking, including threats based on emerging technologies. A decreasing science and technology intellectual base is likely to diminish the United States' ability to deter these threats. More simply stated, brainpower itself provides deterrence capability. If the adversary knows the United States has the intellectual ability to understand and counter threats, the chance of achieving his desired effect decreases. This change in the adversary's decision equation deters him from acting. Likewise, existing weapons are a key component of the US deterrent posture, and those weapons also require individuals with the intellectual capability to keep them viable. According to one

estimate, the Pentagon is at risk of running out of scientists to operate and upgrade the nation's arsenal of intercontinental nuclear and conventional missiles.[7]

As technology advances exponentially, risk increases due to dependence on vulnerable major networks such as the electrical grid and the Internet. Not only are more aspects of human endeavors relying heavily on these networks, but as time goes on, the United States is losing the necessary knowledge base required to revert to previous ways of doing business in a crisis. This increased dependence on high-value systems is a compelling reason why maintaining a robust pool of people with critical STEM knowledge is essential to successfully deterring adversaries.

If the United States does not take the actions necessary to stay at least even, if not ahead, in science and technology, there will be significant and very negative impacts. No other nation is its equal in scientific and technological accomplishments, but this does not make the United States invulnerable. The globalized world requires that the United States be at least on par with all potential adversaries in every technology field so not even one adversary can get an advantage by an outpacing advance in one area. If an adversary were to develop an advantage in a technology beyond what the United States could deter or counter, that would cause a change in the balance of world power. For this reason, the United States must stay even or ahead in all areas or be prepared to exist in a world where it is not the number one power.

Current Status and Trends

The number of university degrees a nation awards in S&E is an indicator of a nation's capacity to innovate in those arenas. S&E graduate enrollment in the United States declined in the latter half of the 1990s but has increased steadily since 1999. The most recent data, published by the National Science Foundation in 2010, shows that the number of bachelor's degrees awarded in 2007 increased in most technical fields, except computer sciences.[8] Although it is difficult to determine the specific number of degrees required to keep an advantage, a positive trend is promising and far better than the alternative.

Students in the United States on temporary visas earned only 4 percent of the technical bachelor's degrees awarded in 2007, but foreign students make up a much higher proportion of the master's and doctoral degree recipients. In 2007 foreign students earned 24 percent of S&E master's degrees and 33 percent of doctoral degrees, bringing the total number of doctorates earned by foreign students to 13,700—a new peak.[9] The United States should encourage these stu-

dents to stay and work for US interests. John Smart, preeminent scholar on the future of technology and founder of the Acceleration Studies Foundation, points to the US culture of innovation and the ability to do valuable research as advantages foreign students see for studying in the United States.[10] The next step must be recruiting and retaining individuals in the high-skill work force.

Foreign-born intellectual capital is a critical asset. The United States has depended on the diversity, competition, and personal drive contributed by foreign students both during their education and afterwards in the highly skilled work force. Fortunately, through 2007 the trend of foreign-born students choosing to study in the United States is positive, as is the trend of foreign-born graduates who intend to stay here after graduation (fig. 1).

The United States is still the destination of the largest number of foreign students, but the numbers are trending downward. The US share in 2000 was 25 percent, but in 2006 it had fallen to 20 percent. The United Kingdom, Germany, and France are the other top destinations.[11] This is a trend worthy of close attention because attracting foreign students is a primary way of recruiting foreign talent for the

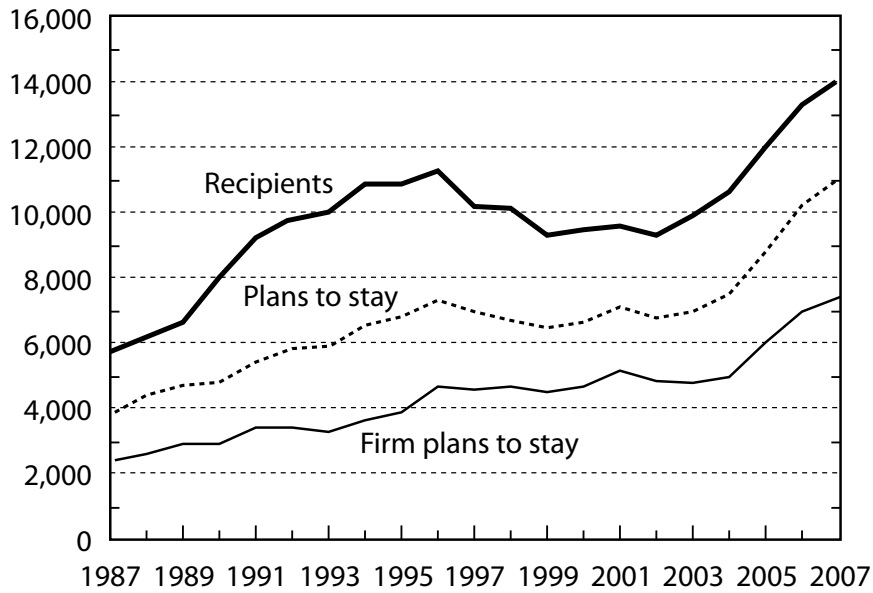

Figure 1. Plans of foreign recipients of US S&E doctorates to stay in the United States: 1987–2007. (*Adapted from* National Science Foundation, "Survey of Earned Doctorates," special tabulations, 2009.)

long term. Historically, graduate-level science and technology programs in US universities have been the world's benchmark. This acknowledged excellence, combined with the US culture of innovation, made degrees from US universities attractive to both US-born and international students. The secondary effect of attracting foreign students to US universities is that many of the international students have historically remained in the United States after graduation, increasing the intellectual resources available to US educational institutions, private companies, and government institutions.

Increased competition from other countries expanding their recruitment efforts is not the only threat to the United States attracting foreign students. Several trends threaten to decrease the US advantage in attracting foreign talent between now and 2035. First, US security concerns have increased greatly since the terrorist attacks of 9/11; as a result, visa procedures are more daunting, including those for foreign students and for foreign graduates of US universities who wish to stay in the United States to work. Second, at the same time that US policies are making it more difficult for foreigners to stay, improving conditions in many competitor nations are making it more attractive for foreigners educated in the United States to return home. The knee-jerk reaction to 9/11, which tightened visa policies, created a two-year decline in the number of foreign students in the United States. This trend later reversed, with the number of foreign S&E graduate students in US institutions increasing in the fall of 2006.[12] The number of student and exchange-visitor visas issued in 2006 was higher than ever before, and the sum of the other high-skill-related visa categories was near the 2001 high, suggesting the United States continues to attract those with advanced education.[13] This improvement bodes well for recovery in the areas of recruiting and retaining intellectual capital, but the dip must be heeded as a warning of how easily the trend can be reversed. The foiled terrorist attack on a Northwest Airlines flight to Detroit on Christmas Day 2009 returned national attention to visas for foreigners. US policy makers must understand that any tightening of visa restrictions may seem to provide short-term improvements in security, but it could result in a long-term decrease in the capability to deter the very threats we are bracing against.

Finally, the pervasive interconnectedness or "flattening" of the world is a trend that has made it more possible and palatable for foreign-born graduates who do stay in the United States to still commit all or part of their efforts to interests in their countries of origin rather than using them to benefit the United States.[14] The United States must develop a strategic plan now to continue to ensure adequate science and technology skills for 2035 and beyond.

Attracting foreign students is only the first step in securing foreign-born intellectual capital for the United States. Obtaining student visas is not the only issue. After graduation, many foreign graduates have difficulty obtaining visas to stay in the United States. In a study of approaches to strengthening scientific technology, Col Walter Juzukonis pointed out that the United States provides fast-track citizenship for foreign nationals who serve in the US military and proposes a similar fast-track approach for foreign nationals who have earned doctorate degrees in fields we need to bolster.[15]

Historically the United States has benefited from "brain drain"—when highly skilled immigrants contribute educational and economic assets to a country that hosts them for extended periods or permanently.[16] The brain drain from foreign countries is created by a lack of opportunity for individuals to be innovative in their home countries. The United States provides attractive opportunities in a culture of innovation, and the brain drain for other nations in turn becomes a brain surge for the United States. A 2006 report on Brazilian, Chinese, and Italian students in the United States showed that social responsibility and perceived opportunities in their home countries were strong factors in their decision to stay in the United States or return to their country of origin.[17] The United States can increase the potential for foreign graduates to stay here by providing incentives that outweigh their desire to return to their home countries. Investing resources and creativity in influencing these decisions will provide payback if it means the United States retains STEM-educated, innovative individuals.

In today's environment, the United States must recognize and prepare for multiple levels of external threats. Easy access to information increases the possibility of high-tech threats being wielded not only by nation-states but also by groups and individuals. Some see this as an impetus for tighter restrictions on visas and the naturalization policy. Ironically, these same policies make it more difficult to expand the pool of individuals with technology and science skills needed to counter those threats. National policy makers must work these issues aggressively and recognize that keeping science- and technology-educated individuals out of the United States is a prescription for increased external threats and decreased capability to deter or counter them.[18]

T. A. Frank, an Irvine Fellow at the New America Foundation, proposes that one way to regain our dominance in the tech sector would be to get more of the brightest people in the world to move here. He contends that because roughly a quarter of US technology and engineering start-ups have founders who were born abroad, it would benefit

the United States to encourage more talent to come here and stay here. Frank supports a plan whereby any student with an advanced degree in science, technology, engineering, or math would be offered a reasonable chance at permanent residency in the United States, with the requirement of employment in that field. A bill presented by Republican senator John Cornyn in 2007 would have removed caps on employment-based green cards for workers with advanced degrees. The bill did not pass, and neither did a similar one presented by Senator Arlen Specter. The aim should be to prevent an exodus of the people educated in the United States. Some think this policy will hurt low-income Americans. Historically, this is not true because an increase in high-skill workers tends to create additional jobs, not take them.[19]

Existing Initiatives

Many ongoing initiatives are encouraging the future growth of technological expertise. Great examples already exist of politicians and educators focusing on this important venture. President Obama made STEM education a national priority by putting emphasis on science and technology early in his administration. Prior to that, initiatives already were underway at lower levels in the United States, driven by the efforts of interest groups, states, and individual politicians.

Even before his inauguration, President Obama recognized that science and technology need to be reinvigorated.[20] The president made an early announcement that physicist John Holdren would serve as assistant to the president for science and technology and director of the White House Office of Science and Technology Policy. In addition to putting a priority on filling this key position, President Obama started talking publicly about improving education in STEM areas. In remarks to the National Academy of Sciences, President Obama quoted Abraham Lincoln's statement regarding his purpose in creating that organization—to add "the fuel of interest to the fire of genius in the discovery of new and useful things."[21] President Obama stated, "Science is more essential for our prosperity, our security, our health, our environment, and our quality of life than it has ever been before."[22] In his remarks, he committed to use polices and incentives to exceed the level of research and development the United States achieved at the height of the space race. He also committed to improve education in math and science. The president pointed out that more than 20 percent of high school students in math and more than 60 percent in chemistry and physics are taught by teachers without expertise in those fields. He created an incentive for states making commitments to math and science education to compete for additional

funds. Further, in response to the United States' trailing other nations in creating scientists and engineers, he set a goal for America to have the highest proportion of college graduates in the world by 2020. He also pledged to triple the number of National Science Foundation graduate research fellowships.[23] The tone of his entire speech was one of dedication to reinvigorating the nation's commitment to science and technology to stay competitive academically and economically.

President Obama is doing more than just talking about improving technology education—he included substantial funding in the proposed fiscal year (FY) 2011 budget specifically targeted at creating the next generation of scientists and engineers who can help drive economic growth in the coming decades. The budget provides $300 million in new grants for states to develop and implement instructional practices and improve teaching and learning in science and math. The Investing in Innovation Fund totals $500 million and includes $150 million for competitive grants for school districts, nonprofits, and other organizations to test, validate, and scale promising strategies to improve teaching and accelerate student learning in STEM subjects. The budget also directs the Department of Education to work with the National Science Foundation and other federal agencies to identify the most effective interventions that can help states, schools, and teachers improve STEM outcomes.[24] Setting the goal for 2020 and providing funding for initiatives show the administration's dedication to the future of science and technology brainpower. These are all good concepts but only become of value if implemented. The current fiscal crisis in the United States puts all such programs at risk, and the political environment may not be conducive to supporting such expenditures for both fiscal and nationalistic reasons. Advocates must continue to make arguments for science and technology education that strongly illustrate the long-term advantages of increasing the current STEM capabilities.

The administration is not alone in attempting to reinvigorate science and technology education in the United States. In 2005 a coalition of 15 business-oriented organizations, Tapping America's Potential, set a challenge to double the number of American graduates with bachelor's degrees in science, technology, engineering, and mathematics from 200,000 to 400,000 by 2015. The number increased each year through 2006, but not enough to meet the goal. Falling short of the target may not be statistically relevant because the target was chosen based on the professional judgment of business people, rather than the needs of the nation. However, the fact that business leaders are giving the issue specific attention is a positive indicator that experts understand the importance of intellectual capital.

Colorado provides one outstanding example of a state-level project to invigorate technology education. Four institutions—the Metropolitan State College of Denver, Colorado School of Mines, Community College of Denver, and Cherry Creek School District—have formed an unprecedented alliance called the Colorado Academy for the Development of STEM-Related Careers (ADSC). It is designed to position the state as a leader in STEM education and to ensure that its students, from kindergarten through graduate level, are connected to cutting-edge innovation. Colorado's governor, Bill Ritter, has embraced and supported ADSC's vision. The academy's initial focus will be on air and space—providing education, scholarships, internships, career guidance, and mentoring to students desiring skills needed to build air and space careers. The Colorado ADSC will provide educational certifications and specialized training that connect its targeted learning communities from kindergarten to doctoral programs to ensure job readiness and career enhancement. It will also collaborate with Colorado Workforce Centers, which will facilitate training and assist in job placement.[25] This program could be used as a model for other states and, if leveraged properly, could educate and inspire a whole generation of US students.

Individual politicians have also recognized the importance of STEM education. Republican congressman Randy Forbes (VA) obtained a National Science Foundation grant of $989,747 for Virginia State University to target minority students to increase the pool of STEM students. In the United States, this segment of the population has been underrepresented in the STEM fields, and tapping into that resource is another potential method to increase the intellectual capital for the future. The money will fund a three-year study aimed at improving test scores for minority students in STEM fields. Forbes hopes the study can become an education model. He said that it "is about more than just advancing test scores and equality in education; it is about economic advancement and ensuring that the United States retains its edge in the math, science and technology fields—a critically important requirement in today's global economy."[26] While the intent is good and should be supported, it does have the scent of "pork" politics, so proper arguments need to accompany such proposals to defend them in the political arena.

The issues of creating and maintaining intellectual capital are complex and require a multifaceted approach. The initiatives listed above merely provide examples of methods which could yield benefits. Globalization increases competition for intellectual capital and makes it critical for all levels of US government, business, and education to

find innovative, effective ways to encourage STEM education and attract and retain STEM-educated researchers and workers.

Implications for Deterrence in 2035

All indications are that technology will continue to develop at an increasing rate and that globalization will continue to "flatten" the world. The world of 2035 will benefit from positive technology innovations which improve health care, information availability, energy sources, and human performance. The technologies that will make these improvements possible will also offer adversaries opportunities to use them for negative purposes. As always, US national security in 2035 will depend upon the ability to deter adversaries. Intellectual capital in STEM professions, whether residing in US- or foreign-born individuals, is the foundation of any deterrence. STEM knowledge is an enabler for deterrence.

Deterrence is dependent upon a potential adversary determining that an action on his part will either fail to get the result he seeks or will create an intolerably high cost or risk.[27] The United States relies on deterrence as a major element of national security strategy and, to keep it viable, must stay aware of developing technological advances. This can only be accomplished if the United States harnesses the capabilities of individuals who can understand and competitively operate in the fields of nuclear weaponry, cyber warfare, chemistry, molecular biology, nanotechnology, directed energy, and the space domain. In addition to understanding evolving technologies, the United States must maintain existing deterrence options, like nuclear and conventional weapons, while developing new offensive and defensive weapons. Deterrence is crucially dependent on science and technology.

Space as a Case Study: The United States May Not Have an Advantage in 2035

There will be many areas of concern for deterrence in 2035. Primary among these will be threats in cyber, nuclear, biological, directed energy, nano, and space technologies. The space domain provides a valuable example as a critical area in which the United States must be prepared to deter threats in the future. It also provides a good example of second-order effects because space is an industry which drives economic growth. According to *The Space Report 2009*, "It is unclear whether the U.S. education system can drive growth in the number of new skilled science and technology graduates, espe-

cially those with advanced degrees, needed to replace veteran U.S. space workers who are retiring."[28] The number of bachelor's degrees awarded in "space critical" fields—Earth and atmospheric sciences, mathematics, computer science, and engineering—dropped by 8 percent between 1986 and 2006.[29]

These trends do not bode well for the future of the space industry or for national security interests in the space domain. The demand for key space industry occupations is projected to grow over the next 10 years, and unless the number of space-critical graduates increases or the United States is able to recruit foreign talent, jobs will go unfilled.[30] As *The Space Report 2009* notes, "The key to maintaining US technology preeminence is to encourage and develop skilled scientists and engineers who strengthen the space industry."[31] The US space industry is just one example of a domain in which the United States may not maintain intellectual dominance through 2035.[32] Each area of potential threat must be evaluated individually; space provides just one clear example of the criticality of maintaining intellectual dominance.

Conclusion

Maintaining the advantage in science and technology intellectual capital is critical to the future of US security. Current trends are positive, and initiatives are underway to grow, attract, and maintain enough qualified individuals to stay ahead of adversaries. However, the past decade has shown that these trends are vulnerable to sudden change. The tightening of visa processes after 9/11 demonstrated that the inflow of foreign students and experts can drop quickly. Although keeping terrorists out is vital, the federal government must also recognize the ramifications of impeding one source of technical expertise. In the near term, the United States likely will continue to rely on foreign-born individuals to maintain its science and technology advantage. If the United States chooses to reduce its historic dependence on foreign-born brainpower, there must be a corresponding increase in homegrown expertise. The most robust pool of individuals can be amassed both by attracting foreign-born students and experts and by increasing the presence of US-born personnel who are highly educated in the technology arena.

President Obama has said that improving science and technology education is a matter of national importance, and he included substantial funding in the proposed FY 2011 budget. Industry, state, and local initiatives are also in place to provide educational opportunities to increase the number of US-born students earning technology de-

grees. Adjusting visa and immigration laws to enable the United States to attract and retain even more talent from other nations will reduce the threat of the United States falling behind in the capability to lead innovation in science and technology. Its lead in technology is crucial to deterring adversaries, whether they are nation-states, nonstate actors, or individuals.

If the United States does not maintain the lead in critical technologies like nuclear weaponry, biological warfare, nanotechnology, cyber warfare, directed energy, and space technology, one or more adversaries likely will take advantage of areas of weakness. Current deterrence depends on the adversary believing that the United States has the capability to deter and the will to take decisive action. The capability is created by those who understand cutting-edge technology. If an adversary did not think the United States could act decisively, he would be more likely to take offensive action. A cyber attack could interfere with almost any US data system and could potentially disrupt most US military operations. A space attack could eliminate access to the global positioning system (GPS), which, at a minimum, would make navigation nearly impossible and disrupt banking worldwide. A biological attack could eradicate a vast portion of the US population. These are examples of events that, undeterred and uncountered, could change the balance of power and threaten the American way of life. Current intellectual capacity makes deterrence viable and supports development of methods to recover if one of these attacks should occur. Without qualified scientists and engineers, the United States could not replace or establish a workable alternative for the GPS after a space attack. Likewise, vaccinations and antidotes would not be available to counter or minimize the impact of a biological attack. These are just two examples of a plethora of possible threats if the United States does not maintain intellectual superiority.

The United States enjoys its position as the one remaining superpower in large part because of its broad spectrum of intellectual expertise in technology fields. In his February 2010 State of the Union address, President Obama stated that the United States is not going to be "number 2." Maintaining the position as "number 1" means more than maintaining national security. As the leader of technology development, the United States also gets to set policy. This has worldwide implications for areas like human genome mapping, nuclear weaponry, and biological warfare. As the leader in these areas, the United States can best influence international treaties, bans, and agreements. Intellectual capital is a critical national security resource that cannot be regained rapidly if it is allowed to deteriorate. Keeping the advantage is a wise investment in the future.

Notes

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Abbreviations

ADSC	Academy for the Development of STEM-Related Careers
FY	fiscal year
GPS	global positioning system
S&E	science and engineering
STEM	science, technology, engineering, and mathematics