Assessing the Need for Nanotechnology Education Reform in the United States

EDWARD T. FOLEY[*] and MARK C. HERSAM[**]

ABSTRACT

Historically, the U.S. has been the global leader in the development of nanotechnologies that are widely believed to be the foundation of the next industrial revolution. However, unless fundamental changes are made in the educational infrastructure in the U.S. to reverse the general erosion of science, technology, engineering, and math ("STEM") education, and to address the specific growing need for a robust nanotechnology workforce, current trends in the global demographic of the high-technology talent pool and R&D infrastructure will lead to a shift in the global dominance in science, technology, and engineering from the U.S. to Asia. For the U.S. to reverse these trends and thus maintain its technological and economic leadership, the infrastructure for nanotechnology education needs to be significantly enhanced. In particular, this infrastructure should include educational models and curricula that will institutionalize an interdisciplinary education, thus exposing students to the connections between disciplines and their relationship to nanotechnology at all levels. The future nanotechnology workforce will also require an increased role for demographic groups that have historically been underrepresented in STEM related fields. Nanotechnology research universities are positioned to play an important role in initiating this educational reform. While programs in nanotechnology are currently being developed for the K-16 level and the general public, significantly more effort is needed to develop effective and comprehensive nanotechnology education reform.

I. INTRODUCTION

The vision of nanotechnology, a term first coined by Norio Taniguchi of Tokyo Science University in 1974,[1] was first set forth in a talk by Richard Feynman entitled "There's Plenty of Room at the Bottom," given during the annual meeting of the American Physical Society at the California

---

[*] Edward T. Foley is a Senior Research Associate in the Department of Materials Science & Engineering at Northwestern University. He may be reached by e-mail at eddie@northwestern.edu.

[**] Mark C. Hersam is an Assistant Professor in the Department of Materials Science and Engineering at Northwestern University. He is a recipient of the Presidential Early Career Award for Scientists & Engineers (PECASE) award, as well as an educator at the National Center for Learning & Teaching (NCLT) in Nanoscale Science & Engineering. He may be reached by e-mail at m-hersam@northwestern.edu, and can be found on the internet at http://www.hersam-group.northwestern.edu.

[1] N. Taniguchi, *On the basic Concept of 'Nano-Technology'*, PROC. INTL. CONF. PROD. ENG. TOKYO, PART II, JAPAN SOCIETY OF PRECISION ENGINEERING (1974).

Institute of Technology in 1959.[2] The development of the Scanning Tunneling Microscope in 1982,[3] and the Atomic Force Microscope in 1986[4] ushered in a new era of scientific research, where the physical structure and properties of materials could be directly studied, manipulated and engineered at the atomic scale. At the same time, understanding in all scientific disciplines has been increasing at an exponential rate and has been converging at the nanometer scale.[5] As a result, research into the development of nanotechnologies in broadly diverse disciplines has exploded, leading to great promise in developing breakthrough technologies in materials and manufacturing, nanoelectronics, medicine and healthcare, environment and energy, chemical and pharmaceutical industries, biotechnology and agriculture, computation and information technology, and national security.

In 2001, President Clinton established the "National Nanotechnology Initiative - Leading to the Next Industrial Revolution."[6] The National Nanotechnology Initiative ("NNI") defines nanotechnology as encompassing the science, engineering, and technology related to the understanding and control of matter on the length scale of 1 to 100 nanometers, including the research and development of materials, devices, and systems that have novel properties and functions due to their nanoscale dimensions or components.

Other nations, most notably those in Asia and the European Union, have followed the lead of the U.S., such that global spending by governments in nanotechnology R&D increased eightfold from 1997 to 2005 to a current annual level of more than $4 billion. Overall, the global investment by both public and private sectors is now approximately $9 billion annually. Presently, the U.S. holds a clear lead in investment in nanotechnology R&D, the number of nanotechnology related patents and publications, and the number of start-up companies based in nanotechnology.[7]

While the U.S. has been playing the leadership role in the R&D of emerging nanotechnologies, a dramatic global shift is also underway in the high-technology talent pool. Without corrective action, the global dominance of science, technology, and engineering will likely follow the high-technology talent pool from the U.S. to Asia. The future leaders in the coming nanotechnological revolution will likely not be those countries that helped develop the basis for nanotechnologies, but will be those countries that have what the President's Council of Advisors on Science and Technology ("PCAST") has termed the "innovative ecosystem" to bring these nanotechnologies to the global marketplace. Due to the erosion of science, technology, engineering, and math ("STEM") education in the U.S. over the past twenty years and the fundamental changes in the educational system required for the development of a nanotechnology workforce, the U.S. now faces a serious threat to its global economic leadership in the area of nanotechnology.[8]

---

[2] R. P. Feynman, *There's Plenty of Room at the Bottom*, 23 ENGINEERING & SCIENCE 22 (1960).

[3] G. Binnig, H. Rohrer, Ch. Gerber, and E. Weibel, *Surface Studies by Scanning Tunneling Microscopy*, 49 PHYSICAL REVIEW LETTERS 57 (1982).

[4] G. Binnig, C. F. Quate, and Ch. Gerber, *Atomic Force Microscope*, 56 PHYSICAL REVIEW LETTERS 930 (1982).

[5] NATIONAL SCIENCE FOUNDATION, CONVERGING TECHNOLOGIES FOR IMPROVING HUMAN PERFORMANCE, NANOTECHNOLOGY, BIOTECHNOLOGY, INFORMATION TECHNOLOGY, AND COGNITIVE SCIENCE (M. C. Roco & W. S. Bainbridge, eds. 2002) *available at* http://www.wtec.org/ConvergingTechnologies/ (last visited July 12, 2006).

[6] NATIONAL SCIENCE AND TECHNOLOGY COUNCIL COMMITTEE ON TECHNOLOGY, SUBCOMMITTEE ON NANOSCALE SCIENCE, ENGINEERING AND TECHNOLOGY, NATIONAL NANOTECHNOLOGY INITIATIVE: THE INITIATIVE AND ITS IMPLEMENTATION PLAN (2000) *available at* http://www.nano.gov/html/res/nni2.pdf (last visited July 12, 2006).

[7] PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY, THE NANOTECHNOLOGY INITIATIVE AT FIVE YEARS: ASSESSMENT AND RECOMMENDATIONS OF THE NATIONAL NANOTECHNOLOGY ADVISORY PANEL (2005) *available at* http://www.nano.gov/html/res/FINAL_PCAST_NANO_REPORT.pdf (last visited July 12, 2006).

[8] THE NATIONAL NANOTECHNOLOGY INITIATIVE: RESEARCH AND DEVELOPMENT LEADING TO A REVOLUTION IN TECHNOLOGY AND INDUSTRY - SUPPLEMENT TO THE PRESIDENT'S FY 2006 BUDGET (2005) *available at* http://www.nano.gov/NNI_06Budget.pdf (last visited July 12, 2006).

This paper outlines the scope of this problem and highlights issues of particular concern. In this manner, future nanotechnology education reforms can be better focused towards effecting positive change.

II. REALIZING THE PROMISE OF NANOTECHNOLOGY

The development of nanotechnology has been realized through the convergence of all scientific disciplines on the nanometer scale. As a result, its impact will be broader and more far-reaching than other technological revolutions of the past, perhaps even more significant than the development of silicon-based microelectronics. The impact of future nanotechnologies and where these nanotechnologies will find their way to the global marketplace are reflected in the trends in global investment strategy in nanotechnology R&D. Global productivity in nanotechnology R&D can be measured in terms of nanotechnology-related publications, start-ups, and patents. The U.S. has dominated the development of future nanotechnologies, but its future dominance and ability to capitalize on these developments is clearly at risk, particularly from Asian competitors.

The technical advisory group ("TAG") for PCAST has identified areas in which nanotechnology will likely make a significant impact in the near-, mid-, and long-term. In the near term (1-5 years), TAG members expect that nanotechnology will yield greatly improved nanocomposites, nanomembranes and filters for water purification, improved catalysts, solid-state chemical and biological sensors, medical diagnostic devices, and batteries. In the mid-term (5-10 years), TAG members foresee nanotechnology leading to targeted drug therapies, enhanced medical imaging, improved solar cells, efficient water-to-hydrogen conversion, and technology for carbon sequestration. In the long term (20+ years), TAG predicts that nanotechnology may lead to the development of drug delivery through cell walls, molecular electronics, all-optical information processing, neural prosthetics, and the conversion of energy from thermal and chemical sources in the environment.[9]

Investment trends provide an independent means of forecasting the relative impact of nanotechnology in different technological areas. Private sector investment should reflect the target areas for near-term commercial application, and the two largest target industries are biomedical/life sciences and materials. Lux Research estimates that of the $1.1 billion in venture capital invested in nanotechnology from 1998 to 2004, 41% has been in electronics and semiconductors, and 40% has been in nanobiotechnology.[10]

The U.S. federal government has historically played the lead role in the long-term development of nanotechnology, and its current investment strategy is a reflection of nanotechnology's long-term impact. This investment strategy is revealed through the seven program component areas (PCAs) of the NNI 2006 budget request. These PCAs and their respective funding requests include Fundamental Nanoscale Phenomena and Processes ($234 million), Nanomaterials ($228 million), Nanoscale Devices and Systems ($244 million), Instrumentation Research, Metrology, and Standards for Nanotechnology ($71 million), Nanomanufacturing ($47 million), Major Research Facilities and Instrumentation Acquisition ($148 million), and Societal Dimensions ($82 million). The Societal Dimensions PCA includes approximately $39 million for environmental, health, and safety R&D, and $43 million for education-related activities and for research on the broad implications for nanotechnology on society. The five agencies investing the most in nanotechnology R&D (NSF, Department of Defense, Department of Energy, National Institutes

---

[9] PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY, *supra* note 7.

[10] *Id.*

of Health, and the National Institute for Standards and Technology) each have investments distributed across six of the seven PCAs.[11]

The development of nanotechnology has largely been the result of strong investment in nanotechnology R&D on the part of the world's two largest economies, the U.S. and Japan, and government leadership has been paramount to the realization of the nanotechnological revolution. In 2004, the U.S. and Japan accounted for more than 60% of the global investment in nanotechnology R&D at $3.3 billion and $2.1 billion, respectively. Historically, the U.S. and Japan governments have been the backbone of global nanotechnology R&D, and currently, more than 50% of global spending on nanotechnology R&D comes from world governments. However, in 2004, spending by companies based in the U.S. and Japan reached $1.7 billion and $1.1 billion, respectively, thereby surpassing the government expenditure in both nations.[12] The U.S. continues to lead the global investment in nanotechnology on an absolute basis. However, while the U.S. federal government investment is leveling off, the global investment in nanotechnology R&D continues to rise.[13] The U.S. has already lost the lead in spending on a relative basis, and the relative difference in spending is amplified when correcting for purchasing-power parity. On this basis, in 2004, the per-capita spending in the U.S. of $5.42 was nearly doubled by Taiwan at $9.40, and exceeded by Japan at $6.30 and South Korea at $5.62. In 2004 China's government spending was $130 million, but when corrected for purchasing-power parity, Chinese spending equaled $611 million, or 38% of the government expenditure in the U.S.[14]

U.S. universities have been the driving force behind the realization of commercially viable nanotechnologies, and 85% of U.S. corporations active in nanotechnology R&D interviewed by Lux Research have university collaborations. A representative sample of 109,728 peer-reviewed journal articles on nanotechnology shows that 24% are authored by U.S. based scientists, followed by China at 13%, and Japan at 11%.[15] By searching the Web of Science database using the keyword "nano*," the yearly production of nanotechnology publications worldwide has increased approximately 8-fold in the past ten years, and more than doubled between 2000 and 2004. While the U.S. has dominated in publication productivity over this entire period, its share of publications has decreased from 40% in the early 1990s to less than 30% in 2004. Performing a similar search in three high-impact journals—*Science*, *Nature*, and *Physical Review Letters*—shows that the U.S. has an even greater lead, with more than 50% of the world total in 2004. However, in these high-profile journals, there has also been a steady increase in the percentage of publications originating from other countries since the early 1990s. In a similar study, Zucker and Darby summarize, "Taken as a whole, these data confirm that the strength and depth of the American science base points to the United States being the dominant player in nanotechnology for some time to come, while the United States also faces significant and increasing international competition."[16]

Two indicators of near-term commercial applications in nanotechnology are investment in nanotechnology start-ups made by venture capital firms, and nanotechnology-related patents and patent applications. In these areas, as well, the U.S. has played the dominant role. The number of new start-ups whose business plan includes nanotechnology is increasing exponentially.[17] Half of the 1200

---

[11] THE NATIONAL NANOTECHNOLOGY INITIATIVE, *supra* note 8.

[12] *Nanotechnology: Where Does the U. S. Stand?*, Hearing before the Research Subcommittee of the H. Comm. on Science, 109th Congress (2005) (statement of Matthew Nordan).

[13] PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY, *supra* note 7.

[14] *Nanotechnology: Where Does the U. S. Stand?*, *supra* note 12.

[15] *Id.*

[16] PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY, *supra* note 7.

[17] Hearing on H.R. 766, The Nanotechnology Research and Development Act of 2003 before the H. Comm. on Science, 108th Congress (2003) (statement of C. A. Batt).

nanotechnology start-ups active worldwide in 2004 were located in the U.S., and the U.S. claims 56% of venture capital deployed in start-ups globally.[18] Investment in U.S. nanotechnology start-ups totaled $400 million in 2004.[19] With regard to nanotechnology-related patent production, the U.S. has dominated since the early 1980s. Performing a search of patents in the U.S. Patent and Trademark Office (USPTO) database using a list of nanotechnology keywords shows that in 2003 the U.S. was assigned more than five times the number of nanotechnology-related patents (5,228) than its nearest competitor, Japan (926). The number of nanotechnology-related patents appearing in the USPTO database has been growing significantly faster than the USPTO database as a whole, especially since 1997. The rate of nanotechnology-related patent production increased 50% between 2000 and 2003, as compared to 4% for patents in all fields. While over 60% of all nanotechnology-related patents at the USPTO are assigned to the U.S., the rate at which other countries are assigned nanotechnology-related patents is increasing. Between 1988 and 2002, the rate of U.S. patent production increased by a factor of 6.3, while Japan patent production increased by a factor of 11. In 2003, several countries experienced fast growth, including South Korea (ranked 6th from 13th), Netherlands (ranked 7th from 12th), Ireland, and China (both first year in the top 20).[20] In many promising applications, foreign researchers have outpaced the U.S. in developing intellectual property. Through February 2005, 31% of carbon nanotube display application patents were assigned to South Korea, 29% to Japan, and 17% to both the U.S. and Taiwan.[21]

From the above data it is clear that governments and industry around the globe recognize the impact that nanotechnology will have on future economies, have followed the U.S. lead in nanotechnology R&D, and are catching up rapidly. Countries not known for innovation in science and technology are being educated in U.S. universities, reading U.S. scientific publications and patent applications, and are able to acquire instrumentation needed for nanotechnology research, without having to pay for the twenty years of development in R&D infrastructure and skill sets necessary to create this instrumentation in the first place. While the U.S. currently maintains an impressive lead in investment, publications, and patents, it is clear that there has been a steady erosion of this lead over time, and that the U.S. faces increasing global competition for the future nanotechnology market share.

III. GLOBALIZATION AND THE HIGH-TECHNOLOGY TALENT POOL

Over the past two decades, globalization, access to capital, changing dependencies on natural resources, dynamic world labor markets, and social and political climates have all had a major impact on global economies and on technological development. These global changes present risks for individual nations, but also present opportunities for those best situated to take advantage of them. Asian countries are aggressively acting to attract R&D investment and participation in high-tech industries. From 1980 to 2001 the U.S. share of high tech exports dropped from 29.9% to 17.3%, while the Asian share increased from 7.4% to 27.4%.[22] From 1988 to 2001 the percentage of U.S. patents held by Asian companies increased from 1.7% to 12.3%. A changing demographic in the global and domestic high-tech talent pool, and an increase in high-tech talent in Asia, coupled with lower wage structures, threatens U.S.-based high-tech manufacturing and leading edge R&D.[23]

---

[18] *Nanotechnology: Where Does the U. S. Stand?, supra* note 12.

[19] PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY, *supra* note 7.

[20] Z. Huang, H. Chen, Z.-K. Chen, and M. C. Roco, *International Nanotechnology Development in 2003: Country, Institution, and Technology Field Analysis Based on USPTO Patent Database*, 6 J. NANOPART, RES. 325 (2004).

[21] *Nanotechnology: Where Does the U. S. Stand?, supra* note 12.

[22] COMMITTEE ON THE ENGINEER OF 2020, PHASE II, COMMITTEE ON ENGINEERING EDUCATION, NATIONAL ACADEMY OF ENGINEERING, EDUCATING THE ENGINEER OF 2020: ADAPTING ENGINEERING EDUCATION TO THE NEW CENTURY (2005).

[23] PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY, *supra* note 7.

The fall of the Berlin wall in 1989 marked a major shift in global economies, as the end of the cold war saw former communist regimes embracing a free market system. The development of the internet, web-based communication, and information management systems has allowed individuals, corporations, and nations to more effectively exploit a rapidly evolving and increasingly interdependent global economy. With web-based management of inventory and product flow, a global supply chain can synchronize its distribution networks. Taking advantage of these developments, Wal-Mart has become China's eighth largest trading partner, and when adjusting for the value of its currency and low domestic prices, economists estimate that China has now become the world's third-largest economy[24,25] In a global economy that is becoming intensely integrated, the pace of technological development has greatly accelerated. Personal mobile integration into the web through high-speed wireless networks has meant that the population affected by this technological development is inherently multicultural, multidisciplinary, and able to access information, exchange ideas, and organize collaborative communities with unprecedented freedom. The effects of these and future technological developments will be more seamless, transparent, and significant in the future.[26]

Multi-national corporations can now much more effectively exploit a global talent pool that is becoming increasingly unified, and great incentives exist to move labor, manufacturing, and R&D offshore. These incentives include lower labor cost, proximity to growing markets, reduced R&D cost, minimal U.S. regulation, fewer technology transfer limitations, lower corporate tax rates, highly skilled and eager R&D personnel, increasingly high-quality research universities, technological development abroad, and joint and cooperative research. Globalization has shown that capital, factories, labor, and laboratories move to where there is the greatest promise of return. High-end services like electronic design, applied research, aerospace design, technical consulting, and x-ray assessment can be done more economically in the developing world via the internet. Forrester Research forecasts that due to global demographic trends, 3,300,000 jobs will move overseas from 2003 to 2014. From 1994 to 2000, U.S. companies increased R&D spending in China from $7 million to $506 million.[27] From 1993 to 1997, the Organization for Economic Co-Operation and Development countries increased their number of science and engineering research jobs by 23%, more than twice the rate in the U.S (11%). The Asian Technology Information Program reports that China is especially strong in nanomaterials development, and that China's nanomaterials research focus, its low cost of doing business, its talented labor pool, and its potentially large domestic market could provide incentive for further investment by foreign corporations seeking to capitalize on nanomaterials development. Other Asian countries are focusing nanotechnology research efforts where they hold a strategic advantage. Korea and Taiwan are focusing on nanoelectronics, and Singapore is placing emphasis on nanobiotechnology.[28]

The development of the internet and its effects on the global economy are forcing global competition in nearly every sector of the economy, and workers must compete on a global playing field. The pace of current technological development drives skill sets and qualifications continually near obsolescence. As the Committee on Prospering in the Global Economy of the 21st Century notes, "For the United States to compete, then, its workers can and must bring to the workplace not only technical skills and knowledge, but other valuable skills: knowledge of other cultures and the ability to interact comfortably with diverse clientele; and the motivation to apply their skills. U.S. workers also must be able to communicate

---

[24] T. L. FRIEDMAN, FARRAR, STRAUS & GIROUX, THE WORLD IS FLAT - A BRIEF HISTORY OF THE TWENTY-FIRST CENTURY (2005).

[25] K. Bradsher, *Chinese Economy Grows to 4th Largest in the World*, N.Y. TIMES, Jan. 25, 2006.

[26] NATIONAL ACADEMY OF ENGINEERING, THE ENGINEER OF 2020: VISIONS OF ENGINEERING IN THE NEW CENTURY (2004).

[27] PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY, *supra* note 7.

[28] *Id.*

effectively orally and in writing, lead teams and manage projects, and solve problems."[29] High-end technology is now developed by highly integrated virtual global teams, and a dynamic global economy and political environment demand workers with a new world view. The National Academy of Engineering ("NAE") has described the necessary attributes of the engineer of 2020 as strong analytic skills, practicing ingenuity, creativity, communication, a command of the principles of business and management, leadership, high ethical standards, professionalism, dynamism, agility, resilience, flexibility, and engaging in life long learning.[30]

Future technological development, the realization of the nanotechnological revolution will be the result of fierce global competition but will also only proceed through unprecedented global cooperation. This global cooperation will necessitate a broader consideration of social issues. By 2020, the world's population will reach 8 billion, with a 1.5 billion increase located mostly in poor urban centers of developing countries that lack the economic, social, and physical infrastructures to support their burgeoning populations. Also by 2020, more than 50% of the world's population could be under the age of 20, and this youth bulge will occur mostly in sub-Saharan Africa, Afghanistan, Pakistan, Mexico, and countries of the Middle East. Countries that have experienced a similar youth bulge in the recent past include Iran, Northern Ireland, Gaza, and Sri Lanka, all regions of recent social and political instability. In developed countries, life expectancy will increase and the percentage of those beyond retirement age will swell, placing a larger economic burden on the young. If current trends persist, by 2050, almost half of the U.S. will be non-white.[31] During the 1990s, the combined population of African Americans, Native Americans, Pacific Islanders, and Hispanics/Latinos grew 13 times faster than the non-Hispanic white population, and the Hispanic population grew 58% between 1990 and 2000.[32]

Ultimately, a nation's economic strength and security result from the wealth created by its intellectual resources. PCAST defines a nation's innovative ecosystem as consisting of inventors, technologists, and entrepreneurs; a motivated workforce; world-class research universities; highly productive R&D centers; vibrant venture capital industry; and a government funded basic research focused in areas of greatest potential. The strength of a nation's native STEM skills is the core driver of this innovative ecosystem. STEM capabilities have penetrated every aspect of American work and life. 55% of the CEOs of Fortune 500 companies have STEM backgrounds.[33] Past economic studies have estimated that as much as 85% of measured growth in U.S. per capita income is due to technological change. The National Academy of Sciences (NAS) and NAE councils have concluded that the weakening of science and technology in the U.S. will degrade its social and economic conditions, and its ability to compete for high-quality jobs.[34] Global competition for science and engineering talent is intensifying such that the U.S. may not be able to rely on the international science and engineering labor market to fill unmet skill needs.[35] PCAST concludes that the U. S. must take aggressive steps to maintain the strength of its innovative ecosystem, or it risks losing its economic leadership.[36]

---

[29] COMMITTEE ON PROSPERING IN THE GLOBAL ECONOMY OF THE 21ST CENTURY: AN AGENDA FOR AMERICAN SCIENCE AND TECHNOLOGY, COMMITTEE ON SCIENCE, ENGINEERING AND PUBLIC POLICY, THE NATIONAL ACADEMY OF SCIENCES, THE NATIONAL ACADEMY OF ENGINEERING, AND THE INSTITUTE OF MEDICINE OF THE NATIONAL ACADEMIES, RISING ABOVE THE GATHERING STORM, ENERGIZING AND EMPLOYING AMERICA FOR A BRIGHTER ECONOMIC FUTURE (2005).

[30] NATIONAL ACADEMY OF ENGINEERING, *supra* note 26.

[31] COMMITTEE ON THE ENGINEER OF 2020, *supra* note 22.

[32] NATIONAL ACADEMY OF ENGINEERING, *supra* note 26.

[33] PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY, *supra* note 7.

[34] COMMITTEE ON PROSPERING IN THE GLOBAL ECONOMY OF THE 21ST CENTURY, *supra* note 29.

[35] NATIONAL SCIENCE BOARD, THE SCIENCE AND ENGINEERING WORKFORCE REALIZING AMERICA'S POTENTIAL (2003) *available at* http://www.nsf.gov/nsb/documents/2003/nsb0369/nsb0369.pdf (last visited July 12, 2006).

[36] PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY, *supra* note 7.

IV. THE "QUIET" CRISIS IN STEM EDUCATION

Richard Smalley, Nobel Laureate in Chemistry, states that:

> Chemistry, physics, and materials science are at the core of nanotechnology. These are the fields that discovered the atom and understood its inner workings, and developed the science of combining them in precise structures, and developed the tools with which these nanostructures are probed and visualized. These are the fields that are developing the requisite fundamental knowledge, and the computational algorithms to realistically predict behavior. As nanotechnology develops, the critical, core areas of physics and chemistry in our nation's universities will become much more intimately coupled to engineering, to industry and society as a whole. . .[37]

The large research university in the U.S. is arguably the most creative and culturally diverse environment in the world today. The brightest and most ambitious, the very cream of the global intellect, come to U.S. universities from virtually every country in the world to collaborate and compete in developing the knowledge and tools necessary for the realization of future technologies. For the past twenty years, universities in the U.S. have been at the very core of the global innovative ecosystem, and have played the lead role in developing the foundation for the global nanotechnological revolution. For the past twenty years, as well, the U.S. has failed to reverse decay in its K-12 STEM educational system.

As a result, the U.S. has not adequately empowered an entire generation of its citizenry to pursue and obtain college degrees in nanotechnology-related STEM fields, degrees which would have allowed them to participate and compete in the knowledge-based and technologically-driven global economy that U.S. universities have played such a central role in creating. If the U.S. is going to compete effectively in the coming century, it cannot squander this precious human resource. Shirley Ann Jackson, president of the American Advancement of Science in 2004, has coined this erosion in the U.S. native science and engineering base, which has always been the source of U.S. innovation and rising standard of living, a "quiet crisis."[38] Here, quotation marks may be used because, for more than twenty years, numerous reports sponsored by the federal government and private sector have called for a massive capital investment in and a radical reform of the K-12 STEM educational infrastructure and pedagogy. Yet, until recently, these informed and impassioned calls have fallen on deaf ears. While current U.S. leadership has begun to bring attention to this crisis,[39] and major U.S. news outlets have begun to highlight this issue,[40] there has been insufficient political will to effect any of the significant changes recommended.

Hanushek and Kimiko have analyzed four decades of data on the correlation between STEM education and long-term economic health, and have found a strong statistical relationship between K-12 math and science scores and a country's GDP growth rates.[41] The noncompetitive condition of U.S. K-12 math and science education has been well documented and does not bode well for the future of U.S. high-tech competitiveness. With the exception of Switzerland, the U.S. spends more per student than any other country, and yet, in the 2000 National Assessment of Educational Progress, less than one third of U.S. students in the 4th and 8th grades, and less than one fifth of U.S. students in 12th grade performed at, or above, proficient levels in math and science. Furthermore, the 1999 International Math and Science

---

[37] NATIONAL SCIENCE FOUNDATION, SUBCOMMITTEE ON NANOSCALE SCIENCE, ENGINEERING, AND TECHNOLOGY, SOCIETAL IMPLICATIONS OF NANOSCIENCE AND TECHNOLOGY (2001) *available at* http://www.wtec.org/loyola/nano/NSET.Societal.Implications/ (last visited July 12, 2006).

[38] T. L. FRIEDMAN, FARRAR, STRAUS & GIROUX, *supra* note 24.

[39] State of the Union Address by President George W. Bush, January 31, 2006 *available at* http://www.whitehouse.gov/stateoftheunion/2006/index.html (last visited July 12, 2006).

[40] M. D. Lemonick, *Are We Losing Our Edge?*, 167 TIME MAGAZINE 22 (2006).

[41] PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY, *supra* note 7.

Study showed that U.S. students in the 12th grade were ranked 19th out of 21 nations in math, and 16th out of 21 nations in science.[42]

Some suggest that these comparisons may merely serve to highlight the huge funding disparities that exist between U.S. school districts. Unlike most other western nations, scholastic achievement in the U.S. varies widely from school to school, and from state to state. The math performance of 8th grade students in some states is as high as the best countries in the world, while the performance of students from other states is at levels comparable to scarcely developed countries. Students in many U.S. suburban schools enjoy the very best education, with smaller classes, more computers, and significantly higher salaried teachers, while students in urban and rural schools face gross overcrowding, decayed buildings, and inadequate funding for even basic instruction. Standardized test scores generally reflect this huge disparity in resources.[43]

In the vast majority of the 15,000 school districts in the U.S., the pool of qualified math and science teachers is woefully inadequate. The opportunity cost of being a K-12 math or science teacher is just too great, and the attrition rate is very high: 33% during the first three years, and 46% during the first five years. Consequently, most school districts are constantly recruiting and training new and unqualified teachers.[44] The chance that a U.S. student in grades 5-8 is being taught math by an out-of-field teacher (one who has not majored in, or been certified to teach the subject being taught) is 69%. For physical science it is an astonishing 93%. In grades 9-12 the chance of being taught math by an out-of-field teacher are 31%, and for physical science it is 63%. In the National Academies sponsored report "Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future," the Committee on Prospering in the Global Economy of the 21st Century concludes that there are few factors more important for the U.S. to successfully compete in the 21st century than the need to recruit, educate, and retain excellent K-12 teachers who understand biology, chemistry, physics, and mathematics. Achieving an equitable distribution of funding and high-quality teaching should be a top priority issue in the U.S.[45]

The chronic and widespread shortage of qualified K-12 math and science teachers in the U.S. and an enlightened and aggressive effort on the part of other nations to attract foreign investment in their native high-tech talent pool and R&D infrastructure have led to a dramatic reduction in the relative growth in the number of U.S. first university degrees in STEM related fields. From 1975 to 2003 the percentage of U.S. 24-year-olds earning a first degree in natural science or engineering remained relatively constant, increasing modestly from about 4% to 6%, while the percentages in Taiwan and South Korea rose dramatically from just over 2% to 16.4% and 12.5%, respectively. Several European countries more than tripled their percentages, including France, the United Kingdom, and Ireland, to 11.4%, 10.0%, and 9.6%, respectively. The U.S. is currently ranked 32nd out of 90 countries for which these data are tabulated.[46] [47,48]

Over the past twenty years, about 30% of entering college students in the U.S. (95% of these students were U.S. citizens or permanent residents) intended to major in science or engineering, but these disciplines have seen the lowest retention rates. From 1990 to 2000, less than half of these students completed a degree, and those who opted out of these programs were disproportionately women and minorities. Only 6% of U.S. undergraduates study engineering, second lowest among developed

---

[42] *Id.*

[43] COMMITTEE ON PROSPERING IN THE GLOBAL ECONOMY OF THE 21ST CENTURY, *supra* note 29.

[44] PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY, *supra* note 7.

[45] COMMITTEE ON PROSPERING IN THE GLOBAL ECONOMY OF THE 21ST CENTURY, *supra* note 29.

[46] NATIONAL SCIENCE BOARD, SCIENCE AND ENGINEERING INDICATORS, Vol. 1 (2004).

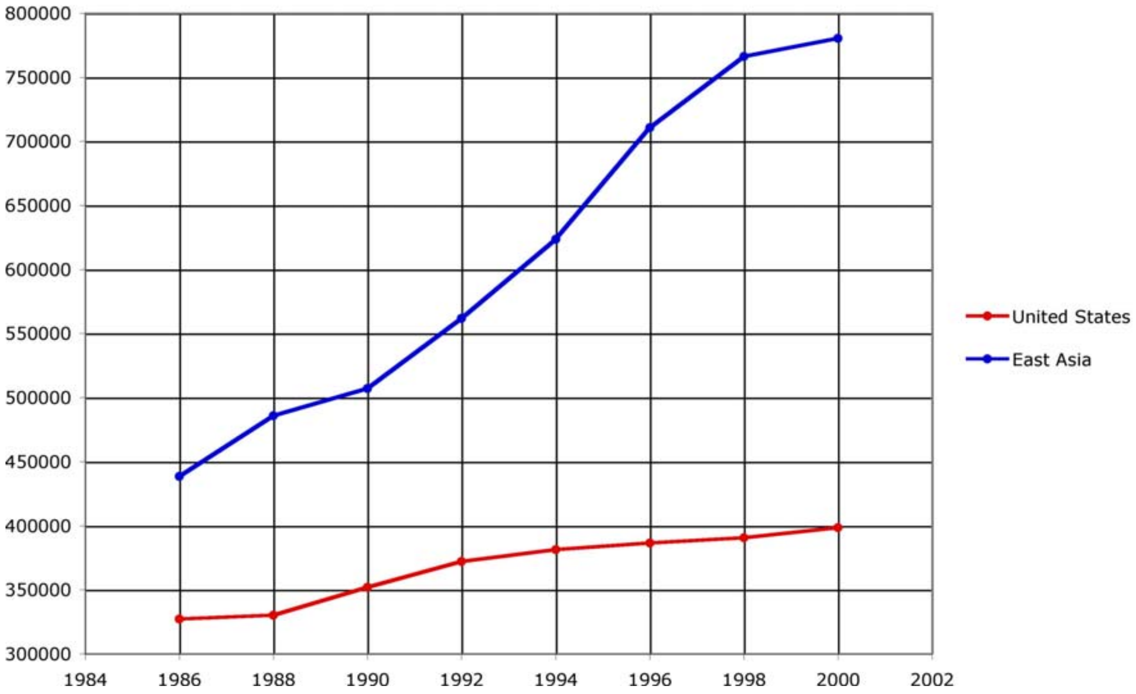
[47] NATIONAL SCIENCE BOARD, SCIENCE AND ENGINEERING INDICATORS, Vol. 1 (2006).

[48] NATIONAL SCIENCE BOARD, SCIENCE AND ENGINEERING INDICATORS, Vol. 2, Appendix Tables (2006).

countries, compared with 12% in Europe, 20% in Singapore, and 40% in China.[49] In the U.S., only 40 to 60% of entering engineering students persist to a degree, and women and minorities are at the low end of this range.[50] In China, 39% of first university degrees are in engineering, and China is producing three times the number of trained engineers than the U.S.[51] While growth in the number of science and engineering undergraduate degrees in the U.S. has remained relatively flat for the past twenty years, other countries, particularly those in East Asia (see Figure 1), have substantially increased the growth rate of science and engineering graduates and are thus attracting jobs and investment in their high-tech sectors from global corporations.[52,53]

FIGURE 1: SCIENCE AND ENGINEERING FIRST UNIVERSITY DEGREES IN THE U.S. AND EAST ASIA

Between 1986 and 2000, the annual growth in first university degrees in science and engineering increased by more than 75% in East Asia, and less than 19% in the U.S. In this plot, East Asia represents the combined total of Japan, China, and South Korea.[54]



---

[49] COMMITTEE ON PROSPERING IN THE GLOBAL ECONOMY OF THE 21ST CENTURY, *supra* note 29.

[50] COMMITTEE ON THE ENGINEER OF 2020, *supra* note 22

[51] PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY, *supra* note 7.

[52] *Id.*

[53] NATIONAL SCIENCE BOARD, *supra* note 48, at Appendix Tables (2006).

[54] NATIONAL SCIENCE BOARD, SCIENCE AND ENGINEERING INDICATORS, Vol. 2, Appendix Tables (2004).

The K-16 STEM educational system in the U.S. is the pipeline by which its native high-tech talent is nurtured and directed into the global high-tech talent pool and R&D infrastructure. However, alarming trends in the production of science and engineering doctorates and the development of higher education and R&D infrastructures in other nations, particularly those in East Asia, indicate the global dominance of science and engineering is shifting from the U.S. to Asia.

As the world's economies have become more tightly integrated, and systems for sharing and disseminating information have been transformed, corporations are aggressively working to more effectively exploit the global high-tech talent pool. Over the past twenty years, the degradation of the U.S. STEM educational pipeline has made U.S. research universities and the U.S. economy critically dependent on a rising flow of foreign high-tech talent into the U.S. Global production of science and engineering doctorates has increased dramatically in recent years, and in 2002, 78% of science and engineering doctorates were granted outside the U.S. The European Union granted one-third of the new science and engineering doctorates, and one third of the engineering doctorates were awarded in Asia. The U.S. granted 15% of the world's engineering doctorates, but students on temporary visas earned more than half of these degrees. Among doctorate holders in the U.S. in 2003, a majority in computer science (57%), electrical engineering (57%), civil engineering (54%), and mechanical engineering (52%) were foreign-born. From 1983 to 2003, Asian countries provided nearly 70% of U.S. foreign science and engineering doctorates, with China, Taiwan, South Korea, and India providing more than half of the total number.[55]

These countries have learned from the U.S. model and are providing incentives for students to study science and engineering, and are investing heavily in higher education and R&D infrastructures. Developing countries like China, India, and South Korea are becoming less dependent on the U.S. for training and have begun to attract significant foreign investment in R&D. Similarly, more of their citizens are choosing to return from the U.S. after graduation or to pursue advanced degrees within their own countries. The disparity in science and engineering doctorate production by East Asian countries at home and abroad compared with U.S. citizens within the U.S. has been steadily increasing with time (see Figure 2).[56]

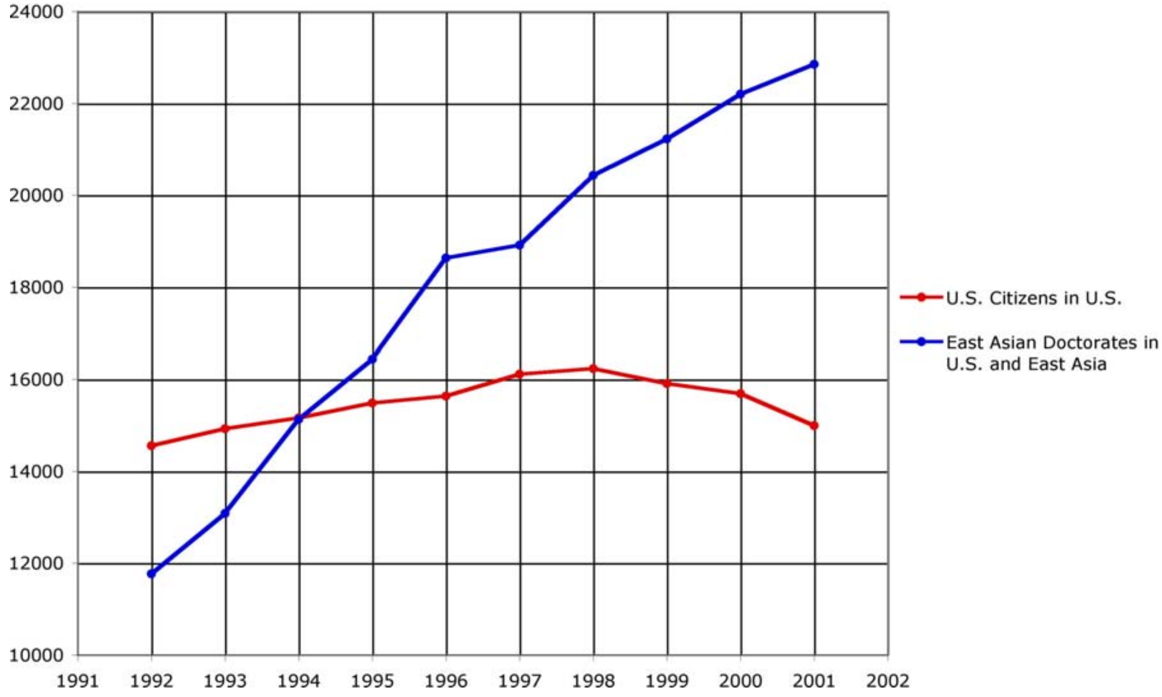
---

[55] NATIONAL SCIENCE BOARD, *supra* note 47.

[56] NATIONAL SCIENCE BOARD, *supra* note 54, at Appendix Tables.

FIGURE 2: SCIENCE AND ENGINEERING DOCTORATES AWARDED TO U.S. AND EAST ASIAN CITIZENS

In this plot, East Asia represents China, Japan, South Korea, and Taiwan. Data for South Korea in 2001 are estimated.[57]



From 1992 through 2001 the number of science and engineering doctorates awarded to U.S. citizens in the U.S. remained relatively flat, peaking in 1998. The number of doctorates awarded to East Asian citizens in the U.S. and students in East Asian universities increased linearly and almost doubled in the same period, and is now more than a factor of 1.5 greater than that for U.S. citizens in the U.S. The greatest growth in East Asian doctorates occurred in China, Taiwan, and South Korea, where science and engineering doctorate production in U.S. and domestic universities increased by more than 500% in China, close to 400% in Taiwan, and close to 300% in Korea. China R&D spending increased almost 700% from 1991 to 2003, to a level of $84.6 billion, placing China in third place, behind only the U.S. and Japan.[58]

The global trends in science and engineering doctorate production and R&D investment are reflected in science and engineering publication output. While the U.S. output of science and engineering publications has been flat since 1990, publication output from both Western Europe and Asia have been increasing linearly, and their combined output is now more than a factor of 1.5 higher than the U.S. (see Figure 3).[59]

---

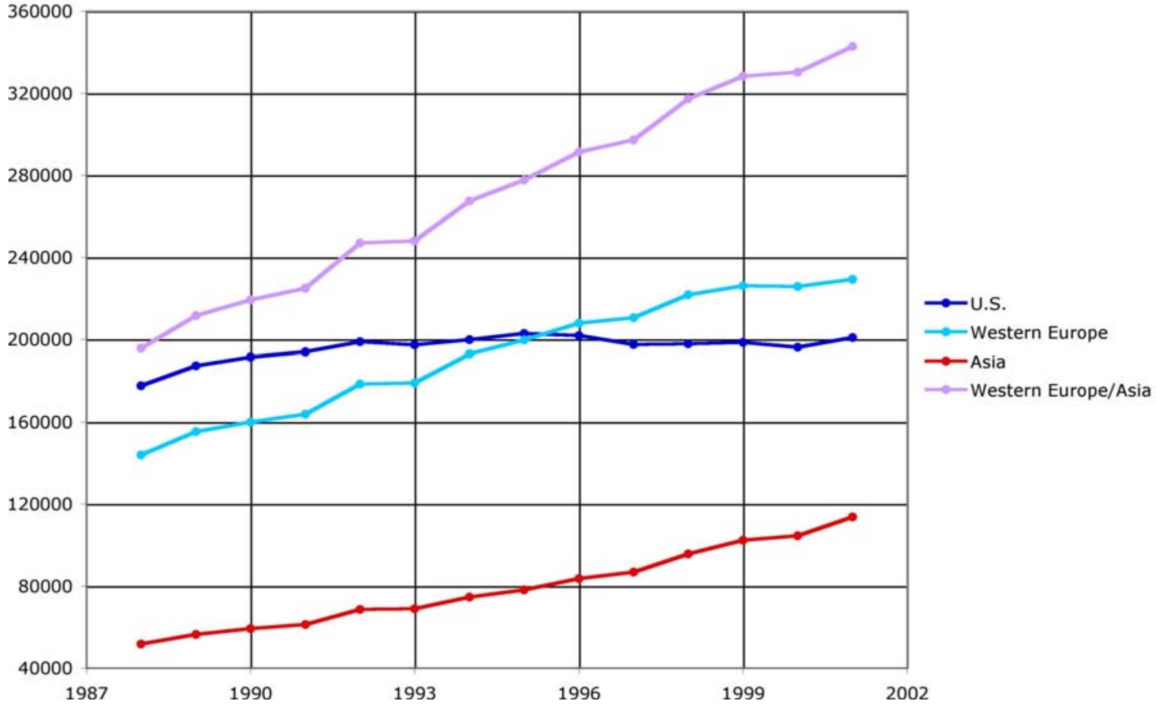
[57] *Id.*

[58] NATIONAL SCIENCE BOARD, *supra* note 47.

[59] NATIONAL SCIENCE BOARD, *supra* note 54, at Appendix Tables.

FIGURE 3: SCIENCE AND ENGINEERING PUBLICATIONS IN THE U.S., WESTERN EUROPE AND ASIA

Science and engineering publication output from 1988 to 2001 for the U.S., Western Europe, Asia, and Western Europe and Asia Combined. [60]



The number of jobs in the U.S. labor force that require science and engineering skills is growing at about 5% per year, a factor of five greater than the rest of the labor force. The U.S. has met this growing demand, not by making the long term investment in enlarging its native STEM educational pipeline, but rather, by attracting a greater number of foreign students to U.S. universities for graduate study and then allowing them to remain in the U.S. to pursue their careers. Between 1990 and 2000, foreign-born people with bachelor's degrees in science and engineering occupations rose from 11% to 17%, those with master degrees rose from 19% to 29%, and those with doctorates rose from 24% to 38%.[61] The five-year stay rates for U.S. science and engineering doctoral degree recipients with temporary visas was at 61% in 2003.

The U.S. strategy of reliance on foreign talent to compensate for the inadequacy of its native STEM educational pipeline is rapidly becoming untenable for many reasons. The globalization of the science and engineering workforce continues to increase, the location of science and engineering training and employment is becoming more internationally diverse, and science and engineering workers are becoming more internationally mobile. R&D spending and business investment are increasingly crossing

---

[60] *Id.*

[61] NATIONAL SCIENCE BOARD, AN EMERGING AND CRITICAL PROBLEM OF THE SCIENCE AND ENGINEERING LABOR FORCE – A COMPANION TO SCIENCE AND ENGINEERING INDICATORS (2004).

international borders in search of available talent, and workers are crossing borders in search of the most creative and lucrative work.[62]

In response to the terrorist attacks on September 11, 2001, the U.S. instituted changes in its immigration policy that have made it more difficult and time consuming to process visa applications. As a result, the numbers of student, exchange visitor, and other high-skill-related visa applications have declined. From 2001 to 2003, the number of foreign students enrolling for the first time dropped sharply and was most pronounced in mathematics and computer science (-28%), and engineering (-17%). While the U.S. has placed restrictions on its immigration policy, Japan has revised its immigration laws, making it easier for high-skilled workers to obtain temporary visas that allow for employment and residence for an indefinite period. As a result, from 1992 to 2003, high-skilled worker migration to Japan increased by 93% to 268,045 workers. This number is equivalent to half of the number of Japanese university graduates entering the labor force each year, and is more than the number entering the U.S. in similar categories.

Another important factor affecting the growth in the U.S. science and engineering workforce is its aging population. Now 29% of all science and engineering degree holders, and 44% of science and engineering doctorate holders, are greater than 50 years old. Over the next decade, the number of individuals with science and engineering degrees reaching traditional retirement age is expected to triple.[63]

All of the above factors point to a significant slowing in the growth of the U.S. science and engineering workforce over the coming decade, at a time when other nations will experience accelerated growth, particularly those in East Asia. These trends have led Richard Smalley to conclude that by the year 2010, 90% of all Ph.D. holders in physical science will be Asian, and 50% of them will be working in Asia.[64]

The factors that have led to the current crisis in U.S. STEM education have gone unchecked for more than three decades and have led the Hart-Rudman Commission on National Security/21st Century, which predicted a major attack on U.S. soil six months before September 11, 2001, to state that:

> In this commission's view, the inadequacies of our systems of research and education pose a greater threat to U.S. national security over the next quarter century than any conventional war that we might imagine. American national leadership must understand these deficiencies as threats to national security. If we do not invest heavily and wisely in rebuilding these two core strengths, America will be incapable of maintaining its global position long into the 21st century.[65]

---

[62] NATIONAL SCIENCE BOARD, *supra* note 47.

[63] *Id.*

[64] *Nanotechnology: Where Does the U. S. Stand?, supra* note 12.

[65] COMMISSION ON NATIONAL SECURITY, ROAD MAP FOR NATIONAL SECURITY: IMPERATIVE FOR CHANGE, THE PHASE III REPORT OF THE U. S. COMMISSION ON NATIONAL SECURITY/21ST CENTURY (2001) *available at* http://www.govinfo.library.unt.edu/nssg/PhaseIIIFR.pdf (last visited July 12, 2006).

V. STEM AND NANOTECHNOLOGY EDUCATION REFORM

In the Strategic Plan of the NNI, it is argued that nanoscale science, engineering, and technology education can help to produce the next generation of researchers and innovators, provide the workforce of the future with math and science education and technological skills they will need to succeed, and educate a citizenry capable of making well-informed decisions in an increasingly technology-driven society.[66] For the development of an effective system of nanotechnology education in the U.S., and for the U.S. to compete effectively in a rapidly developing technologically-driven global economy, a fundamental and dramatic reformation of its K-16 STEM educational system must be realized.

Foremost, this reform should include a massive investment in the recruitment, training, and retention of qualified K-12 math and science teachers. A new educational paradigm should be implemented in which curricula are interdisciplinary from the beginning, thus introducing students to the connections between disciplines at the most fundamental levels and their relevance to the latest technological developments. An emphasis should also be placed on nurturing students' ability for lifelong independent learning. In order to effectively recruit, educate, and retain a rapidly changing student demographic, the U.S. must achieve a more equitable distribution of quality K-12 math and science education, enabling a greater percentage of minority students to take advanced placement (AP) exams. Greater financial incentives are required to attract the best and brightest students to attain STEM-related degrees and pursue STEM-related careers and graduate study. U.S. universities need to adapt their undergraduate STEM programs to more effectively recruit, educate, and retain women and minority students, and curricula need to include STEM and nanotechnology-related interdisciplinary education[29] as elements of the general education across all disciplines. A greater investment needs to be made in STEM-related nanotechnology education research in order to develop the most effective curricula, and guide changes in any future nanotechnology educational reforms.

The realization of such sweeping and fundamental reforms will necessitate unprecedented bipartisan support and cooperation among federal, state, and local leadership. Educating the general public in nanotechnology will help in its rapid adoption in society, will inspire children to pursue nanotechnology-related careers, and will help to create the political will needed to effect any meaningful educational reform. U.S. nanotechnology research universities are positioned to play a key role in initiating these educational reforms, and in maintaining U.S. leadership in the future nanotechnological revolution.

From its inception, a major goal of the NNI has been to "develop educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology."[67] Through the NNI, the National Science Foundation ("NSF") is the lead agency in nanotechnology educational programs beyond graduate training. The NSF plans to spend $28 million in the fiscal year 2006 for nanotechnology educational programs, including curriculum development in universities, integration of research and education, distance learning, and courses and tutorials by professional societies.[68]

Currently, the NSF is funding two activities focused specifically on nanotechnology education. The first is the Nanotechnology Center for Learning and Teaching ("NCLT") at Northwestern University. This center works to develop scientist educators at the middle school, high school and secondary levels, and serves as a clearinghouse for educational materials, instructional methods, and activities in

---

[66] COMMITTEE ON TECHNOLOGY, NATIONAL SCIENCE AND TECHNOLOGY COUNCIL, NATIONAL NANOTECHNOLOGY INITIATIVE STRATEGIC PLAN (2004) available at http://www.nano.gov/NNI_Strategic_Plan_2004.pdf (last visited July 12, 2006).

[67] *Id.*

[68] PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY, *supra* note 7.

nanotechnology education.[69] The second activity is the Nanoscale Informal Science Education ("NISE") Network which fosters informal education through learning outside of the traditional classroom. This network links science museums and other informal science education organizations with nanoscale scientific research organizations.[70]

In the modern age of globalization, workers in high-technology fields are expected to adapt, learn, and communicate in an inherently interdisciplinary and multicultural context, and in a continually evolving technological and economic landscape. Traditionally, students of STEM related disciplines have been taught the language and methods of investigation unique to each discipline. Then, only after reaching the height of their specialization, are students expected to learn the broader, deeper connections among the disciplines. Mihail C. Roco, a leading architect of the NNI, calls this educational structure the "pyramid of learning" and suggests that reversing this pyramid will expedite the development of a U.S. nanotechnology workforce.[71] Demonstrating how all knowledge is connected and integrated at an early educational stage will reduce the reliance on knowledgebase and enhance the ability to learn new concepts and integrate them into a contextual understanding.

Nanotechnology research universities will play the leading role in the development of this new educational paradigm. Collaborative efforts are underway between faculty, post-doctoral research associates, graduate and undergraduate students from all STEM related disciplines, K-12 educators and students, museums, and informal centers of learning to develop an integrative and interdisciplinary approach, utilizing student-centered discovery-based problem solving learning experiences, intimately related to cutting-edge advancements in nanotechnology at all levels.[72]

VI. CONCLUSION

While nanoscience has been maturing for the past twenty years, the promise of the nanotechnological revolution is only now just emerging. In testimony before the Research Subcommittee of the House Committee on Science, Mathew M. Nordan of Lux Research, Inc. projects that nanotechnology will affect nearly every type of manufactured good over the next ten years, being incorporated into 15% of global manufacturing output totaling $2.6 trillion in 2014.[73] It has been estimated that by 2015 there will be 2 million jobs created in nanotechnology worldwide, 0.8 to 0.9 million in the U.S. alone, and that 5 million additional jobs will be created in nanotechnology related areas.[74,75]

However, globalization, the development of the internet, information technology, and mobile communications, and the movement of manufacturing, finance, engineering, and research overseas have intensified the global competition for science and engineering talent, with the strongest competition coming from East Asian countries.[76,77] For the past twenty years, while nanotechnologies have been

---

[69] National Science Foundation Press Release, 05-179, *New Grants are Awarded to Inform the Public and Explore the Implications of Nanotechnology* (2005) *available at* http://www.nsf.gov/news/news_summ.jsp?cntn_id=104505&org=NSF (last visited July 12, 2006).

[70] *Id.*

[71] M. C. Roco, *Converging Science and Technology at the Nanoscale: Opportunities for Education and Training,* 21 NATURE BIOTECHNOLOGY 1247 (2003).

[72] M. C. Hersam, M. Luna, and G. Light, *Implementation of Interdisciplinary Group Learning and Peer Assessment in a Nanotechnology Engineering Course,* 93 J. OF ENG'G EDUC. 49 (2004).

[73] T. L. FRIEDMAN, FARRAR, STRAUS & GIROUX, *supra* note 24.

[74] M. C. Roco, *supra* note 71.

[75] M. C. Roco, *Nanotechnology-A Frontier for Engineering Education*, 18 INT. J. ENG. ED. 488 (2002).

[76] T. L. FRIEDMAN, FARRAR, STRAUS & GIROUX, *supra* note 24.

[77] NATIONAL SCIENCE BOARD, *supra* note 46.

borne largely through the creative ecology of graduate research at U.S. universities, the U.S. has suffered profound erosion in the core of its native scientific and engineering base—STEM education at the K-12 level.[78] The failure of the U.S. STEM educational system to adequately prepare an entire generation of students and to respond to the needs of a rapidly changing student demographic has made U.S. universities and the U.S. economy critically dependent on an influx of foreign science and engineering talent.

In its companion report to Science and Engineering Indicators 2004, the National Science Board ("NSB") concludes that if current trends continue, the number of jobs in the U.S. economy requiring science and engineering training will grow, the number of U.S. citizens prepared for these jobs will, at best, be level, and the availability of people from other countries who have science and engineering training will decline. The NSB describes these trends as a threat to the economic welfare and security of the U.S.[79]

In his 12th Annual Report to the Massachusetts Board of Education in 1884, Horace Mann, widely regarded as the father of public school education in the U.S., writes:

> Education then, beyond all other devices of human origin, is a great equalizer of the conditions of men . . . It does better than to disarm the poor of their hostility toward the rich: it prevents being poor. . . That political economy, therefore, which busies itself about capital and labor, supply and demand, interests and rents, favorable and unfavorable balances of trade, but leaves out of account the elements of a wide-spread mental development, is naught but stupendous folly. The greatest of all the arts in political economy is to change a consumer into a producer; and the next greatest is to increase the producing power—and this to be directly obtained by increasing his intelligence.[80]

These words have never been more relevant with regard to the intense international competition for a future share of the global high-tech talent pool and its implication for future U.S. economic leadership and national security. A century later, Terrel H. Bell, the U.S. Secretary of Education in 1983, commissioned the report, "A Nation at Risk," which issued a clarion call, waking up millions of Americans to the crisis in U.S. K-12 education.[81] This report cast educational reform as a national security issue and defined the principle challenge of K-12 educational reform as the promotion of successful learning among students from all backgrounds.

While the findings of "A Nation at Risk" were widely accepted and were responsible for making K-12 educational reform a national priority, the reforms implemented in its wake over the past twenty years have proven largely ineffectual in improving overall U.S. K-12 math and science proficiency and have fallen far short of broader, more far-reaching reforms called for by numerous committees commissioned by the federal government and private sector. The Koret Task Force on K-12 Education notes that, in the twenty years following "A Nation at Risk," about eight million children have entered the U.S. K-12 educational system with little hope of improved school performance or student achievement. They conclude for an effective K-12 educational reform to occur, the U.S. must find the resolve to carry out a

---

[78] COMMITTEE ON THE ENGINEER OF 2020, *supra* note 22.

[79] NATIONAL SCIENCE BOARD, *supra* note 61.

[80] HORACE MANN, THE TWELFTH REPORT TO THE MASSACHUSETTS BOARD OF EDUCATION (1884).

[81] NATIONAL COMMISSION ON EXCELLENCE IN EDUCATION, A NATION AT RISK: THE IMPERATIVE FOR EDUCATIONAL REFORM (1983) *available at* http://www.ed.gov/pubs/NatAtRisk/index.html (last visited July 12, 2006).

bottom-to-top reconstruction of its K-12 education delivery system constructed around clear principles, sound ideas, and learning-centered rules, incentives, and power relationships.[82]

This kind of radical overhaul of the U.S. K-12 educational system can only be realized on a national level through strong federal leadership, and by building broad bipartisan support on the federal, state, and local levels. The U.S. has failed to adequately inspire and educate an entire generation of its students to careers in STEM-related fields. The STEM educational pipeline to graduate level research in nanotechnology can be 20 years or more in length, and as the National Science Board notes, "If action is not taken now to change these trends, we could reach 2020 and find that the ability of U.S. research and education institutions to regenerate has been damaged and their preeminence has been lost to other areas of the world."[83]

---

[82] MANN, *supra* note 80.

[83] NATIONAL SCIENCE BOARD, *supra* note 61.