Embracing Globalization: Meeting the Challenges to U.S. Scientists and Engineers

Assuring a Globally Engaged Science & Engineering Workforce

WORKSHOP REPORT

"Nothing in life is to be feared. It is only to be understood."

Marie Curie

Dear Colleagues:

It is with great pleasure that I present this Sigma Xi report: *Embracing Globalization: Meeting the Challenges to U.S. Scientists and Engineers*. The report emanates from a three-day workshop held September 20–22, 2006, at National Science Foundation Headquarters in Arlington, Virginia. At this workshop Sigma Xi brought together researchers, educators, industry representatives, and NSF staff to grapple with the question of how to meet today's challenge of assuring a globally competent U.S. science and engineering workforce in the future.

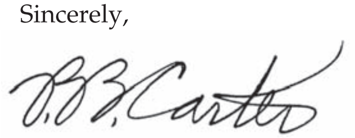
This report emphasizes the important role that the U.S. government must play in supporting science, technology, engineering, and mathematics education and basic research, pointing out that various elements of global competence should be embedded in all aspects of curriculums, research strategies, and innovation activities. The report also calls for U.S. government agencies to foster a sea change in the scientific and engineering community and the general public by making a global perspective in science and engineering institutions the norm rather than the exception.

The federal government, however, is only one player in this important undertaking. Active partnerships must be created between government agencies at the federal, state, and local levels and academia and industry. These partnerships will promote intellectual and economic advances that can ultimately result in the sustainable development of our national economy and the improvement of the welfare of our citizens.

Our Sigma Xi Steering Committee and staff have been working diligently for the past eighteen months to organize the growing resources and ideas that are beginning to arise to define globalization in a meaningful way for science and engineering and to provide recommendations for all of the major actors to define important partnerships and programs that will assure continued U.S. science and engineering leadership in a global environment.

This work has been supported by National Science Foundation Grant Number 0541960. Sigma Xi appreciates NSF's support and the opportunity to play an active role in stimulating and advancing the role of science and engineering in meeting the challenges of globalization.

Sincerely,



Philip B. Carter, Ph.D.
Executive Director, 2006-2007
Sigma Xi, The Scientific Research Society

Sigma Xi
The Scientific Research Society

Steering Committee Members

Vera Alexander, Dean Emeritus, School of Fisheries and Ocean Science, University of Alaska Fairbanks

Julio Ibarra, Executive Director, CIARA, Florida International University

Wayne Johnson, Vice President for University Relations, Hewlett Packard

Gretchen Kalonji, Director of International Strategy Development, University of California Office of the President

Kathleen Kennedy, Vice President for Education and Training, North Carolina Biotechnology Center

Mark Lazar, Deputy Vice President for Scholarships, Training Programs, and International Operations, International Institute of Education

Juan Lucena, Associate Professor, Liberal Arts and International Studies Division, Colorado School of Mines

H. Dean Sutphin, Professor, Agriculture and Extension Education, Virginia Polytechnic and State University

Principal Sigma Xi Staff

Elizabeth J. Kirk, Visiting Sigma Xi Scholar and Principal Investigator

Philip B. Carter, Executive Director, Sigma Xi and Co-Principal Investigator

Acknowledgements

The Sigma Xi Steering Committee on a Globally Engaged Workforce wishes to acknowledge the contribution of Sigma Xi staff and others to the organization of the three-day workshop and production of this final report.

First and foremost we wish to acknowledge the work of Elizabeth J. Kirk, Sigma Xi Visiting Scholar and Principal Investigator on the NSF grant that supported the Committee's efforts. She was the primary organizer of the three-day workshop and contributed major sections of the final report which integrated the findings and recommendations of our twelve panels.

We also wish to thank several Sigma Xi staff members, present and past, for their assistance in making the workshop a success: Christine Piggee, Martin Baucom, Sharlini Sankaran, and John Rintoul. Finally, we also wish to acknowledge the work of Angie Porter, Amos Esty, and Spring Davis for editing and preparation of the final report and Web site.

Table of Contents

Executive Summary

I. Introduction

Two pieces of information, although seemingly unrelated, highlight the challenges facing the United States as it attempts to remain competitive in the face of economic globalization. First, the nation lost almost 300,000 high-tech jobs to competition from abroad between 1998 and 2003, and today U.S. companies often cannot fill their personnel needs domestically because of a lack of scientific, engineering, and technical expertise. Second, despite rapid air transportation and global cultural and economic ties, unofficial figures state that only about 21 percent of U.S. citizens hold passports.[1] Success in a global economy will require the U.S. to address both of these issues by helping its scientists and engineers to achieve "global competence."

According to a 1994 Rand Corporation study, "Cross-cultural competence was considered by members of both the academic and corporate communities to be the most important new attribute for future effective performance in a global marketplace... However, it is what U.S. citizens are most lacking."[2]

A report published by the National Association of State Universities and Land Grant Colleges in October 2004 defines what is lacking—global competence, defined as the ability "not only to contribute to knowledge, but to comprehend, analyze, and evaluate its meaning in the context of an increasingly globalized world."[3] The necessary skills include the ability to work effectively in international settings and to adapt to diverse cultures, perceptions, and approaches; familiarity with the major currents of global changes and the issues they raise; and the capacity for effective communication across cultural and linguistic boundaries. Related to scientists and engineers, Downey *et al*. have defined global competence as "the knowledge, ability, and predisposition to work effectively with people who define problems differently than they do."[4]

While other studies address specific issues concerning U.S. economic competitiveness,[5] this report addresses how the challenges of globalization affect the world of science and engineering (S&E), and what actions and programs are needed to ensure that the scientific, technical, engineering, and mathematical (STEM) workforce of the future will be globally competent. More specifically, it asks two important questions: First, what can U.S. institutions that support S&E education, research, and innovation do to promote the changes needed to assure that U.S. scientists and engineers will be proactively engaged in the best research, development, and innovation around the globe? Second, what types of partnerships linking academia, industry, and government can most effectively achieve this goal? The report presents findings and recommendations presented at the Sigma Xi workshop "Assuring a Globally Engaged Science and Engineering Workforce," which took place in September 2006 at National Science Foundation (NSF) Headquarters in Arlington, Virginia.

The Changing Nature of Discovery and Innovation

For much of the 20th century, our classical notion of science pictured a lonely scientist (perhaps with a few assistants keeping notebooks) in a laboratory making an autonomous scientific discovery. Over time, as others duplicated the results, the discovery would become common knowledge and be added to the larger body of accepted scientific theories. Sometimes, as others challenged accepted knowledge, a "paradigm shift" would occur.[6] In this model, conferences and printed publications were the norm for exchanging information.

New information and communications technology (ICT) has revolutionized the scientific process. Now, knowledge of discoveries is disseminated quickly all over the globe. Scientific teams working across disciplines and across national boundaries are collaborating, sharing equipment and data, and publishing their findings in peer-reviewed journals—in both online and hard-copy formats.

"Big Science" topics such as global climate change, pandemics, natural resource management, and international terrorism now command international teams of scientists and engineers working to find solutions to truly global problems. In addition, ICT capabilities allow for the integration of local and traditional knowledge into mainstream science, resulting in the development of centers of excellence in specific areas of science and engineering, even in geographically remote regions. Thus, developments in science and technology have the potential to reach into and affect everyone's life, regardless of where they live.

Despite increasing cooperation across national borders, it is becoming more apparent that the approaches that scientists and engineers take to define and study a problem are deeply rooted in the cultures and educational systems in which they are trained. In addition, how this knowledge and subsequent innovations are applied within different societies is also influenced by the culture of those societies.

Globalization, then, does not infer the evolution of a single, global S&E culture. Rather, globalization and the technology linking scientists and engineers around the world challenge us to recognize and appreciate how science, technology, and innovation are executed in different national and cultural settings. Those countries (and those workforces) that can grasp and integrate these varied approaches will tend to be the leaders and beneficiaries of globalization. From a U.S. perspective, in particular, globalization means that more and more discoveries and innovations are going to come from beyond the borders of the United States. To maintain its preeminence, the U.S. S&E workforce must be prepared to actively participate in these processes. At the moment, however, the U.S. workforce is relatively immobile when compared to other developed countries.[7]

The United States is not the only country trying to gain an edge as globalization advances. Many national leaders want strong indigenous education, research, and innovation communities that can help to identify and solve regional problems and provide economic security. The "Green Revolution" model of borrowing knowledge and know-how from developed countries no longer holds. ICT has allowed for casting broad education and research nets over remote areas of the world, facilitating international collaborations that bear fruit locally. Globalization in this context involves the flow of ideas and knowledge across national boundaries and cultures.

International efforts, like those provided by the United Nations and other international and regional organizations, link scientists and engineers in developing countries and give them the tools they need. In the process, the global S&E community is developing a respect and appreciation for local knowledge, talent, and solutions to problems. International efforts to provide global tertiary education and research nets recognize that knowledge can be found anywhere and that innovation takes place whenever there is a local problem that requires S&E skills. Globalization, then, means the closer integration of S&E communities around the world through the use of multicultural teams and their ICT resources in the shared discovery of new knowledge—and the translation of that knowledge into sustainable innovations that promote societal well-being.

The World Bank has identified four pillars that hold up the knowledge economy, each of which is important for competing in a globalized economy:

- **Education and Training:** An educated and skilled population is needed to create, share, and use knowledge.
- **Information Infrastructure:** A dynamic information infrastructure—ranging from radio to the Internet—is required to facilitate the effective communication, dissemination, and processing of information.

- **Economic Incentive and Institutional Regime:** A regulatory and economic environment that enables the free flow of knowledge, supports investment in ICT, and encourages entrepreneurship is central to the knowledge economy.
- **Innovation Systems:** A network of research centers, universities, think tanks, private enterprises, and community groups is necessary to tap into the growing stock of global knowledge, assimilate and adapt it to local needs, and create new knowledge.

The connection between the globalization of S&E and the globalization of the economy lies in the discovery of new knowledge that can be translated into economic value. For countries or regions that want to participate proactively in globalization, this means having an indigenous S&E workforce and infrastructure that can attract and sustain investment—both from domestic and foreign sources—and work in international settings to take advantage of discoveries and innovations around the world.

The challenge facing the U.S. today, according to economist Lester Thurow, is not losing jobs to India and China, but the failure to create sustained economic opportunities to keep its own technically trained people employed.[8] From an economic perspective, then, the main challenge for the local, state, and federal governments is to ensure that regions throughout the country provide a skilled S&E workforce that will attract domestic and foreign investment, leading to employment both here and abroad.

U.S. government agencies that fund S&E education and research are not responsible to shareholders but to the American public and its leadership. Agencies like the National Science Foundation play key roles in ensuring cutting-edge academic research and quality education that feed into enterprise research, which takes ideas and transforms them into a service or product. Under the Learning goal of NSF's four goals of Discovery, Learning, Research Infrastructure, and Stewardship, one of NSF's priorities is to:

> Prepare a diverse, globally engaged science, technology, engineering, and mathematics (STEM) workforce. NSF will focus on broadening participation in STEM disciplines. We will work with academic and industry partners to ensure that STEM education and workforce preparation are broadly available, for the technical workforce as well as for future scientists and engineers, and provide the skills and knowledge needed to flourish in a global knowledge economy.[9]

This report on the Sigma Xi workshop focuses on the "globally engaged" or "globally competent" aspect of this priority and how NSF and other federal, state, and local government agencies, as well as academia and industry, can continue to strengthen the four pillars of the knowledge economy.

As Indira Samarasekera stated in her keynote address at the workshop:

> As we advance into the 21st century, it is now clear that ***the rapid pace of science and engineering must be tempered with a new sensibility—an international sensibility*** that embraces and can bend to accommodate the nuances of cultural diversity.
>
> This new sensibility—as much as any technological breakthrough—will be what ensures our ability to achieve sustainable innovation, the kind that delivers not only in sustained competitiveness, but is continually improving the quality of life for people in North America and around the globe.[10]

II. NSF's Role in the Evolving Global S&E System

The National Science Foundation and other federal science, engineering, and technology funding agencies can do much to create a global culture within the educational and research institutions they support. From a strategic-planning perspective, these agencies must take a long view toward changing the culture of the public and the S&E community, encouraging them to embrace globalization, by fostering proactive programs and institutional changes within educational and research institutions where students, faculty, and researchers participate in a global environment. The idea that such engagement by scientists and engineers is the rule rather than the exception can be nurtured through the following institutional actions by NSF and other agencies:

By creating an environment that provides incentives for applicants to consider their role in the global S&E community, NSF and other government agencies and their programs can be instrumental in developing a globally competent S&E workforce.

1. Add to its Foundation-wide strategic plan an element that will embed global competence and global sensibility skill sets throughout all of NSF's research and education programs. Priority should be placed on the ability to rapidly replicate excellent models of education, research, and innovation throughout the U.S. S&E community.
2. Strengthen NSF's cooperation with other U.S. agencies, such as the National Institutes of Health, the Department of Agriculture, the Department of Energy, the Department of Defense, and the National Aeronautics and Space Administration, to enhance the S&E globalization plan.
3. Increase the number of NSF offices abroad that provide targeted reports so that NSF and other government agencies are knowledgeable about science, engineering, and innovation research carried out in specific regions and can coordinate joint collaborations more effectively.
4. Increase forums and programs with academia, government, and industry to enable more effective cross-border collaborations.
5. Elevate the dialogue with the public and policymakers to create a forum for explaining the importance of global S&E involvement and to help institute reforms in academia and elsewhere, based on proven models, designed to make cross-cultural collaborations the norm rather than the exception.
6. In addition to requiring discussions of intellectual merit and broader implications in proposals, a third area could be required that discusses either the project's global impact or how the project will improve the global competence of the researchers involved. If not made a separate category, include a global component in the "broader impact" section.
7. Collect data from Principal Investigators (PIs) and Co-PIs about international activities and formal institutional ties to international collaborators.
8. Provide more funding for global competence activities throughout all types of NSF education and research programs. (See Chapters IV, V, and VI.)

By creating an environment that provides incentives for applicants to consider their role in the global S&E community, NSF and other government agencies and their programs can be instrumental in developing a globally competent S&E workforce.

III. The Evolution of a Globally Competent Scientist or Engineer

According to several speakers at the workshop, employers hiring scientists, engineers, and technologists look for the following basic characteristics:

Domain Knowledge

- Expertise in a specific field
- Ability to plug into and work effectively with existing human and ICT networks to gain information and conduct research

Professional Competence

- Practical ingenuity
- Creativity
- Cognitive skills (analytical and problem-solving skills)
- Communication and social skills
- Ability to work in teams or unite individuals possessing diverse skills to a common purpose

Globalization will increasingly require scientists and engineers to work with peers around the world. To this end, education in other regions and cultures is needed, hopefully resulting in what Downey and others call "global competence." In addition to the domain and professional-competence elements, a globally competent scientist or engineer would possess the following traits:

- The knowledge, ability, and predisposition to frame scientific questions and seek answers with people who have perspectives different than their own
- The ability to work with scientists and engineers from other countries and to understand their social and intellectual approaches to science and discovery and how they approach or bound problems differently
- The motivation to pursue knowledge in different contexts and cultures
- The ability to work in the dense networks that are evolving around the globe to share experiments, equipment, and results

In addition, a globally competent engineer would be able to:

- Frame problems within a socio-technical and operational context particular to a specific culture or nation
- Be culturally sensitive to differences in:
  - Approaches to design

  - Business environments and local economies
  - Customs, laws, value systems, and thinking

Ideally, both scientists and engineers would also:

- Possess language skills of another country or region (non-U.S. companies seem to value this skill more than U.S. companies)
- Handle the conflict between the need for more information and the need to act with flexibility and agility in uncertain situations
- Be able to use the tools necessary to operate in a global S&E environment by understanding how science and engineering can take place across nations and cultures to result in discoveries, products, or services assembled across time zones, borders, and engineering practices

Finally, taking these skill sets one step further, Samarasekera[11] proposed the development of scientists and engineers (as well as others) who are world citizens, and who, regardless of the culture in which they find themselves:

- Possess cultural fluency—that is, they know how to listen to and read other cultures with enormous sensitivity to values, traditions, and motivations.
- Can translate this fluency into building relationships and taking leadership roles, while being sensitive to what is acceptable and effective in different cultures.

Also at the workshop, Wayne Johnson and Tricia Hitmar[12] added that today's scientist and engineer, as he or she moves up the career ladder, often combines basic S&E skills with experience in marketing, finance, trade or patent law, management, and leadership to advance his or her company's goals and values. These individuals are still a part of the S&E community, although they have taken on managerial and other roles.

IV. K-12 Education

While K–12 education was not a major focus of the workshop, participants emphasized the importance of attracting and retaining students to science early to assure a well-educated workforce pool and public. The importance of well-trained, globally competent teachers was also stressed; teachers who are willing and able to integrate global competence skills into their curriculums.

To prepare K–12 students for the workforce of the future, NSF, the Department of Education, and other institutions can support activities that:

1. Send more science and math education post-graduates and teachers abroad to learn new teaching methods, especially in those countries where students fare better in math and science education.
2. Promote industry/school partnerships that support teacher training, curriculum development, mentoring, and outside class activities that include global competence skills.
3. Support pilot projects that involve students in international research either through virtual learning environments or hands-on research abroad. These models must be easily transferable to other schools, maximizing the impact.
4. Provide opportunities for students to interact with educators and mentors who have been actively involved in teaching and working in multicultural environments.
5. Begin to collect information about the international activities of K–12 science teachers for possible inclusion in NSF's *Science and Engineering* reports, including any international engagement activities that can be used as benchmarks to develop a more globally oriented S&E education.
6. Support foreign language and culture classes, including bilingual programs and magnet schools, to promote bilingual education and cultural fluency. Explore programs that look to build upon cultural diversity within specific communities to provide learning experiences that can contribute to global competence activities on the post-secondary level. These programs should include practical conversational and S&E vocabulary to develop the communication skills needed to work in technical fields. Sponsor bilingual science fairs and summer institutes that may or may not include students from other countries.

The Elementary, Secondary, and Informal Education (ESIE) programs in NSF's Education and Human Resources Directorate (EHR) is where global-impact elements can be more fully integrated, including the Discovery Research K–12, Informal Science Education, Information Technology Experiences for Students and Teachers, Presidential Awards for Excellence in Mathematics and Science Teaching (or some new award program), and the NSF Academies for Young Scientists. Specific disciplinary programs within NSF can be tapped to identify junior and senior scientists and engineers who could serve as mentors or trainers in community projects that foster globally sustainable research and innovation. Moreover, this specific type of activity can be more clearly defined as part of the "broader impact" element in NSF proposals.

V. Undergraduate and Graduate Education

Tertiary education—including two-year institutions, four-year colleges and universities, and post-graduate education—provides the S&E workforce of the future. Community colleges, which are locally funded and draw from the rich cultural diversity of the region, are educational institutions that provide for community-based technical training in such areas as IT, health care, mechanics, and other fields that directly meet the workforce needs of that community and state in which they reside. They also provide an opportunity for STEM and other students to enter into four-year institutions. According to the Bureau of Labor Statistics, holders of associate's degrees, bachelor's degrees, and master's degrees make up about 85 percent of the non-academic S&E workforce, so these levels should be a key focus for providing a well-trained globally competent workforce in the future.[13]
These three levels are key targets for attracting and retaining STEM majors, for attracting and retaining women and minorities, and for embedding global competence skills into STEM curriculums.

The recommendations below evolved from the panel discussion on these issues, including the role that virtual learning spaces can play in providing international research and education experiences for students who cannot travel and as an introduction for students who will travel later in their studies. While many undergraduate programs support exchange programs, very few are currently focused on meaningful experiences for STEM students.

Recommendations for Undergraduate and Graduate Education and Research

Community Colleges[14]

1. Provide specific programs for CC faculty and administrators (including counselors) to participate in cross-cultural programs and share the benefits with their students.
2. Identify successful models for transitioning CC students into STEM careers and promote their implementation throughout key CC systems.
3. Work with state governments to develop STEM curriculums that seamlessly move CC students into four-year institutions and foster global competence skills that can be continued in those four-year institutions.
4. Encourage more CC cooperation with four-year colleges and universities and industry—especially those colleges and industries with global partners.
5. Support CC partnerships with global industries that are located locally and develop curriculums to meet that community's needs in high-tech industries. Possible methods include using mentors from other countries where that company has a presence and providing internships abroad.

Virtual Learning Spaces

1. Explore how virtual learning spaces can be used specifically for STEM education and research by tapping the learning environments that today's students and tomorrow's ICT will provide, while at the same time creating an environment that fosters long-term commitment to science and engineering exploration.[15]
2. Enhance programs that would develop creative, cost-effective, and innovative virtual learning and research experiences for students, both as an initial step to global competence and for students who cannot travel because of lack of funds, disabilities, or other reasons. Examine ways in which virtual learning can be incorporated into cross-cultural STEM curriculums, including "think spots" where students and faculty jot down ideas in a common space and where students can stop and revisit experiments across time and geographic space.
3. Evaluate existing virtual learning programs to see which ones are more effective and which ones are as good as or better than face-to-face foreign-exchange programs.
4. Include faculty development programs that advance virtual learning laboratories and develop curriculums that prepare S&E students to understand and tap into the dense networks being used for research and innovation.

Undergraduate and Graduate Education

1. Support more STEM faculty teaching and research exchanges to ensure understanding of global competence and the value in cross-cultural research and education projects. Set benchmarks for increasing faculty involvement.
2. Develop STEM undergraduate and graduate curriculums that integrate global competence elements as part of the core curriculum. Explore what it means for scientists and engineers to be globally competent and develop evaluation criteria on both the individual and institutional levels to assess the value of specific programs in achieving these competencies. Specific disciplinary programs within NSF and other agencies should target a specific subfield or area for developing pilot programs where global competence is most needed.
3. Expand support for *reciprocal* multidisciplinary, multinational research teams involved in long-term, curriculum-based programs that encourage the involvement of students, faculty, industry, and other relevant players.
4. Support pilot five-year STEM/language programs.
5. Work with the Department of State, Department of Education, and other funding agencies to develop specific programs geared toward S&E projects, especially those programs that foster broad U.S. geographic distribution and favor low-income and minority institutions. Examine how Marie Curie–type grants, Fulbright, Fulbright Hays, Benjamin A. Gilman International Scholarship Programs, the Fund for the Improvement of Postsecondary Education (FIPSE), and other programs can be leveraged or modified to broaden the impact of such exchanges.

6. Examine how U.S.-sponsored international programs can be leveraged with other countries or other players (such as industry, international organizations, etc.) to encourage multinational collaborations.[16] Work with other S&E funding agencies abroad to encourage cross-cultural teams to work on submitting proposals together.
7. Work with other S&E funding agencies abroad to encourage cross-cultural teams to work on submitting proposals together and to develop mechanisms for joint review of collaborative proposals to avoid the perception of "double jeopardy" that discourages collaborative proposals.
8. Encourage integrating international research agendas into the numerous centers of excellence that NSF and other government agencies have established throughout the U.S. in both disciplinary and interdisciplinary areas.[17]
9. Work with other federal agencies to remove barriers to cross-cultural research and training.
10. Support long-term longitudinal studies that address the question of whether achieving global competence provides students with better career choices. Evaluation criteria could include information comparing students who did have cross-cultural experiences with those who did not in areas such as retention rates in STEM fields, the attraction and retention of women and minority students into STEM majors, GPAs, years to graduation, and career choices. Also, support research that would test the hypothesis that time spent studying or researching abroad is of equal academic value to (and perhaps greater professional value than) semesters spent in the U.S.
11. Fund research that helps to better define what it means to be a "successful" scientist or engineer within the global economy. Although contributions to basic research, publications, patents, and other indicators of career success within academia are already measured, "success" within industry might mean something different, such as promotion to management or other leadership positions not currently measured as an indicator of success.
12. Develop indicators of S&E global competence that can be collected across nations and over time on both the individual and institutional levels. In the global economy, these measures will have to be expanded to capture multinational brain circulation.
13. Universities can do much to foster global STEM competence by requiring students to have experiences working in cross-cultural environments, publicizing the successes involved in their international programs, and tapping alumni and corporate relations to set up international programs with faculty and students.

VI. Cyberinfrastructure

While the concept of technology infrastructure is not new[18] exponential advances in computation, storage, networking, visualization, sensors, and software are providing the means for scientists to solve increasingly complex problems and to see deeper into phenomena.[19] In response to the question: "How can NSF, as the nation's premier agency funding basic research, remove existing barriers to the rapid evolution of high performance computing, making it truly usable by all the nation's scientists, engineers, scholars, and citizens?", the Blue Ribbon Advisory Panel on Cyberinfrastructure, used the term "cyberinfrastructure" to recognize these capabilities in their report:[20]

> ... a new age has dawned in scientific and engineering research, pushed by continuing progress in computing, information, and communication technology, and pulled by the expanding complexity, scope, and scale of today's challenges. The capacity of this technology has crossed thresholds that now make possible a comprehensive "cyberinfrastructure" on which to build new types of scientific and engineering knowledge environments and organizations to pursue research in new ways and with increased efficacy.

The cyberinfrastructure concept is dynamic: it is being shaped by the communities that are using its technologies, as well as reciprocally changing the practices and standards of these communities. Recognizing the transformative effects technology can have on the organization of work in science, NSF has embarked on a comprehensive cyberinfrastructure vision for science and engineering research and education.[21] Similarly, the European Commission has articulated a vision, termed "e-Infrastructure," for the next generation of science and education for the European community.[22] Individual countries have and are developing similar initiatives. The United Kingdom is recognized for the e-Science[23] initiative that is paralleled with the U.S. Cyberinfrastructure initiative. Asia-Pacific nations are following suit and developing national e-Infrastructure/e-Science initiatives.

The U.S. workforce must possess the capability to perform and innovate in a global economy. The U.S. has been at the center of technological innovations, principally due to the Internet and how it evolved. However, as the world becomes more globally connected, other nations are rapidly developing their workforce to perform in a global information-driven society. Cyberinfrastructure will play a critical role in developing a globally engaged U.S. workforce by:

- Enabling the U.S. workforce to work effectively in a global setting
- Developing new processes that enable multi-disciplinary global collaborations to conduct effective basic research
- Facilitating and enabling scientists and engineers to work in geographically dispersed teams of people of diverse backgrounds and cultures
- Improving communication, information sharing, and collaboration to lower the barriers to innovation

The U.S. workforce of the future will use cyberinfrastructure tools to effectively participate and shape the future global information society. As the rate of technological change continues to accelerate, it will be essential for the workforce of the future to have the aptitude and the ability to keep learning and updating its knowledge and continue contributing to society. Cyberinfrastructure tools will enable our workforce to:

- Create new virtual spaces to stimulate and facilitate innovation and to capture and manage knowledge
- Increase performance of employees in a competitive environment
- Acquire or pioneer innovative work practices to capture and manage knowledge
- Improve employees' abilities to collaborate with people with different experiences and backgrounds
- Facilitate the ability of scientists, engineers, and practitioners to work across disciplinary lines and to form new models and paradigms that lead to discovery
- Manage the challenges presented by cultural and linguistic diversity and geographical distance

NSF and other funding agencies that have been at the forefront of supporting U.S. cyberinfrastructure research and development can help ensure continued U.S. leadership by supporting the following recommendations.

Recommendations:

1. Support further long-term educational, training, and research experiences that provide experts with the ability to create middleware and applications software to more fully integrate education and research programs into the global Web-based backbone. Provide institutional support for researchers who must integrate technology with their scientific research. Expand these activities so that more undergraduate and graduate students have experiences abroad working with other high-end users.
2. Provide adequate time for face-to-face exchanges to enable researchers and their students to work together productively in cyberspace.
3. Support expansion of the grid system so that more users, here and abroad, can have access to an (open) science grid.
4. Work with industries, community colleges, and universities to identify educational needs for technologists to support the ever-growing requirements for technical support services.
5. Revisit how today's generation of learners can best use ICT tools to create virtual learning spaces and "plug and play" approaches to education, research, and innovation.
6. Support students conducting research abroad. The Pacific Rim Experience for Undergraduates (PRIME) is a good model that could be replicated. The East Asia Pacific Summer Institute (EAPSI) is a wonderful model for individuals to work abroad.

7. Create a rotating post-doc program that would allow U.S. and foreign post-docs to exchange places in their programs.
8. Expand the Partnership for International Research and Education (PIRE) activity to reflect the needs of ICT researchers.

VII. Integrated Models for S&E Workforce Development: Case Studies in North Carolina and California

Nowhere else does the education/workforce nexus become more apparent than at the state level where states and local municipalities are actively engaged in the training and retraining of their residents in order to promote economic growth. As manufacturing jobs such as textiles and heavy machinery are increasingly sent abroad, states are committing more and more resources to provide the workforce training that will attract U.S. and foreign investment in major high-tech industries.[24]

Two case studies are offered here—biotechnology in North Carolina and nanotechnology in California—to describe how state-supported institutions are fostering academic-industry partnerships to train residents for high-tech jobs. In both case studies, the aspect of "global competence" was clearly missing as workforce issues took on the task of providing "domain knowledge" and "professional competence" skills as defined earlier. There was no clear grasp of the notion that a European or Asian company setting up facilities in the United States might approach problems differently. The two recommendations below are aimed at beginning a dialogue between federal and state agencies, as well as industry and academia, to see how global competence skills can be explicitly considered at the state and local levels.

Recommendations for workforce development:

1. Develop state-based pilot programs that look at all levels of workforce development, from K–12 through continuing education, to see where global competence activities can be embedded into the education, research, and training processes.
2. See how Small Business Innovation Research, Advanced Technology Education Centers, and other federal programs can be better integrated into state strategic plans for development of a S&E workforce.

VIII. Summary and Conclusions

Economic globalization is a complex and dynamic concept. Economists are now beginning to examine both the basic elements and unforeseen consequences of globalization. Within the academic community there is a growing realization that the students, faculty, and researchers of tomorrow will need to be globally competent.

What this means for scientists and engineers is just beginning to be explored by the institutions that educate and train them and the industries that employ them. Many nations are investing time and resources into developing the four pillars of a knowledge economy: education and training, information infrastructure, economic incentive and institutional regimes, and innovation systems.

To date, the United States has successfully supported all four of these pillars, but some are being weakened by a declining S&E workforce. Countries such as China, India, and Japan are challenging U.S. preeminence in providing centers of excellence for high-tech research and development, and countries around the globe are competing to provide a highly skilled workforce that will meet the requirements of a globalized economy.

What is needed in the U.S., at minimum, is:

- Education and research institutions that embed global competence skills at all levels of training, starting with K–12 education and continuing throughout the life of the scientist or engineer.
- A change in the culture of U.S. educators, administrators, faculty, students, and the public to one where meaningful international collaboration is the norm rather than the exception.
- That states and regions ensure that their citizens possess the global competence to attract and retain domestic and foreign investment in high-tech industries and have a workforce that can work well either within the U.S. or abroad.
- A dynamic, flexible infrastructure that integrates science, engineering, and ICT to involve human and non-human resources that can tap into and actively participate in the creation of new knowledge and innovation wherever and whenever it is being generated.
- Mechanisms to build strong government, academic, and industry ties that bolster the U.S. system of innovation in a global environment.

Will the U.S. take the bold leap forward to embrace globalization? Will the U.S. be able to achieve the international sensitivity needed to understand and appreciate the nuances of the cultural diversity that are alive, well, and thriving around the globe? If we continue to rest on our past accomplishments rather than to meet these new challenges with our ingenuity, flexibility, and abundant resources, then we will fall behind. The United States has served as a model of knowledge and innovation that other nations continue to adapt for their own needs. Now it is up to us to take the next step forward—to provide the means of integrating scientists and engineers into science and engineering communities around the world so that the shared discovery of new knowledge and the translation of that knowledge into sustainable innovation can truly promote societal well-being.

Executive Summary Endnotes

1 Official statistics seem unavailable, but please see http://www.gyford.com/phil/writing/2003/01/31/how_many_america.php for some unofficial analysis.

2 Bikson, T. K. and S. A. Law, *Global Preparedness and Human Resources: College and Corporate Perspectives,* (Santa Monica, CA: Rand Corporation, 1994).

3 http://www.nasulgc.org/CIP/Task%20Force/Call_to_Leadership.pdf

4 Downey, G, *et al*, The Globally Competent Engineer: Working Effectively with People Who Define Problems Differently, *Journal Of Engineering Education 95* (April 2006), 1–16.

5 See, for example, National Academies, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*, (National Academies Press, 2007) and National Innovation Initiative, *Innovate America: Thriving in a World of Challenge and Change, 2004*, http://www.innovateamerica.org/webscr/NII_EXEC_SUM.pdf.

6 Kuhn, T., *The Structure of Scientific Revolutions* (Chicago: University of Chicago Press, 1962).

7 See, for example, the OECD table which reflects the percentage of highly skilled workers migrating to other OECD countries: http://oberon.sourceoecd.org/vl=1851751/cl=16/nw=1/rpsv/scoreboard/gb06b.htm.

8 Interview with Lester Thurow, *CIO Magazine,* December 15, 2003.

9 U.S. National Science Foundation, *2006 Strategic Plan,* http://www.nsf.gov.

10 Keynote address, "Assuring a Globally Engaged Science and Engineering Workforce Workshop," National Science Foundation, September 22, 2006.

11 See Samarasekera, 2006.

12 See presentations by Wayne Johnson and Tricia Hitmar, "Assuring a Globally Engaged Science and Engineering Workforce Workshop," National Science Foundation, September 20, 2006.

13 U.S. Bureau of Labor Statistics, Current Population Statistics (2000), *Science and Engineering Indicators,* 2006.

14 Two specific NSF programs can be tapped to include more aspects of global competence or cross-cultural experiences for CC students in this vein. The first is the Course, Curriculum, and Laboratory Improvement (CCLI) Program in NSF's Division of Undergraduate Education which can encourage CC/university relationships that include an international dimension and also foster the development of curriculums and facilities that meet the challenges of high-tech industries and begin to prepare future scientists and engineers in "global competence" skills. The second is the Advanced Technological Education (ATE) Centers Program which can add a cross-cultural dimension by fostering education/industry partnerships with global companies (which it is already doing), providing specific activities to provide, in addition to basic skill sets, cross-cultural activities to build on the ability of technologists to work for foreign companies, to work in teams that are cross-cultural, and to work in foreign cultures.

15 NSF can explore this through its Advanced Learning Technologies and Social Sciences Programs.

16 For NSF this might include such programs as the Program on International Research and Education (PIRE), International Graduate Education, Research and Training (IGERT) Program, Developing Global Scientists Engineers, and other OISE awards. NSF can also see how these programs could be more effectively integrated into its disciplinary programs.

17 For NSF this might include Materials Research Centers, Nanotechnology Centers, Long-Term Ecological Research Centers (LTER), Supercomputing Centers, etc.

18 Star, S. L. and K. Ruhleder, Steps Towards an Ecology of Infrastructure: Complex Problems in Design and Access for Large-Scale Collaborative Systems, *CSCW '94 Proceedings of ACM*, 1994.

19 Robertson, D. S. *Phase Change: the Computer Revolution in Science and Mathematics* (New York: Oxford University Press, 2003).

20 Atkins, D. E. *et al*, *Revolutionizing Science and Engineering Through Cyberinfrastructure: Report of the National Science Foundation Blue-Ribbon Advisory Panel on Cyberinfrastructure* (National Science Foundation, 2003).

21 National Science Foundation, *Cyberinfrastructure Vision for 21st Century Discovery* (Arlington, VA:National Science Foundation, 2007). http://www.nsf.gov/pubs/2007/nsf0728/index.jsp.

22 http://www.eu-egee.org/

23 http://www.rcuk.ac.uk/escience/default.htm

24 For a state perspective, see R. D. Atkinson and D. K. Correa, *The 2007 State New Economy Index: Benchmarking Economic Transormation in the States*, Information Technology Innovation Foundation and the Ewing Marion Kauffman Foundation, 2007. http://www.kauffman.org/pdf/2007_State_Index.pdf. Taking a series of 26 indicators in five categories—knowledge jobs, globalization indicators, economic dynamism, transform to a digital economy, and technological innovation capacity—states were ranked according to their abilities to generate new economic transformations. California ranked fifth and North Carolina ranked twenty-fifth out of the 50 states.

Final Report

I. Introduction and Problem Statement

Two pieces of information, although seemingly unrelated, highlight the challenges facing the United States as it attempts to remain competitive in the face of economic globalization. First, the nation lost almost 300,000 high-tech jobs to competition from abroad between 1998 and 2003, and today U.S. companies often cannot fill their personnel needs domestically because of a lack of scientific, engineering, and technical expertise. Second, despite rapid air transportation and global cultural and economic ties, unofficial figures state that only about 21 percent of U.S. citizens hold passports.[1] Success in a global economy will require the U.S. to address both of these issues by helping its scientists and engineers to achieve "global competence."

According to a 1994 Rand Corporation study, "Cross-cultural competence was considered by members of both the academic and corporate communities to be the most important new attribute for future effective performance in a global marketplace... However, it is what U.S. citizens are most lacking."[2]

> *Global competence is the ability not only to contribute to knowledge, but to comprehend, analyze, and evaluate its meaning in the context of an increasingly globalized world.*

A report published in October 2004 by the National Association of State Universities and Land Grant Colleges further describes "global competence" as the ability "not only to contribute to knowledge, but to comprehend, analyze, and evaluate its meaning in the context of an increasingly globalized world."[3] The necessary skills include the ability to work effectively in international settings and to adapt to diverse cultures, perceptions, and approaches; familiarity with the major currents of global changes and the issues they raise; and the capacity for effective communication across cultural and linguistic boundaries. Related to scientists and engineers, Gary Downey, *et al*. have defined global competence as "the knowledge, ability, and predisposition to work effectively with people who define problems differently than they do."[4]

While other studies address specific issues concerning U.S. economic competitiveness,[5] this report addresses how the challenges of globalization affect the world of science and engineering and what actions and programs are needed to ensure that the scientific, technical, engineering, and mathematics (STEM) workforce of the future will be globally competent. More specifically, it asks what U.S. institutions that support S&E education, research, and innovation can do to promote the changes needed to assure that U.S. scientists and engineers will be proactively engaged in the best research, development, and innovation around the globe. A second question to be addressed is what types of partnerships linking academia, industry, and government can most effectively achieve this goal. The report presents findings and recommendations presented at the Sigma Xi workshop, "Assuring a Globally Engaged Science and Engineering Workforce," which took place in September 2006 at National Science Foundation (NSF) Headquarters in Arlington, Virginia.

Steering Committee member, Wayne Johnson, Senior Vice President for University Relations from Hewlett Packard, remarked after the Workshop:

> I was encouraged to see NSF focused on the global skills and integration of our workforce. At HP, we believe education is fundamental to a healthy economy, especially in the knowledge-based world we live in today. The Global Engagement Workshop provided a unique opportunity to participate, listen, and share in developing feedback for the future. The chance to have meaningful dialogue with NSF was an invaluable opportunity.

The Changing Nature of Discovery and Innovation

For much of the 20th century, our classical notion of science pictured a lonely scientist (perhaps with a few assistants keeping notebooks) in a laboratory making an autonomous scientific discovery. Over time, as others duplicated the results, the discovery would become common knowledge and be added to the larger body of accepted scientific theories. Sometimes, as others challenged accepted knowledge, a "paradigm shift" would occur.[6] In this model, conferences and printed publications were the norm for exchanging information.

New information and communications technology (ICT) has revolutionized the scientific process. Now, knowledge of discoveries is disseminated quickly all over the globe. Scientific teams working across disciplines and across national boundaries are collaborating, sharing equipment and data, and publishing their findings in peer-reviewed journals—in both online and hard-copy formats.

"Big Science" topics such as global climate change, pandemics, natural resource management, and international terrorism now command international teams of scientists and engineers working to find solutions to truly global problems. In addition, ICT capabilities allow for the integration of local and traditional knowledge into mainstream science, resulting in the development of centers of excellence in specific areas of science and engineering even in geographically remote regions. Developments in science and technology thus have the potential to reach into and affect everyone's life, regardless of where they live.

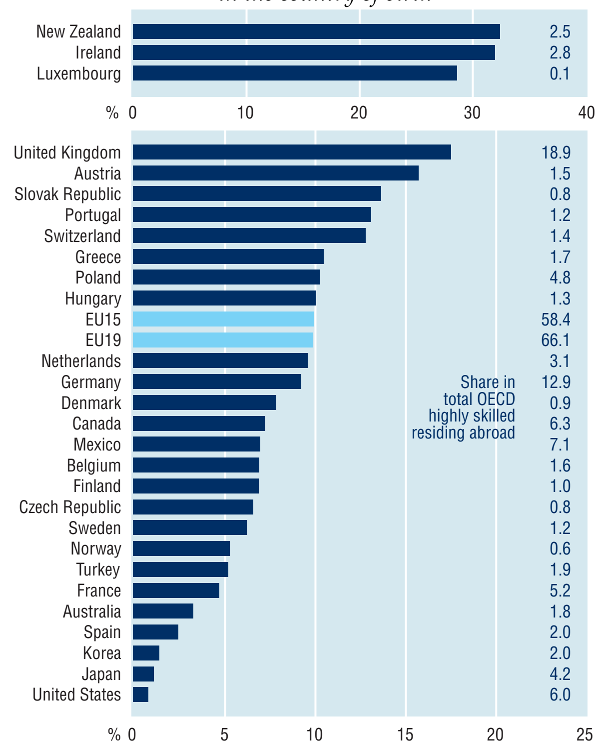
Robert K. Merton, perhaps best known as the founding scholar of U.S. sociology of science, observed that scientists share many norms, including communalism and universalism. The first led scientists around the world to see scientific discoveries as common property to be shared freely in exchange for recognition. The second led them to evaluate truth claims of these scientific discoveries in terms of universal impersonal criteria, not on the basis of nationality, religion, or race. The spirit of these norms is still shared by many scientists who wish to share knowledge freely in exchange for mutual benefit. For example, in a presentation at the Sigma Xi workshop, Takeshi Kishinami and So Kawanobe from Hokkaido University argued that we should foster "intellectual universalism," which they defined as "the spirit to seek knowledge widely from around the world and to cooperate in educating foreigners as well as their own people based on the idea that there are no borders to learning."[7]

Despite increasing cooperation across national borders, it is becoming more apparent that the approaches that scientists and engineers take to define and study a problem are deeply rooted in the cultures and educational systems in which they are trained. In addition, how this knowledge and subsequent innovations are applied within different societies is also influenced by the culture of those societies.

Globalization, then, does not infer the evolution of a single, global S&E culture. Rather, globalization and the technology that links scientists and engineers around the world challenge us to recognize and appreciate how science, technology, and innovation are executed in different national and cultural settings. Those countries (and those workforces) that can grasp and integrate these varied approaches will tend to be the leaders and beneficiaries of globalization. From a U.S. perspective, in particular, globalization means that more and more discoveries and innovations are going to come from beyond the borders of the United States. To maintain its preeminence, the U.S. S&E workforce must be prepared to actively participate in these processes. However, the U.S. skilled workforce has proved to be relatively immobile when compared to other developed countries. *(see Figure 1)*

Figure 1: Highly Skilled Migrants to the OECD Countries, by Country of Birth, 2001*

As a percentage of highly skilled natives in the country of birth



* 2003 for Norway and Sweden; 2002 for Denmark and Ireland; 2000 for Finland, Japan, Korea, Mexico, Switzerland, Turkey and the United States; 1999 for France; 1999-2002 for Germany: 2001 for other countries.

Source: OECD Science, Technology and Industry Scoreboard 2005

The United States is not the only country trying to gain an edge as globalization advances. Many national leaders want a strong indigenous education, research, and innovation community that can help to identify and solve regional problems and provide economic security. The "Green Revolution" model of borrowing knowledge and know-how from developed countries no longer holds. ICT has allowed for casting broad education and research nets over remote areas of the world, facilitating international collaborations that bear fruit locally. Globalization in this context involves the flow of ideas and knowledge across national boundaries and cultures.

International efforts, like those provided by the United Nations and other international and regional organizations, link scientists and engineers in developing countries and give them the tools they need. In the process, the global S&E community is developing a respect and appreciation for local knowledge, talent, and solutions to problems. International efforts to provide global tertiary education and research nets recognize that knowledge can be found anywhere and that innovation takes place whenever there is a local problem that requires S&E skills. Globalization, then, means the closer integration of S&E communities around the world through the use of multicultural teams and their ICT resources in the shared discovery of new knowledge—and the translation of that knowledge into sustainable innovations that promote societal well-being.

Globalization and the Economy

The concept of economic globalization that emerged in the 1980s describes a world that has shrunk due to the widespread use of information and communications technology; the rearrangement of production, distribution, and consumption of goods and services; and unprecedented levels of mobility of labor and capital. Much like the roles ships and airplanes have played by moving goods and people around the globe, ICT has served to move knowledge and services. Economies today are driven not by manufacturing goods, but by using knowledge and innovation to produce new goods and services in a dynamic global environment. But much as the Age of Exploration and the Industrial Revolution proceeded without particular guiding plans, globalization is proceeding with its own set of unforeseen economic, social, and political consequences. The major difference, however, is that other players beside nation-states are the major drivers in the process of globalization.

According to economist Joseph Stiglitz, globalization holds great promise for both developed and developing countries. "The great hope of globalization," he writes, "is that it will raise living standards throughout the world: give poor countries access to overseas markets so that they can sell their goods, allow in foreign investment that will make new products at cheaper prices, and open borders so that people can travel abroad to be educated, work, and send home earnings."[8] He contends, however, that economic globalization has outpaced political globalization and has led to some serious unintended consequences. As a result, a new management system is needed to ensure that economic globalization delivers on its promises.

In his book *The World is Flat*, journalist Thomas Friedman discusses the effects of globalization on manufacturing.[9] Initially, outsourcing by the United States and European countries to other countries was for manufacturing, but more and more, almost all parts of the production cycle—from basic research and support services to added improvements—can be undertaken by countries such as India, Russia, and China. Research is being increasingly outsourced to places such as Ireland and Israel. The operations in this cycle can be divided into concrete tasks, assigned to different places around the globe, and then horizontally and seamlessly integrated in real time. The linear nature of the production cycle no longer holds when a nation takes basic knowledge and provides new products and services as offshoots.

Friedman goes on to say that the American system contains a combination of elements that are ideally suited for nurturing individuals who can compete and thrive in this so-called "flat world":

1. Research universities that create a steady stream of competitive experiments, innovations, and scientific breakthroughs
2. University–business technology centers to create new products
3. Available risk capital and investment mechanisms (like venture capital and the stock market) to support emerging ideas or growing companies[10]

These elements, combined with enforceable intellectual property laws, flexible labor laws, a large consumer market, and political stability, all help to translate ideas into economic productivity and wealth.

The World Bank has identified four pillars that hold up the knowledge economy, each of which is important for competing in a globalized economy:

- **Education and Training:** An educated and skilled population is needed to create, share, and use knowledge.
- **Information Infrastructure:** A dynamic information infrastructure—ranging from radio to the Internet—is required to facilitate the effective communication, dissemination, and processing of information.
- **Economic Incentive and Institutional Regime:** A regulatory and economic environment that enables the free flow of knowledge, supports investment in ICT, and encourages entrepreneurship is central to the knowledge economy.
- **Innovation Systems:** A network of research centers, universities, think tanks, private enterprises, and community groups is necessary to tap into the growing stock of global knowledge, assimilate and adapt it to local needs, and create new knowledge.

From an industry perspective, according to Wayne Johnson, knowledge-based economies involve "employing a region's knowledge and educational resources to gain economic advantage in a global economy."[11] Richard Vaz, the Director of Worcestor Polytechnic Institute's Interdisciplinary and Global Studies Division, argues that from an international-development perspective, globally engaged scientists and engineers can "understand the impacts of engineering solutions in a global and societal context and that these solutions will result in wise, informed, and economically sustainable development."[12] These two approaches are not necessarily equivalent, but the knowledge and abilities needed to achieve these goals are very similar.

The connection between the globalization of S&E and the globalization of the economy lies in the discovery of new knowledge that can be translated into economic value. For countries or regions that want to participate proactively in globalization, this means having an indigenous S&E workforce and infrastructure that can attract and sustain investment—both from domestic and foreign sources—and work in international settings to take advantage of discoveries and innovations around the world.

The challenge facing the United States today, according to economist Lester Thurow, is not losing jobs to India and China, but the failure to create sustained economic opportunities to keep its own technically trained people employed.[13] From an economic perspective, then, the main challenge for the local, state, and federal governments is to ensure that regions throughout the country provide an S&E skilled workforce that will attract domestic and foreign investment, leading to employment both here and abroad.

U.S. government agencies that fund S&E education and research are not responsible to shareholders but to the American public and its leadership. Agencies such as the National Science Foundation play key roles in ensuring cutting-edge academic research and quality education that feed into enterprise research, which takes ideas and transforms them into a service or product. Under the Learning goal of the National Science Foundation's four goals of Discovery, Learning, Research Infrastructure, and Stewardship, one priority is to:

> Prepare a diverse, globally engaged science, technology, engineering, and mathematics (STEM) workforce. NSF will focus on broadening participation in STEM disciplines. We will work with academic and industry partners to ensure that STEM education and workforce preparation are broadly available, for the technical workforce as well as for future scientists and engineers, and provide the skills and knowledge needed to flourish in a global knowledge economy.[14]

This report on the Sigma Xi workshop focuses on the "globally engaged" or "globally competent" aspect of this priority and on how NSF and federal, state, and local government agencies, along with academia and industry, can continue to strengthen the four pillars of the knowledge economy. The major question to be addressed is what role federal agencies such as NSF can play in ensuring that the U.S. S&E workforce is capable of continued leadership in knowledge discovery and innovation in a globally competitive environment. Moreover, it asks what partnerships these agencies can foster with academia, industry, and others to further their globalization strategies.

As Indira Samarasekera stated in a keynote address to the GEW workshop:

> As we advance into the 21st century, it is now clear that the rapid pace of science and engineering must be tempered with a new sensibility—an international sensibility that embraces and can bend to accommodate the nuances of cultural diversity.
>
> This new sensibility—as much as any technological breakthrough—will be what ensures our ability to achieve sustainable innovation, the kind that delivers not only in sustained competitiveness, but is continually improving the quality of life for people in North America and around the globe.[15]

TRENDS IN THE U.S. STEM WORKFORCE AND R&D FUNDING

According to NSF's report *Science and Engineering Indicators 2006*, there are currently more than 4 million people employed in S&E jobs in the U.S. *(see Figure 2)*, and an additional 8 million who work in jobs somewhat related to S&E. About one-third of S&E graduates do not work directly or indirectly in their area of specialization. Of S&E workers, approximately 59 percent work in for-profit industries; among PhDs, about 33 percent work in for-profit industries and 44 percent work in colleges and universities.[16] According to projected trends, future science and technology jobs will grow at a faster rate than the number of U.S. students going into these fields.

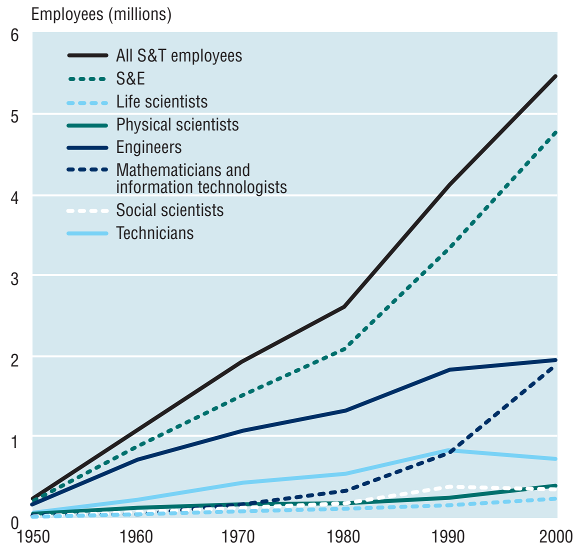
The Organization for Economic Cooperation and Development (OECD) reports that the United States spent approximately $298 billion of the $810 billion spent worldwide in 2003 on research and development.[17] From 1990 to 2002, foreign investment in U.S. R&D grew from 8 to 14 percent of industrial R&D, from $8 billion to $27 billion. From 1994 to 2002, U.S. investment in R&D abroad grew from $12 billion to $21 billion.

Of U.S. R&D investment, 70 percent is provided by private industry and is primarily applied R&D. Most of the basic research is still conducted by U.S. government agencies or institutions funded by them (e. g. universities, federally funded research and development corporations, etc.). Of the $106.5 billion of U.S. federal R&D funding, about 74.8 percent is related to defense.

According to Marie Thursby[18] and others, the role of the U.S. as the preeminent player in the process of globalization is being challenged for many reasons:

- U.S. students are falling in rank in international mathematics and science tests and competitions.[19]
- Fewer foreign students are attending U.S. undergraduate and graduate institutions and staying in the U.S. to work. Many scientists and engineers are being

FIGURE 2: SCIENCE AND TECHNOLOGY EMPLOYMENT, 1950-2000



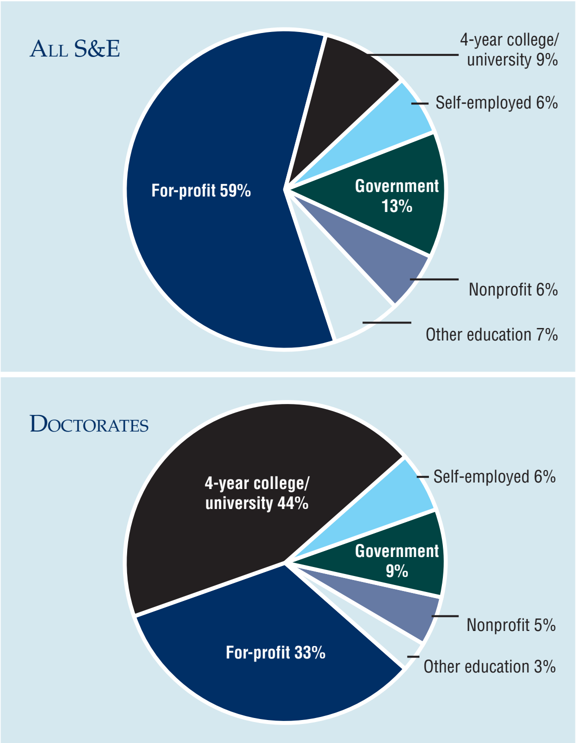
S&T = science and technology

Note: Data include those with bachelor's degrees or higher in science occupations, some college and above in engineering occupations, and any education level for technicians and computer programmers.

Source: B.L. Lowell, Estimates of the Growth of the Science and Technology Workforce, Commission on Professionals in Science and Technology (forthcoming). See appendix table 3-1.

Science and Engineering Indicators 2006

FIGURE 3: EMPLOYMENT SECTOR FOR ALL S&E DEGREE HOLDERS AND S&E DOCTORAL DEGREE HOLDERS, 2003



Source: National Science Foundation, Division of Science Resources Statistics, SESTAT, preliminary estimates (2003), http://sestat.nsf.gov. See appendix table 3-9.

Science and Engineering Indicators 2006

lured back to their own countries or to other countries that have made it more attractive to work abroad.[20]

- The percentage of U.S. authors of journal articles in world-class publications is decreasing.
- U.S. companies are increasing R&D investments abroad.[21]
- Only one percent of U.S. college students travel abroad to study, and only about 20 percent of U.S. faculty has collaborated with foreign scholars.[22]
- Only six of the world's 25 most competitive IT companies are based in the U.S.; 14 are based in Asia.
- Foreign-owned companies and inventors account for nearly half of all U.S. patents.
- Sweden, Finland, Israel, Japan, and South Korea each spend more on R&D as a share of gross domestic product than the U.S.
- More and more of the world's scientists and engineers will be in Asia, particularly in China, which is the largest producer of college graduates.
- China overtook the U.S. in 2003 as the top global recipient of foreign direct investment.

As these trends show, the U.S. S&E community faces several challenges, including the following:

- Assuring that there are **adequate numbers** of scientists, engineers, and technologists to fill the education, research, and industrial workforce of the future
- Being able to **effectively incorporate under-represented and emerging minorities** into the workforce to take advantage of demographic changes
- Assuring that the S&E workforce is able to meet the **globalization challenges** of participating in and assimilating discoveries and innovations no matter where they occur

This report will focus on the third challenge and discuss the first two only as they have an impact on the third.

Figure 4: S&E Jobs, 2002 and Projected 2012

(Thousands)

OCCUPATION	2002	2012	CHANGE
All occupations	144,014	165,319	21,305
S&E	4,873	6,119	1,246
Computer/ mathematical scientists	2,504	3,480	976
Engineers	1,478	1,587	109
Life scientists	214	253	39
Physical scientists	251	287	36
Social scientists/ related occupations	426	512	86

Source: U.S. Department of Labor, Bureau of Labor Statistics, Office of Occupational Statistics and Employment Projections, National Industry-Occupation Employment Projections 2002–2012 (2004).

Science and Engineering Indicators 2006

II. NSF's Role in the Evolving Global S&E System

The National Science Foundation and other federal science, engineering, and technology funding agencies can do much to create a global culture within the educational and research institutions they support. From a strategic-planning perspective, U.S. S&E agencies must take a long view toward changing the culture of the public and the S&E community, encouraging them to embrace globalization by fostering proactive programs and institutional changes within educational and research institutions where students, faculty, and researchers participate in a global environment. The idea that such engagement by scientists and engineers is the rule rather than the exception can be nurtured through the following institutional actions by NSF and other agencies:

1. Add to its foundation-wide strategic plan an element that will embed global competence and global sensibility skill sets throughout all of NSF's research and education programs. Priority should be placed on the ability to rapidly replicate excellent models of education, research, and innovation throughout the U.S. S&E community.
2. Strengthen NSF's cooperation with other U.S. agencies, such as the National Institutes of Health, the Department of Agriculture, the Department of Energy, the Department of Defense, and the National Aeronautics and Space Administration, to enhance the S&E globalization plan.
3. Increase the number of NSF offices abroad that provide targeted reports so that NSF and other government agencies are knowledgeable about science, engineering, and innovation research carried out in specific regions and can coordinate joint collaborations more effectively.

4. Increase forums and programs with academia, government, and industry to enable more effective cross-border collaborations.
5. Elevate the dialogue with the public and policy-makers to create a forum for explaining the importance of global S&E involvement and to help institute reforms in academia and elsewhere, based on proven models, designed to make cross-cultural collaborations the norm rather than the exception.
6. In addition to requiring discussions of intellectual merit and broader implications in proposals, a third area could be required that discusses either the project's global impact or how the project will improve the global competence of the researchers involved. If not made a separate category, include a global component in the "broader impact" section.
7. Collect data from Principal Investigators (PIs) and Co-PIs about international activities and formal institutional ties to international collaborators.
8. Provide more funding for global competence activities throughout all types of NSF education and research programs. (See Chapters IV, V, and VI.)

By creating an environment that provides incentives for applicants to consider their role in the global S&E community, NSF and other government agencies and their programs can be instrumental in developing a globally competent S&E workforce.

III. The Evolution of a Globally Competent Scientist or Engineer

During the three-day workshop, it became apparent that although participants held many similar viewpoints, there are a number of possible ways to define a "globally engaged" or "globally competent" scientist or engineer. The knowledge, skills, and predisposition needed to be globally competent seem to be positioned on a continuum from the individual who possesses what Gary Downey defines as "global competence" to a broader, more universal set of skills that Indira Samaresakera defines as "cultural fluency" or "global sensibility."

As a first priority, globally competent scientists and engineers must have the basic education and training that provides them with "domain knowledge"—that is, expertise in their specific S&E field. As fields have become more specialized and new technologies have been developed to explore them, curriculums have become filled with specialized courses earlier and earlier in a four-year college education.

Adding to the increased complexity and specificity of scientific disciplines are the new challenges of emerging fields such as biotechnology and nanotechnology that cut across both disciplines such as biology, chemistry, and physics and across various application sectors such as agriculture, medicine, instruments, and ICT. Moreover, as ideas move from basic research and knowledge-discovery to innovation and commercial applications, there is an added emphasis on understanding other disciplines and working in interdisciplinary teams of scientists, engineers, and even specialists in social science, law, and business and finance. Thus, new curriculums are emerging that are interdisciplinary in nature and involve working in interdisciplinary teams. The need for interdisciplinary approaches reaffirms the need for understanding, valuing, and effectively engaging perspectives other than your own (i.e., global competence), even within the United States.

The need for interdisciplinary approaches reaffirms the need for understanding, valuing, and effectively engaging perspectives other than your own.

Finally, in the 21st century, these processes are occurring not only within a particular institution, region, or country, but across the globe. Working in different cultures and national systems is becoming the norm rather than the exception. These changes are occurring rapidly. Colleges and universities, as well as institutions that benefit from and support students and faculty, need to consider how to meet the challenges posed by globalization. According to several speakers at the workshop, employers hiring scientists, engineers, and technologists look for the following basic characteristics:

Domain Knowledge

- Expertise in a specific field
- Ability to plug into and work effectively with existing human and ICT networks to gain information and conduct research

Professional Competence

- Practical ingenuity
- Creativity
- Cognitive skills (analytical and problem-solving skills)

- Communication and social skills
- Ability to work in teams or to unite individuals possessing diverse skills to a common purpose

Globalization will increasingly require scientists and engineers to work with peers around the world. To this end, education in other regions and cultures is needed, hopefully resulting in what Downey and others call "global competence." In addition to the domain and professional-competence elements, a globally competent scientist or engineer would possess the following traits:

- The knowledge, ability, and predisposition to frame scientific questions and seek answers with people who have perspectives different from their own
- The ability to work with scientists and engineers from other countries and to understand their social and intellectual approaches to science and discovery and how they approach or bound problems differently
- The motivation to pursue knowledge in different contexts and cultures
- The ability to work in the dense networks that are evolving around the globe to share experiments, equipment, and results

In addition, a globally competent engineer would be able to:

- Frame problems within a socio-technical and operational context particular to a specific culture or nation
- Be culturally sensitive to differences in:
  - Approaches to design
  - Business environments and local economies
  - Customs, laws, value systems, and thinking

Ideally, both scientists and engineers would also:

- Possess language skills of another country or region (non-U.S. companies seemed to value this skill more than U.S. companies)
- Handle the conflict between the need for more information and the need to act with flexibility and agility in uncertain situations
- Be able to use the tools necessary to operate in a global science and engineering environment by understanding how science and engineering can take place across nations and cultures to result in discoveries, products, or services assembled across time zones, borders, and engineering practices.

Finally, taking these skill sets one step further, Samarasekera proposed at the workshop the development of scientists and engineers (as well as others) who are world citizens, and who, regardless of the culture in which they find themselves:

- Possess cultural fluency—that is, they know how to listen to and read other cultures with enormous sensitivity to values, traditions, and motivations.
- Can translate this fluency into building relationships and taking leadership roles, while being sensitive to what is acceptable and effective in different cultures.

Also at the workshop, Wayne Johnson and Tricia Hitmar added that today's scientist and engineer, as he or she moves up the career ladder, often combines basic S&E skills with experience in marketing, finance, trade or patent law, management, and leadership to advance his or her company's goals and values.[23] These individuals are still a part of the S&E community, although they have taken on managerial and other roles.

Developing global competence begins with K–12 education and extends throughout the working life of the individual.

IV. K-12 Education

This educational level was not the specific focus of the workshop, but many presenters emphasized the importance of elementary and secondary education in training the S&E workforce of the future. Specifically, participants saw the necessity of working with K–12 institutions to help identify critical skills and knowledge sets that will be needed in the future. Furthermore, teachers need assistance in building curriculums and programs that will meet those needs. Companies like Hewlett Packard are now working in the U.S. and abroad to help teachers identify these skills and to provide programs for high school students that will attract more students into STEM fields.

Successful programs in K–12 education will both help provide the elemental skill sets needed in specific disciplines or applications and help teachers and students alike to develop cognitive and communication skills across cultures and national boundaries. Furthermore, a better understanding of cultural differences among national approaches to teaching and research could provide teachers and students with improved learning models that can be adapted to U.S. classrooms. Such an understanding might also help improve U.S. performance in international tests, while not stifling the creativity and flexibility that is the benchmark of the American education system.[24] Programs to meet the needs of K–12 educators and students can take place in several areas, including:

Curriculum development. New curriculums can be encouraged that integrate local ethnic and cultural groups into learning, including language training where relevant, and integrate industry needs from local communities or regions. Early education should also promote domain knowledge, analytical skills (problem solving, creativity, etc.), and communication skills (both oral and written). The priority should be to find ways to quickly assess those relevant and successful curriculums that are dynamic, low cost, and highly effective. These models should be Web-based and quickly accessible so that they can be scaled up to be integrated rapidly into existing curriculums without the long waiting period needed to get findings into printed textbooks.

Developing global competence begins with K–12 education and extends throughout the working life of the individual.

Teacher training. Exposing teachers to international activities can help them gain a better understanding of non-U.S. teaching methods and approaches to learning. Such activities can also consist of helping teachers develop projects with students from other countries in virtual or real-time environments. These methods should be replicated easily to encourage the greatest number of educators (train the trainer) for innovative teacher training at all levels.

Classroom activities. Education and training experiences in which U.S. students work directly with students from other countries, either virtually or in real-time environments, can help students to develop cultural sensibility and cross-cultural communication skills.

Out-of-class activities. These activities can involve the use of mentors and role models to provide extracurricular programs to lead students to STEM fields that have direct application to real-world problems and sustainable economic development and innovation.

To prepare K–12 students for the workforce of the future, NSF, the Department of Education, and other institutions can support activities that:

1. Send more science and math education post-graduates and teachers abroad to learn new teaching methods, especially in those countries where students fare better in math and science education
2. Promote industry/school partnerships that support teacher training, curriculum development, mentoring, and outside class activities that include global competence skills
3. Support pilot projects that involve students in international research either through virtual learning environments or hands-on research abroad. These models must be easily transferable to other schools to assure the greatest impact
4. Provide opportunities for students to interact with educators and mentors who have been actively involved in teaching and working in multicultural environments
5. Begin to collect information about the international activities of K–12 science teachers for possible inclusion in NSF's *Science and Engineering* reports, including any international engagement activities that can be used as benchmarks to develop a more globally oriented S&E education
6. Support foreign-language and culture classes, including bilingual programs and magnet schools, to promote bilingual education and cultural fluency. Explore programs that look to build upon cultural diversity within specific communities to provide learning experiences that can contribute to global competence activities at the post-secondary level. These programs should include practical conversational and S&E vocabulary to develop the communications skills needed to work in technical fields. Sponsor bilingual science fairs and summer institutes that may or may not include students from other countries.

The Elementary, Secondary, and Informal Education (ESIE) programs in NSF's Education and Human Resources Directorate (EHR) is where global-impact elements can be more fully integrated, including programs such as Discovery Research K–12, Informal Science Education, Information Technology Experiences for Students and Teachers, Presidential Awards for Excellence in Mathematics and Science Teaching (or some new award program), and the NSF Academies for Young Scientists. Specific disciplinary programs within NSF can be tapped to identify junior and senior scientists and engineers who could serve as mentors or trainers in community projects that foster globally sustainable research and innovation. Moreover, this specific type of activity can be more clearly defined as part of the "broader impact" element in NSF proposals.

V. Undergraduate and Graduate Education

Currently, there are approximately 17 million students in post-secondary education in the United States. Of these, about 40 percent are in community colleges and other two-year institutions. Among students in four-year institutions, only about one-third will enter STEM fields. S&E bachelor's degrees made up 32 percent of all bachelor's degrees awarded in 1983 and in 2002, fluctuating between 30 percent and 34 percent in the intervening years. Bachelor's degrees in the natural sciences (physical, life, environmental, and computer sciences, and mathematics) are about 12 percent, engineering baccalaureates are about 5 percent, and social/behavioral science baccalaureates are about 15 percent of all baccalaureates awarded.[25]

From a student's perspective, there are at least three primary motivations to enter S&E fields. The first is a basic curiosity about how the world works. The second is to learn research and engineering skills to solve real-world problems such as hunger, pollution, and disease. The third is to gain a well-paying job upon graduation. These three motivations are not necessarily mutually exclusive. According to the Bureau of Labor Statistics, holders of associate's degrees, bachelor's degrees, and master's degrees will make up about 85 percent of the non-academic S&E workforce, so these levels should be a key focus for providing a well-trained globally competent workforce in the future.[26] In addition, if these graduates are to work in a global environment, then the colleges and universities training these students must make the institutional, curricular, and pedagogical changes necessary to ensure that their graduates are "globally competent" and "globally sensitive."

According to Peter McPherson, Chair of the Commission on the Abraham Lincoln Study Abroad Fellowship Program, legislation is being considered to provide the support to send one million U.S. students abroad each year by 2016–2017. The Lincoln Commission report states that students who have studied abroad 1) use their acquired language skills on a regular basis after they return, 2) show increased interest in academic work, and 3) develop a set of career skills they would not have obtained otherwise.[27] Currently, only 5,000 community college students and about 200,000 undergraduate students go abroad each year, and most of these are not STEM majors *(see figure 5)*.[28] One goal, then, is to provide undergraduate STEM students with cross-cultural experiences in either virtual or real-time environments in order to develop the analytical and communication skills needed to work in different fields and cultures.

Community Colleges

Community Colleges (CCs) serve a diverse population of students drawn from the communities in which they live. They receive their funding primarily from state and local resources and accept most students with high school degrees. CCs also attract low-income students who cannot afford four-year colleges and who often use the first two years as a stepping stone to a bachelor's degree.

The fact that CCs are locally funded means that they are closely integrated with their local communities and economic environments, including nearby industries that have an interest in a trained and re-trainable workforce. These students will provide the local workforce of the future in that community. There are two overarching issues that must be addressed in looking at CC students. The first is how to provide incentives to interest them in S&E subjects, and the second is how to tap the rich diversity that this population represents to contribute to the cultural sensitivities and language proficiencies needed in global settings.

There are currently few programs that link motivated students from CCs with those from four-year institutions to develop global competence skills. Fortunately, however, there are many efforts underway to link CCs and four-year colleges to businesses that need to attract and retain technically trained students.[29] These programs can be broadened to include elements that develop global competence.

Four-Year Colleges and Universities: Models for Cross-Cultural Education and Research

Today, international experiences can take many forms, and colleges are experimenting with international elements in S&E education. These can include the following:

1. Virtual learning experiences during a specific course
2. Short-term visits not necessarily tied to a specific course or curriculum
3. Short-term visits followed by a longer stay tied to a specific course or curriculum

FIGURE 5: FIELDS OF STUDY ABROAD, 1993-2004/05

Open Doors 2006, Report on International Educational Exchange

FIELDS OF STUDY OF U.S. STUDY ABROAD STUDENTS, 1993/94 - 2004/05

	PERCENT OF U.S. STUDY ABROAD STUDENTS											
FIELD OF STUDY	1993/94	1994/95	1995/96	1996/97	1997/98*	1998/99	1999/00	2000/01	2001/02	2002/03	2003/04	2004/05
Social Sciences	-	-	-	-	-	20.3	20.1	20.3	21.9	21.3	22.6	22.6
Business & Management	13.6	13.5	13.9	14.6	15.6	17.7	17.7	18.1	17.6	17.7	17.5	17.5
Humanities	-	-	-	-	-	14.6	14.5	14.5	13.8	13.3	13.3	13.3
Other	7.7	6.4	7.5	7.8	4.8	5.6	5.1	4.9	5.2	6.4	7.8	7.8
Fine or Applied Arts	7.7	9.0	6.8	7.1	7.7	8.0	8.6	8.5	8.5	9.0	7.6	7.6
Foreign Languages	11.3	10.3	10.7	9.3	8.0	8.1	8.2	8.2	8.5	7.9	7.5	7.5
Physical Sciences	5.3	6.8	6.8	6.8	7.0	7.4	7.4	7.1	7.6	7.1	7.1	7.1
Education	4.0	3.8	3.7	4.3	4.5	4.2	4.2	4.4	3.9	4.1	4.1	4.1
Health Sciences	1.7	2.1	2.3	2.7	3.2	3.8	2.8	3.2	3.0	3.1	3.4	3.4
Undeclared	3.6	3.3	3.9	3.9	4.2	4.3	5.1	4.5	3.8	3.5	3.4	3.4
Engineering	2.3	2.2	2.1	1.9	2.7	2.8	2.9	2.7	2.9	2.9	2.9	2.9
Math or Computer Sciences	1.1	1.2	1.3	1.6	1.6	1.8	2.0	2.0	2.2	2.4	1.7	1.7
Agriculture	0.9	0.7	1.0	1.2	1.5	1.4	1.4	1.6	1.1	1.5	1.2	1.2
Social Sciences & Humanities	37.1	36.6	35.2	34.0	34.8	-	-	-	-	-	-	-
Dual Major	3.6	4.1	4.7	4.9	4.3	-	-	-	-	-	-	-
Total	76,302	84,403	89,242	99,448	113,959	129,770	143,590	154,168	160,920	174,629	191,321	205,983

* Social Sciences & Humanities were combined until 1998/99.

Source: Institute of International Education

4. Longer-term research/project collaborations that are embedded over a four-year core curriculum, involving students, graduate students, and faculty working with counterparts in the U.S. and abroad
5. Very specialized courses and/or research projects that involve post-graduate students and faculty in international forums

An eventual goal of the S&E globalization process is to embed multinational projects into curriculums so that the skills necessary to attain global competence are developed much more explicitly and completely than they are now.

VIRTUAL LEARNING AND RESEARCH ENVIRONMENTS

Within undergraduate programs, students must learn how to plug into the vast and dense networks that are evolving to allow experimentation and dissemination of scientific findings. Virtual environments allow students from many countries to participate in international learning and research experiences without the costs of bringing multinational teams together. Electronic video conferencing allows researchers to work seamlessly in groups regardless of their location. Geospatial mapping and bioinformatics provide new representations of information that is needed to communicate complex science to all cultures. As Dean Sutphin, Director of the Global Seminar and Institute for Global Learning at Virginia Tech, states:

> Globally accessible electronically based virtual research and learning environments are the 21st-century laboratories for advancing science and developing new knowledge. Bold new policies, procedures, reward systems, and allocation of resources that foster global engagement for science and education are needed to retain and advance U.S. leadership in higher education around the world.

Diana Oblinger from EDUCAUSE observes that students today avail themselves of ICT tools voluntarily and with great enthusiasm inside and outside the classroom. They belong to a digital generation and are closely connected to each other through all kinds of technologies. Oblinger suggests creating implicit learning environments outside the classroom in which "serendipitous meetings" can take place between students and faculty. Together, they would create a "learning space" or "think spots" where they can share ideas. She wants to create a "MySpace" for science where professionals and learners hook into each other and become motivated to acquire the knowledge shared by people in those networks. These students in different locations may be working with data collected by others and work together to solve common problems, developing their own analytical and communication skills. In a virtual laboratory space students could stop and replay an experiment or situation in real time rather than reading words in a book. This type of learning environment is an important way to work with foreign researchers and multinational themes.

Some of these technologies—such as using the Internet and video conferencing—are already being used in many undergraduate programs to provide virtual learning experiences for students across national boundaries.

The Global Seminar. This program is a hybrid between distance learning and classroom learning based on case studies of the use of S&E to address issues such as population, biodiversity, waste management, water quality, food security, and global warming.

It involves 40 universities in 35 countries and uses some 30 decision scenarios in work-group clusters of 5 to 7 institutions. Over a one-semester period, students engage in video conferencing, online chat sessions, and other activities to share information and ideas that cut across the scientific, economic, political, and social elements involved in solving a common problem in a sustainable fashion. Students may or may not travel to their partner countries, but they work together to prepare peer-reviewed reports.[30]

The next two models do not actively engage U.S. students in learning or research activities, but they provide examples of experts in developing countries or emerging economies receiving the training and education they need to develop economic value within their community. They are offered here as a way to find and tap into the types of problems and research in a particular region and to provide educational and research experiences for foreign students, faculty, and researchers who cannot afford to go abroad for their education and research. Such models can be coupled more closely with U.S. universities to provide the types of virtual exchanges available through the Global Seminar.

The Global Open Food and Agricultural University. The Consultative Group on International Agricultural Research (CGIAR) has fifteen centers worldwide. Its goal is to achieve sustainable food security and reduce poverty in developing countries. It has recently established the Global Open Food and Agricultural University, which provides master's-level distance-learning curriculums to teachers and researchers in developing countries using the expertise found in CGIAR centers and their partners. These courses are taken by teachers in indigenous universities who want to improve the quality of their courses and by researchers who want to develop local capacity in areas such as agricultural economics and agribusiness.[31]

UN Global Distance Learning Network. On a broader scale, the United Nations is engaged in the UN Global Distance Learning Network, which helps to develop the four pillars needed for a knowledge economy by providing opportunities for virtual tertiary education in countries that are looking to develop particular niches in the global economy. According to the World Bank's David Gray, "The program targets non-elite learners who might live in remote areas and not have the means to attend institutions of higher education in their own countries, let alone attend foreign universities." These programs provide educational experiences through tertiary education institutions, ensuring the information and education needed to develop local economies. They are also developed with the direct input of the indigenous populations they are serving.[32]

These types of tertiary institutions are quite flexible in providing the learning environments needed and accepted by national and local leaders, local economic developers, and the workforce that will support them. Tertiary education institutions can be established through public colleges and universities, online universities, virtual universities, franchise universities, corporate universities, or tutorial colleges. This form of education does not necessarily result in a four-year degree, but it provides local workforces with the knowledge they need to support economically viable industries within the local and/or global economies. The content of each course is designed specifically for the needs of the consumers (students). Thus, virtual learning provides a basis for both initial and continuing education in a reasonably inexpensive manner.[33]

Such programs are fertile ground for U.S. universities and other institutions to provide cross-cultural partnerships in many areas of science and engineering. They can also allow faculty to gain international teaching experiences that might lead to more long-term collaborations.

Cross-Cultural Exchanges

Compared to students in other developed countries, few U.S. students avail themselves of opportunities to travel and study abroad, especially S&E students. It is becoming evident, however, that as more and more ideas and innovations are being generated in other countries, U.S. scientists and engineers must understand the social and cultural contexts in which they will work in the future. Therefore, learning institutions must create environments where international cooperation on meaningful S&E projects is required. The discovery of new knowledge does not necessarily require such sensitivities, but its implementation within a particular society does. There are several ongoing programs that provide cross-cultural activities, primarily within the areas of engineering, that range from short-course or short periods abroad to four-year (or longer) programs that immerse students in another culture while faculty and students from both countries work together to solve common problems in two different settings.

Compared to students in other developed countries, few U.S. students avail themselves of opportunities to travel and study abroad.

For many students, undergraduate travel-abroad programs are their first chance to travel abroad for educational and research purposes. According to the Institute of International Education, last year some 200,000 U.S. undergraduates traveled to foreign countries. Although many of the top U.S. science and engineering universities receive large numbers of foreign students, none of them made the top 25 institutions in terms of sending students abroad. Many smaller colleges and universities are more actively involved in study-abroad programs. In the past, the countries of destination for U.S. students were primarily English-speaking or non–English-speaking European countries. Now, the experiences for undergraduates are broadening to other countries and regions, including India, China, and Latin America.

Gretchen Kalonji, the Director of International Strategy Development for the University of California, stated that:

> Providing our students with the skills and experiences to enable them to be truly competent in the global science and engineering workforce will require fundamental reformulation of the practice of international "research" and "education." Imaginative approaches to integrating team-based collaborative multinational research into the curriculum, both at graduate and undergraduate levels, will be key both to the professional development of our students as well as to strengthening the capacity of our institutions to address pressing problems facing our societies.

According to a number of workshop participants, successful models of cross-cultural S&E projects share some important traits:

- They assume that the most important research challenges are shared across national boundaries and require multidisciplinary approaches.
- They assume that the further you take a student out of their element, the more significant the impact on their thinking and careers.
- They address sustainable and innovative solutions to common practical problems in new cultural settings.
- They are truly reciprocal in nature.
- They require reforms in higher education that incorporate such experiences within curriculums.
- They are embedded in genuine faculty/graduate student interests on all sides and include reciprocal exchanges.
- They can be time and cost neutral—there is no perceived penalty for time spent abroad.
- They are most beneficial when they take place within curricular structures that have the potential to affect *large* numbers of students on all sides, rather than only the fortunate few.
- They invoke deep partnerships with other allies, including industry, research institutes, state and local governments, and NGOs.

Anecdotal evidence and some preliminary quantitative data suggest that participation in international S&E research projects has a number of beneficial effects:

- Students are more likely to continue in undergraduate research.
- Retention rates in STEM areas are higher for those who participate in international collaborations.
- Grade point averages among students with international experience may be slightly higher.
- Those who participate are more likely to pursue post-graduate education in STEM fields.
- More women than men participate in these voluntary programs, so these programs may provide a means to attract and retain women scientists and engineers. If minority students are allowed to choose the country or region for research, they might similarly be attracted to STEM research and likely to stay in their field of inquiry.
- Those participating in international projects graduated in the same time period as their non-traveling colleagues.
- There may be positive implications for international experiences as one goes further along in his/her career.

However, no long-term longitudinal data yet exist to support these hypotheses.

A number of programs based at U.S. universities already help students and faculty to collaborate on international projects, and these provide models for other such collaborations.

Worcester Polytechnic Institute's Global Perspective Program. This program provides opportunities for students to resolve practical S&E problems in a foreign setting via some 20 International Project Centers on five continents. More than half of WPI's faculty have served as advisors on these projects, and 50 percent of all students have participated in at least one project abroad. According to Richard Vaz, Director of WPI's Interdisciplinary and Global Studies Division, WPI sends more S&E students abroad than any other college or university. It also ranks second among universities that grant doctoral degrees in terms of graduating students with international experience. Students finance the one-term project with additional support coming from the local sponsors (e.g. universities, NGOs, companies). Twenty-four U.S. students and two faculty members work in a specific project full-time that results in a formal project report and oral presentations.[34]

University of Washington–Tohoku University Collaboration on First-Year Engineering Design. This program was launched in 1999 as a model for promoting early involvement of undergraduates in engineering research and design to provide students with practical experience working in bi-national teams. Research projects are chosen based on joint interests of faculty members at Tohoku and UW, and the majority of the work takes place in the laboratories of participating faculty. The program is structured to provide a variety of layers of mentoring: the bi-national freshmen teams are advised by more advanced undergraduates in addition to doctoral students and faculty members. Projects are structured so as to be accessible to relatively novice researchers, but in all cases they address genuine research objectives towards which the creativity of the freshmen researchers can be unleashed. At both institutions, the research takes place within core introductory engineering classes. Communication between the teams takes place electronically, via e-mail and periodic videoconferencing. The collaboration incorporates a very heavy focus on cross-cultural communication skills, and the course culminates in public presentations of the results of the work of the bi-national teams. At UW, the program has been coupled with a freshman seminar on Japanese society, technology, and culture.

Purdue University's Global Engineering Alliance for Research and Education. Purdue has partnered with seven companies (John Deere, General Motors, Ford, Cummins, Siemens, Sunoco, and United Technologies) and three universities (in Karlsruhe, Germany; Shanghai, China; and Bombay, India) to provide classes and internships that are coordinated with the engineering curriculum. Students take language and cultural orientation classes and then spend two- to three-month internships working first domestically and then abroad. The program involves undergraduate, graduate, and faculty exchanges and is 100 percent reciprocal. Participants also work on a two-semester team project. The goal is to create a time- and cost-neutral experience that is firmly embedded in the curriculum. Program directors are currently exploring potential partners in Latin America.[35]

The U.S./Africa International Materials Institute. This virtual institute operates out of Princeton University. Its goal is to foster collaborative research and engineering projects involving undergraduate students, graduate students, senior scientists, and faculty from a set of American and African institutions. The Institute is one of six IMIs supported by NSF. The participants deal with several fields of materials science and work toward approaching and solving common problems. African researchers come to the United States to conduct research using tools that they do not have access to in their home institution. They work with U.S. teams and then return to their home countries to continue their research. Rather than being tied to a specific core course, the Institute fosters projects that cut across two specific areas of materials research—advanced materials (MEMS/thin films and organic electronics, biomaterials) and materials for societal development (affordable infrastructure and thermostructural materials). The results of these activities have uncovered new scientific approaches not found in the U.S. (e.g. approaches to cancer detection) and new approaches from traditional knowledge (e.g. passive solar approaches used in ancient Egypt).

University of Washington–Sichuan University Collaboration on Challenges to the Environment. This program requires strong institutional ties between the two collaborating institutions and promotes long-term, multi-level collaborations on research and educational reform. The collaboration focuses on common environmental challenges facing both southwest China and the U.S. Pacific Northwest, including topics such as water quality and waste-water treatment, "eco-materials," forest ecology, biodiversity, and environmental social sciences. Students participate in joint research on these common challenges, both on their home campuses and in a year-long reciprocal exchange in either the junior or senior year. The program incorporates intensive language instruction and encourages exploration of the social, political, and economic factors that constrain potential solutions to technical problems. While it was originally conceived as an undergraduate international research collaboration, the program has recently been extended to collaborations at the doctoral level with the support of the NSF IGERT program. Because the exchange is reciprocal, and because participants range from novice undergraduates to doctoral students to participating faculty, the model promotes long-term collaboration and professional development through a continuous physical presence on each others' campuses. Benefits reported by the students include:

- Having a home base in a huge university
- Jump-starting creation of an international network of colleagues
- Gaining leadership, management, and communication skills.
- Increasing confidence in the ability to contribute to science and engineering.
- Making connections with industry, government, and a variety of future employers.

All of these models use students and faculty in ongoing research and result in involving undergraduates in international collaborations. However, they differ in some respects:

- They vary in the degree to which they are integrated with curriculums.
- They vary in the degree to which undergraduates, graduates, and faculty are involved.
- Most are bilateral and reciprocal, but some are not. Some involve a consortium of universities that cooperate based on the problem being studied. Some involve just U.S. students going abroad without a mutual exchange of faculty and students.
- Some, more than others, involve studying the culture and language of the host nation.
- Some involve not just academic institutions but industry, local governments, and NGOs.

Barriers to Travel for Students and Faculty

Undergraduates and graduate students

There are many benefits to participating in international exchanges, but some students, especially low-income and underrepresented minority groups, face barriers that prevent them from taking part in cross-cultural programs. Potential problems can include the following:

- The cost of international travel
- Conflicts with other family, community, and career priorities (older students, in particular, may have family obligations that make travel difficult)

Faculty and Post-graduates

For graduate, post-graduate, and faculty exchanges, additional barriers also exist, whether they are to send U.S. researchers abroad or have non-U.S. researchers come to the United States. These include:

- Obtaining work permits for spouses
- Ensuring financial and non-monetary support for families
- Avoiding disruptions to families that result from traveling
- Ensuring access to high-tech equipment

- Obtaining green cards for foreign scientists and engineers
- Overcoming a cap on the number of visas issued for foreign scientists and engineers to work in the United States.

Institutional Barriers to Change

Some of the difficulties associated with promoting cross-cultural programs are the result of resistance from governments and educational institutions. These can include:

- Counselors, administrators, and faculty within the system may not see value in international collaborations, and there may be few incentives for them to engage in international collaborations. Change must come from the top—universities could provide incentives for internationally based curriculums that reflect the teaching and research interests of their faculties.
- Many of the bureaucratic procedures designed to account for collaborations between developed countries pose barriers when applied to developing countries where cultures, currencies, and accounting procedures are very different.
- It is difficult to transfer credits across institutions.
- Fostering cooperation across institutions can run into problems with intellectual property issues because laws vary by country.
- Resources and accounting and accountability practices vary by country. These are especially problematic for long-term projects and facilities that involve many countries.
- Fly America and International Trade and Arms Regulations (ITAR) may be too confining, especially when dealing with developing countries that may not have access to sophisticated equipment.
- Foreign researchers coming to the United States have some U.S. income that is taxable, and in some cases they need to follow U.S. federal regulations when conducting research in their own countries, which may be confining or prohibitive. Many countries have developed bureaucracies to handle such issues within institutions, but many developing countries have not (for example, institutional review committees to look at the use of human and animal subjects, institutional finance reporting structures, etc.).

Brain Drain, Brain Gain, or Brain Circulation?

One of the perceived threats to U.S. preeminence in S&E disciplines is that the number of foreign-trained scientists who remain in the United States after completing their education is declining. It is feared that this trend, coupled with a decline in the number of U.S. students seeking S&E careers, will produce a lack of scientists, technologists, and engineers in education, research, and industry centers. Two approaches can be used to ensure access to the best and brightest minds in the world. The first is to provide the opportunities necessary to attract and retain world-class teachers, researchers, and innovators to U.S. institutions on a long-term basis. This approach is described in the National Academies Study *The Gathering Storm*, cited previously. The second is to provide globally competent U.S. scientists and engineers with opportunities to collaborate with these experts on a reciprocal basis in their own countries. This concept of "brain circulation" is beginning to replace that of "brain drain." As AnnaLee Saxenian noted in *The Brookings Review* (Winter 2002), with respect to the United States:

> "Foreign-born engineers are starting new businesses and generating jobs and wealth at least as fast as their U.S. counterparts. And the dynamism of emerging regions in Asia and elsewhere now draws skilled immigrants homeward. Even when they choose not to return home, they are serving as middlemen linking businesses in the U.S. with those in distant regions."

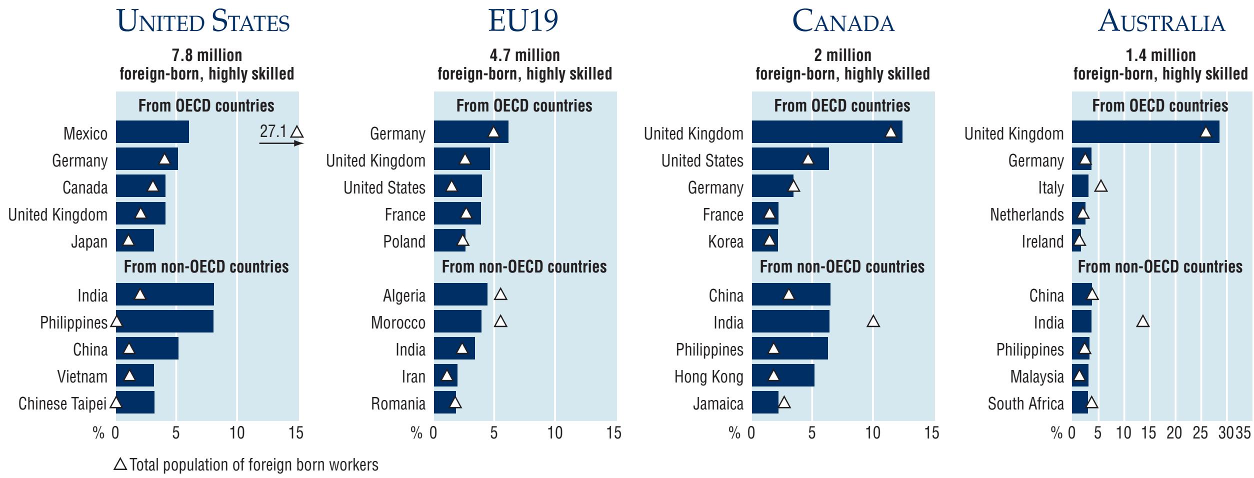
As Figure 6 indicates, developed countries, particularly the United States, continue to attract highly skilled migrants. Data from Open Doors 2006 suggest that the United States is also continuing to attract over 500,000 foreign students each year. The decline in the number of foreign students that began after 2001 is reversing, and a rebound is now predicted.

Other OECD countries are also beginning to attract increasing numbers of highly skilled migrant workers and students, both from other OECD countries and from many developing countries. As Figures 1 and 5 show, however, very few U.S. skilled workers venture abroad. Less than 2 percent of U.S. students and skilled workers study or work abroad.

Many preeminent research institutions throughout the world are positioning themselves as world-class rather than national institutions. They are developing policies to attract the best brains in circulation. In this global competition, as noted elsewhere in this report,

FIGURE 6: MAIN DESTINATIONS OF THE HIGHLY SKILLED MIGRANTS, 2001*

Percentage shares of the 5 top OECD and of the 5 top non-OECD places of birth



* 2003 for Norway and Sweden; 2002 for Denmark and Ireland; 2000 for Finland, Japan, Korea, Mexico, Switzerland, Turkey and the United States; 1999 for France; 1999-2002 for Germany: 2001 for other countries.

Source: OECD Science, Technology and Industry Scoreboard 2005

traditional training is not enough. The best and most competitive brains will also be the most globally competent. U.S. scientists and engineers must participate in the global circulation of knowledge.

RECOMMENDATIONS FOR UNDERGRADUATE AND GRADUATE EDUCATION AND RESEARCH

COMMUNITY COLLEGES[36]

1. Provide specific programs for CC faculty and administrators (including counselors) to participate in cross-cultural programs and share the benefits with their students.
2. Identify successful models for transitioning CC students into STEM careers and promote their implementation throughout key CC systems.
3. Work with state governments to develop STEM curriculums that seamlessly move CC students into four-year institutions and foster global competence skills that can be continued in those four-year institutions.
4. Encourage more CC cooperation with four-year colleges and universities and industry—especially those colleges and industries with global partners.
5. Support CC partnerships with global industries that are located locally and develop curriculums to meet that community's needs in high-tech industries. Possible methods include using mentors from other countries where that company has a presence and providing internships abroad.

VIRTUAL LEARNING SPACES

1. Explore how virtual learning spaces can be used specifically for STEM education and research by tapping the learning environments that today's students and tomorrow's ICT will provide, while at the same time creating an environment that fosters long-term commitment to science and engineering exploration.[37]
2. Enhance programs that would develop creative, cost-effective, and innovative virtual learning and research experiences for students, both as an initial step to global competence and for students who cannot travel because of lack of funds, disabilities, or other reasons. Examine ways in which virtual learning can be incorporated into cross-cultural STEM curriculums, including "think spots" where students and faculty jot down ideas in a common space and where students can stop and revisit experiments across time and geographic space.
3. Evaluate existing virtual learning programs to see which ones are most effective and which ones are as good as or better than face-to-face foreign exchange programs.

4. Include faculty development programs that advance virtual learning laboratories and develop curriculums that prepare S&E students to understand and tap into the dense networks being used for research and innovation.

UNDERGRADUATE AND GRADUATE EDUCATION

1. Support more STEM faculty teaching and research exchanges to ensure understanding of global competence and the value in cross-cultural research and education projects. Set benchmarks for increasing faculty involvement.
2. Develop STEM undergraduate and graduate curriculums that integrate global competence elements as part of the core curriculum. Explore what it means for scientists and engineers to be globally competent and develop evaluation criteria on both the individual and institutional levels to assess the value of specific programs in achieving these competencies. Specific disciplinary programs within NSF and other agencies may target a specific subfield or area for developing pilot programs where global competence is most needed.
3. Expand support for *reciprocal* multidisciplinary, multinational research teams involved in long-term, curriculum-based programs that encourage the involvement of students, faculty, industry, and other relevant players.
4. Support pilot five-year STEM/language programs.
5. Work with the Department of Education and other funding agencies to develop specific programs geared toward S&E projects, especially those programs that foster broad U.S. geographic distribution and favor low-income and minority institutions. Examine how Marie Curie–type grants, Fulbright, Fulbright Hays, Benjamin A. Gilman International Scholarship Programs, the Fund for the Improvement of Postsecondary Education (FIPSE), and other programs can be leveraged or modified to broaden the impact of such exchanges.
6. Examine how U.S.-sponsored international programs can be leveraged with other countries or other players (such as industry, international organizations, etc.) to encourage multinational collaborations.[38]
7. Work with other S&E funding agencies abroad to encourage cross-cultural teams to work on submitting proposals together. Work with S&E funding agencies abroad to develop mechanisms for joint review of collaborative proposals to avoid the perception of "double jeopardy" that discourages collaborative proposals.
8. Encourage integrating international research agendas into the numerous centers of excellence that NSF and other government agencies have established throughout the U.S. in both disciplinary and interdisciplinary areas.[39]
9. Work with other federal agencies to remove barriers to cross-cultural research and training.
10. Support long-term longitudinal studies that address the question of whether achieving global competence provides students with better career choices. Evaluation criteria could include information comparing students who did have cross-cultural experiences with those who did not in areas such as retention rates in STEM fields, the attraction and retention of women and minority students into STEM majors, GPAs, years to graduation, and career choices. Also, support research that would test the hypothesis that time spent studying or researching abroad is of equal academic value to (and perhaps greater professional value than) semesters spent in the U.S.
11. Fund research that helps to better define what it means to be a "successful" scientist or engineer within the global economy. Although contributions to basic research, publications, patents, and other indicators of national career success within academia are already measured, "success" within industry might mean something different, such as promotion to management or other leadership positions not currently measured as an indicator of success.
12. Develop indicators of S&E global competence that can be collected across nations and over time on both the individual and institutional levels. In the global economy, these measures will have to be expanded to capture multinational brain circulation.
13. Universities can do much to foster global STEM competence by requiring students to have experiences working in cross-cultural environments, publicizing the successes involved in their international programs, and tapping alumni and corporate relations to set up international programs with faculty and students.

VI. Cyberinfrastructure[40]

While the concept of technology infrastructure is not new,[41] exponential advances in computation, storage, networking, visualization, sensors, and software are providing the means for scientists to solve increasingly complex problems and to see deeper into phenomena.[42] In response to the question: "How can NSF, as the nation's premier agency funding basic research, remove existing barriers to the rapid evolution of high performance computing, making it truly usable by all the nation's scientists, engineers, scholars, and citizens?", the Blue Ribbon Advisory Panel on Cyberinfrastructure used the term "cyberinfrastructure" to recognize these capabilities in its report:[43]

> … a new age has dawned in scientific and engineering research, pushed by continuing progress in computing, information, and communication technology, and pulled by the expanding complexity, scope, and scale of today's challenges. The capacity of this technology has crossed thresholds that now make possible a comprehensive "cyberinfrastructure" on which to build new types of scientific and engineering knowledge environments and organizations to pursue research in new ways and with increased efficacy.

The cyberinfrastructure concept is dynamic: it is being shaped by the communities that are using its technologies, as well as reciprocally changing the practices and standards of these communities. Recognizing the transformative effects technology can have on the organization of work in science, NSF has embarked on a comprehensive cyberinfrastructure vision for science and engineering research and education.[44] Similarly, the European Commission has articulated a vision, termed "e-Infrastructure," for the next generation of science and education for the European community.[45]

A new age has dawned in scientific and engineering research, pushed by continuing progress in computing, information, and communication technology, and pulled by the expanding complexity, scope, and scale of today's challenges.

Individual countries have and are developing similar initiatives. The United Kingdom is recognized for the e-Science[46] initiative that parallels the U.S. Cyberinfrastructure initiative. Asia-Pacific nations are following suit and developing national e-Infrastructure/e-Science initiatives.

The U.S. workforce must possess the capability to perform and innovate in a global economy. The U.S. has been at the center of technology innovations, principally due to the Internet and how it evolved. However, as the world becomes more globally connected, other nations are rapidly developing their workforce to perform in a global information-driven society. Cyberinfrastructure will play a critical role in developing a globally engaged U.S. workforce by:

- Enabling the U.S. workforce to work effectively in a global setting
- Developing new processes that enable multi-disciplinary global collaborations to conduct effective basic research
- Facilitating and enabling scientists and engineers to work in geographically dispersed teams of people of diverse backgrounds and cultures
- Improving communication, information sharing, and collaboration to result in lowering barriers to innovation

The U.S. workforce of the future will use cyberinfrastructure tools to effectively participate and shape the future global information society. As the rate of technological change continues to accelerate, it will be essential for the workforce to have the aptitude and the ability to keep learning and updating its knowledge to continue contributing to society. Cyberinfrastructure tools will enable the U.S. workforce to:

- Create new virtual spaces to stimulate and facilitate innovation and to capture and manage knowledge
- Improve employees' abilities to collaborate with people with different experiences and backgrounds
- Facilitate the ability of scientists, engineers, and practitioners to work across disciplinary lines and to form new models and paradigms that lead to discovery
- Manage the challenges presented by cultural and linguistic diversity and geographical distance

NSF International Cyberinfrastructure Programs

NSF has a successful history of information and communications technology investments to support the nation's S&E research and education initiatives. The NSF investment portfolio shows an increasing number of international projects that involve geographically dispersed teams of people, facilities, and resources. Many of these investments result in projects that involve sophisticated multi-organizational and international collaborations.

The following describes NSF-funded projects that were presented at the workshop.[47] The projects were selected because they exemplify the use of cyberinfrastructure to solve complex scientific problems that were not previously feasible without cyberinfrastructure. Equally important, these projects are shaping scientists, practitioners, students, and other users through the use of the cyberinfrastructure and producing a cyberinfrastructure-enabled workforce. They show that a key component of global competence will be familiarity with cybertools.

TeraGrid

The TeraGrid is an open scientific discovery infrastructure combining leadership class resources at nine partner sites to create an integrated, persistent computational resource.[48]

Using high-performance network connections, the TeraGrid integrates high-performance computers, data resources and tools, and high-end experimental facilities around the country. Through the TeraGrid, researchers can access over 100 discipline-specific databases. With this combination of resources, the TeraGrid is the world's largest, most comprehensive distributed cyberinfrastructure for open scientific research.

TeraGrid engages the nation's broader science, engineering, and education community in leveraging and creating discovery. Through the Super Computing conference education program, high school faculty and students use the TeraGrid as a learning environment. The nation's Minority Serving Institutions conduct training workshops allowing under-represented communities to use the TeraGrid. Key partnerships with industry on the TeraGrid project are providing an avenue for scientists and students to improve the nation's information infrastructure. Through its active participation in community-building and standards-generating activities, the TeraGrid project is making a significant contribution to shaping the workforce of the future.

International Research Network Connections (IRNC)

The U.S. S&E research and education community communicates, cooperates, and collaborates with colleagues in the global S&E community. Remote instruments—such as telescopes and particle accelerators—data, and other resources dispersed geographically must be accessible to the global scientific community. The NSF IRNC program facilitates global workforce development by providing communications network cyberinfrastructure that bridges the U.S. S&E research and education community with peer communities around the world.

The NSF IRNC program makes it possible for the U.S. science research and education community to directly access resources and to fully engage peers in five continents or regions. Shown in the following list are the project names, the connected region, and the U.S. universities that manage the connections in collaboration with the connected networks:

- **TransPAC2**—linking the U.S. with Japan and beyond, Indiana University
- **GLORIAD**—linking the U.S., China, Russia, and Korea, University of Tennessee, Knoxville

- **TransLight/Pacific Wave**—linking the U.S. and Australia, University of Southern California
- **TransLight/StarLight**—linking the U.S. and Europe, University of Illinois at Chicago
- **Western Hemisphere Research and Education Networks, Links Interconnecting Latin America (WHREN-LILA)**—linking the U.S. and Latin America, Florida International University

The National Science Foundation recognizes that other nations possess resources that are of critical importance to the well-being of the U.S. science research and education programs. The NSF INRC program is a reflection of the value placed by the United States on international collaborations for the advancement of science and technology and to the future development of a global workforce.

Open Science Grid

The Open Science Grid (OSG) is a distributed computing infrastructure for scientific research.[49] OSG has formed a consortium of universities, national laboratories, scientific collaborations, and software developers, bringing petascale computing and storage resources into a uniform shared cyberinfrastructure. Recognizing that science is a global endeavor, OSG collaborates and interoperates with science research grids of other nations. Members of the OSG Consortium contribute effort and resources to the OSG infrastructure and reap the benefits of a shared infrastructure that integrates computing and storage resources from more than fifty sites in the United States, Asia, and South America.

OSG has a comprehensive education and outreach program that is effectively training our future U.S. scientists and practitioners.[50] OSG consortium partners provide undergraduate and graduate students a basic foundation in distributed computing and provide valuable hands-on training in distributed and grid computing techniques. Students learn essential skills that will be needed in the fields of natural and applied science, engineering, and computer science to conduct and support scientific analysis in grid computing environments to facilitate the use of cyberinfrastructure in secondary science education. OSG is collaborating with the NSF pilot project "Interactions in Understanding the Universe" (I2U2) in the support of e-labs based on Grid middleware, as well with the TeraGrid in its Education and Training activities.

CI-Enabled Team Science and Education Programs

Established in 2002, the Pacific Rim Application and Grid Middleware Assembly (PRAGMA)[51] is an organization focused on practically creating, supporting, and sustaining international science and technology collaborations. Specific experiments are postulated, candidate technologies and people are identified to support these experiments, evaluation is performed in the trans-Pacific routine-use laboratory, and successful solutions are integrated into country-specific software stacks or Open Grid Forum (OGF) standards. The group harnesses the ingenuity of more than 100 individuals from 30 institutions to create and sustain these long-term activities. PRAGMA plays a critical role as an international conduit for personal interactions, ideas, information, and grid technology. The multi-faceted framework for collaboration catalyzes and enables new activities because of a culture of openness to new ideas. The pragmatic approach has led to new scientific insights, enhanced technology, and a fundamental sharing of experiences. United States participation in PRAGMA is funded by NSF.[52]

As technology opens borders, educational and professional exchange opens minds.

PRAGMA's focus on collaborations reinforces the key role of cyberinfrastructure, namely to promote team science. Furthermore, PRAGMA's network of researchers provides a framework for novel research apprenticeships, as reflected in the NSF-funded Pacific Rim Experiences for Undergraduates[53] (PRIME,[54] with additional support from Calit2[55]) and the Japanese Ministry of Education, Culture, Science and Technology's Pacific Rim International UniverSities (PRIUS).[56] Each of these programs supports students conducting research at international hosts sites in PRAGMA (and for PRIUS in other sites as well). PRIME adds the essential component of cultural awareness training before, during, and after the nine-week international apprenticeship, based in part on the work reflected in the site, "What's Up with Culture." Interestingly, the sites that accept U.S. students, without remuneration, do so to expose their staff and students to the international experience. Experiences, to date, of sending 36 students, reflect very nicely the statement that "as technology opens borders, educational and professional exchange opens minds."[57] Thus both PRIME and PRIUS are aimed at preparing students to work collaboratively in an international arena.

Finally, the framework of PRAGMA, which is focused on people and applications, has given rise to new science activities that go beyond PRAGMA's members. One example of this is the Global Lake Ecological Observatory Network (GLEON).[58] GLEON's mission is to build an international, multidisciplinary community of researchers focused on understanding and predicting the impact of natural and anthropogenic influences on lake ecosystems across spatial and temporal scales through the use, deployment, and development of emerging observing system technologies and their associated cyberinfrastructure.[59]

NSF and other funding agencies that have been at the forefront of supporting U.S. cyberinfrastructure research and development can help ensure continued U.S. leadership by supporting the recommendations listed below that are key to S&E globalization.

Recommendations

1. Support further long-term educational, training, and research experiences that provide experts with the ability to create middleware and applications software to more fully integrate education and research programs into the global Web-based backbone. Provide institutional support for researchers who must integrate technology with their scientific research. Expand these activities so that more undergraduate and graduate students have experiences abroad working with other high-end users.
2. Provide adequate time for international face-to-face exchanges to enable researchers and their students to work together productively in cyberspace.
3. Support expansion of the grid system so that more users, here and abroad, can have access to an (open) science grid.
4. Work with industries, community colleges, and universities to identify educational needs for technologists to support the ever-growing requirements for technical support services.
5. As stated in Chapter V, revisit how today's generation of learners can best use ICT tools to create virtual learning spaces and "plug and play" approaches to education, research, and innovation.
6. Support students conducting research abroad. PRIME is a good model that could be replicated. The East Asia Pacific Summer Institute (EAPSI)[60] is a wonderful model for students to work abroad.
7. Create a rotating post-doc program that would allow U.S. and foreign post-docs to exchange places in their programs.
8. Expand the Partnership for International Research and Education (PIRE) activity to reflect the needs of ICT researchers.

VII. Integrated Models for S&E Workforce Development: Case Studies in North Carolina and California

Nowhere else does the education/workforce nexus become more apparent than at the state level where states and local municipalities are actively engaged in the training and retraining of their residents in order to maintain economic viability and promote economic growth. Many states are now working to revive economies that have been slowed due to outsourcing in the manufacturing and agricultural sectors and to fluctuations in the stock market. States are becoming major stakeholders in globalization and are investing in education, research, and innovation centers to position themselves as major competitors in high-tech industries. They are also formulating strategic plans that involve the cooperation of educational, research, and industry institutions to ensure that their workforces and work sites will be globally competitive. With rapid changes in the demographic composition of the nation's population, there are further challenges to be met to assure the effective incorporation of underrepresented and emerging minorities into the workforce.

Strategic planning is needed so that educational, research, industry, and business-development institutions work together to develop an economic base in high-tech industries.

North Carolina and California are used here as examples of how states with histories of high-tech industry are approaching future workforce development in two high-tech areas: biotechnology and nanotechnology. Research Triangle Park in North Carolina (NC) and Silicon Valley and other regions in California (CA) are places with proven track records in R&D and commercialization of high-tech industries. Even these places will have to evolve in order to adapt to globalization and to prepare their changing populations to meet the need for a skilled S&E workforce.[61] The *Engineering 2020* report prepared by the National Academy of Engineering states that the U.S. will need an additional 10 million skilled workers by 2020.[62]

North Carolina and California are at the forefront of efforts to address the challenges of global competitiveness.[63] The case studies below reflect a common trait: the view from state leaders that strategic planning is needed so that educational, research, industry, and business-development institutions work together to develop an economic base in high-tech industries, as well as to be able to attract foreign and domestic businesses that provide income and state revenue. Yet while global economic competitiveness is already being pursued, states are only just beginning to address the problem of assuring that they will have globally competent workforces. More must be done to establish multinational, multidisciplinary S&E collaborations that will allow U.S. scientists and engineers to succeed in a global environment.

The Biotech Industry in North Carolina[64]

Some fifty years ago, leaders in North Carolina laid the foundation for transitioning the state's economy from one based on agriculture and traditional manufacturing to one based on science and advanced technology. The development of Research Triangle Park was driven by a spirit of collaboration and long-term investment in the future—a spirit that still characterizes North Carolina today and that has made the state a competitive player in the global economy.

Business Development

North Carolina has become home to the nation's third-largest concentration of biotechnology industries. This is the result of a process initiated 20 years ago with the creation of the North Carolina Biotechnology Center, a nonprofit organization funded by the state to promote economic development through biotechnology. The Center is not a research institute but a catalyzing agency that uses its funding to strategically build the state's capacity for biotechnology research, education, and company formation and recruitment. The Center's tools are competitive grant programs for schools, colleges, and universities; business loans; promoting collaboration among all parties; analysis and research to shape policy and programs; promoting public understanding of biotechnology applications; and special initiatives and projects as needed.

Over this 20-year period, the state has steadily invested in biotechnology in other ways as well, such as major research infrastructure in universities and business-friendly policies. This consistent attention over time to a technology that can be applied in many ways in different industries and markets has paid off.

International Relations

North Carolina's success has made it a destination for many visitors from all over the world seeking to learn how to develop their own economies. The Center often facilitates and/or hosts these visits. The NC Department of Commerce, which is chiefly responsible for recruiting business to the state, operates offices in Canada, Germany, South Korea, China, Japan, and Mexico.

The presence of research and manufacturing sites for several multinational biotechnology and pharmaceutical companies is another major factor in developing international relations and enhancing the overall biotechnology business climate. These corporations have ambitious visions and high expectations, and North Carolina, in responding to their needs and expectations, has built an increasingly targeted and supportive climate for biotech business development. Moreover, North Carolina biotech companies both support K–12 and college education programs and help significantly in recruiting new business to the state. The multinational corporations provide global experiences to employees recruited in-state and promote diversity.

Taking a Holistic, Analytical Approach

North Carolina's deliberately holistic approach depends on a detailed understanding of the process of biotech product discovery and development (see figure below). Its strategy is to develop measures to address inefficiencies and fill gaps along this pathway. These broad-based efforts involving collaborations between business, education, and government contrast with more traditional reactive and physical infrastructure-based economic development.

North Carolina's Strategic Plan[65]

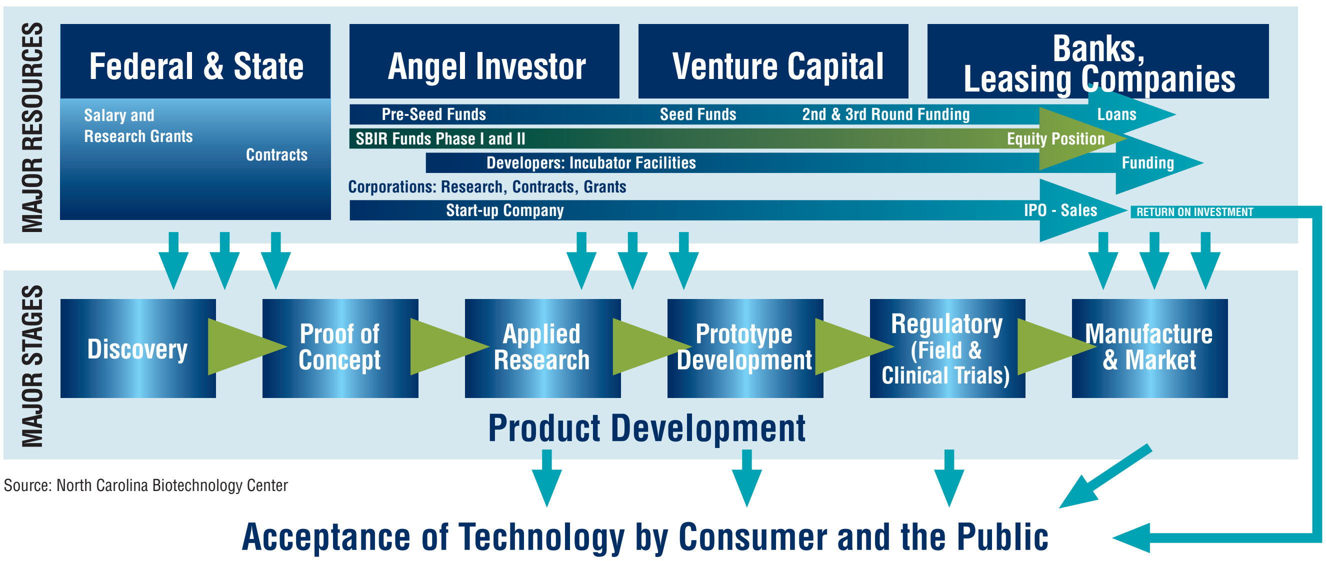
In 2003 Governor Michael F. Easley commissioned the Biotechnology Center to bring together 120 leaders from business, education, and government to formulate a long-term strategic plan to make North Carolina the most attractive place for bioscience business to locate.

A total of 54 specific recommendations were grouped in the following categories:

- Generating new ideas
- Moving ideas to market
- Starting and growing in-state companies
- Recruiting companies from out of state
- Training the workforce
- Strengthening K–12 math and science education
- Strengthening biotechnology and bioscience-based business statewide

Each recommendation was assigned a responsible party and a desired budget (mainly from state funds). The Biotechnology Center tracks progress on these recommendations and makes completing them or supporting others working on them a priority. To date, 37 of the recommended strategies have been completed, are in progress, or are ongoing activities.

Figure 7: Technology Development Funding



Source: North Carolina Biotechnology Center

The Bioscience Business Community

In 2003, there were more than 16,000 employees in biotechnology research and manufacturing in North Carolina (in companies chosen according to a strict definition of "biotechnology"). The state's biotech companies work in agriculture, environmental remediation, industrial chemicals, and pharmaceuticals. The last group is by far the largest. The presence of these companies, as well as the traditional pharmaceutical manufacturing companies that became established in the 1980s, has attracted a comprehensive and diverse group of businesses that provide services to this sector, such as engineering, architectural and construction firms that specialize in building pharmaceutical and biotech research and manufacturing facilities, patent law firms, human resources firms, consultants in FDA regulation, and specialized scientific reagent and equipment suppliers. This growing cluster located in a state with a great quality of life is a powerful attractant and fuels additional growth.

Another broad group of bioscience-based companies includes medical-device manufacturers, natural products manufacturers, and biofuels enterprises. Today, the Center has identified nearly 350 companies in this broad applied bioscience community with over 48,000 employees.

Workforce Development

The diversity of the state's biotech companies is important because there are certain skills and knowledge sets that overlap across the industry. Therefore, students educated in the foundational sciences of biotechnology, bioprocessing, or pharmaceutical manufacturing can find jobs in a larger array of companies than just those that are strictly "biotech." The larger sphere of job opportunities encourages the state and its counties to invest in better educational resources and makes it easier to encourage students to pursue scientific and technical career options.

K–12 Education

A primary education system that stimulates interest in S&E as well as in biotechnology careers is essential to keep the workforce pipeline full. North Carolina has a dozen or more K–12 outreach programs related to biotechnology organized and supported by nonprofits, universities, and corporations. These programs target both students and teachers. The NC Standard Course of Study for middle school and high school science now includes biotechnology as a specific learning objective. Biotechnology is included in Career and Technical Education courses in agriculture, health occupations, technology, and consumer science. New developments in selected schools across the state include globally oriented curriculums, special academies (schools within schools) for biotechnology and biomedical sciences, and innovative professional development programs for elementary and middle school science and math teachers through NSF partnership grants.

Workforce Education Programs

North Carolina's universities and community colleges are the key to workforce development. Both kinds of institutions across the state have had biotechnology-related programs in place since the 1980s.

The newest development in workforce training for the manufacturing side of the biotech and bioscience industries is the Biomanufacturing and Pharmaceutical Training Consortium (BPTC). This is a collaboration between the state's universities and community colleges. Important features of the program include:

- New undergraduate, graduate, and continuing education programs in relevant science and engineering fields
- New laboratory building and GMP pilot plant for research and education, including an aseptic manufacturing training facility—an extremely important and unique feature
- A statewide network of community college centers for curriculum development and training delivery, and a mobile laboratory that can deliver training to a company's doorstep
- A $68 million state investment for start-up and $15 million of in-kind support from industry

North Carolina's Community College System

North Carolina's CC system is the nation's third largest, with approximately 800,000 students enrolling annually. The community colleges play a major role in North Carolina's economic development, providing state-subsidized training for new and expanding industries of all kinds. The growing package of biotechnology-related AAS degrees (17 programs in 16 colleges), certificates, and individual continuing education courses available for job training is the most comprehensive and specifically targeted such collection in the U.S. nonprofit sector, and is a key element in North Carolina's ability to consistently attract and grow pharmaceutical and bioprocess manufacturing businesses.

Companies that locate or expand in North Carolina can get a new-hire training package tailored exactly to their needs—technical or cultural. Features of this service can include:

- Training foreign workers for NC plants
- Training NC workers for assignment in foreign plants
- Including relevant regulatory standards as part of the training
- Job profiling and training needs analysis
- Delivering training when and where needed

Building a Competitive Research Community

The modern research university undoubtedly has an important role in the economic well-being of cities, states, and nations. Universities are evolving quickly to reward innovation and promote entrepreneurial faculty and administrators who have a sense of global and regional possibilities.

As noted above, North Carolina decided to base its future economic development on the innovative potential of the three major research universities that formed the Research Triangle. Today, those universities continue to attract and spin out new biotechnology businesses. As the state now commits to spreading the benefits of bioscience-based economic development across the entire state, the regional universities are expected to play a major catalytic role in creating innovative and entrepreneurial local business environments and training globally competent graduates.

The University of North Carolina system has received significantly increased research funding over the last five years due primarily to increases in federal funding of life science and health-related research. While federal funding still accounts for nearly two-thirds of total research awards, the situation is different on selected campuses. For example, North Carolina State University's research funding is increasingly coming from industry.

A striking example of this is the new North Carolina Research Campus, a $1 billion private business investment to develop a world-class center for research in nutrition and food-crop improvement. Located in a small town at the site of a defunct textile manufacturing facility, this enterprise exemplifies North Carolina's economic development.

As the state now commits to spreading the benefits of bioscience-based economic development across the entire state, the regional universities are expected to play a major catalytic role in creating innovative and entrepreneurial local business environments.

For North Carolina, being globally engaged means being globally competitive through activities such as the following:

- Building relationships with businesses and governments all over the world
- Building a comprehensive, holistic infrastructure to support business based on an understanding of the process of biotechnology product development
- Building a competitive workforce based on a detailed understanding of employer needs, with attention to enhancing education at all levels from K–12 to graduate school
- Building an innovative and entrepreneurial academic research community
- Building pathways for bioscience-based economic development across the entire state
- Building ongoing collaborative relationships among business, government, and academic partners to further all these activities

As shown by these elements, North Carolina is working to develop innovative educational and research collaborations to ensure that the state's high-tech workforce will be globally competent—that is, that workers will be able to work in diverse cultural settings both at home and abroad.

California and Nanotechnology

Strategic Planning in California

California Council on Science and Technology

In 2004, the California Council on Science and Technology (CCST) was asked by the California Legislators Joint Committee on Preparing California for the 21st Century to prepare a set of briefings on the opportunities and challenges in California in the areas of nanoscience and nanotechnology.[66] The report contains twenty-three major recommendations involving several state agencies and departments. The recommendations have the goal of retraining the state's workforce from K–12 education to continuing education.

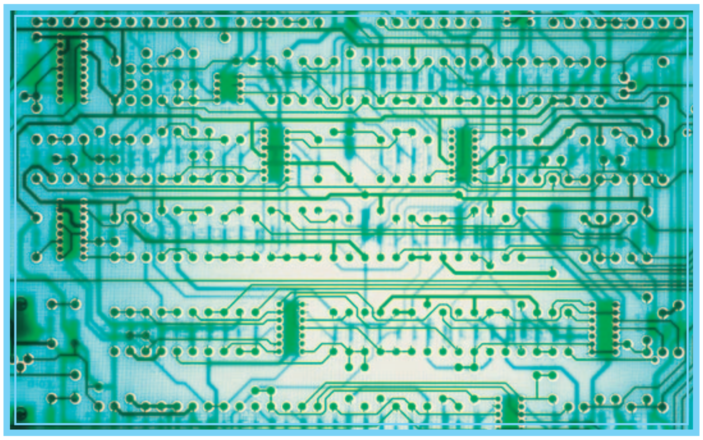
Nanotechnology is a multidisciplinary field that cuts across material sciences, biology, chemistry, physics, and engineering. Applications of the technology involve many sectors of the economy, particularly instruments, healthcare, telecommunications, chemicals, computers, and electricity. To a lesser extent, it may also affect the motor vehicles, plastics, petroleum, glass, fabricated metal, and apparel and textile business sectors.

According to Wasiq Bakkari, from QuantumInsight, who participated in the strategic CCST planning process:

> The bigger impact of nanotechnology will lie in the process where future developments may create new industries around fundamentally new capabilities and markets. This is the ultimate prize California needs to be mindful of. The creation of new industries will determine the future prosperity and leadership of California.

Blue Ribbon Task Force on Nanotechnology

The Blue Ribbon Task Force on Nanotechnology (BRTFN) was created as a joint federal–state venture to "promote California as the national and worldwide center for research, development and commercialization of the nascent nanotechnology industry." The BRTFN released its report, "Thinking Big about Thinking Small," in March 2006. This report provides extensive recommendations on research and development, commercialization, infrastructure, education, policy, and ethics. With respect to preparing a globally competitive workforce, the report puts forward several recommendations, including providing new funds in public university and community college system budgets for the creation of interdisciplinary courses in nanotechnology; encouraging high-tech companies to assist in the creation of courses that support nanotechnology manufacturing; prioritizing the recruitment and training of new teachers and the professional development of existing teachers; and sponsoring efforts to coordinate statewide collaboration of science museums and informal education venues.



Strategic Investments in Nanotechnology

Through the experiences of the semiconductor and ICT revolutions, California possesses dense, flexible networks and relationships among entrepreneurs, venture capitalists, university researchers, lawyers, consultants, highly skilled employees, and others who can translate ideas into new commercial products and services fast enough to be on the edge of the innovation curve. Essentially all of California's research universities have placed a strategic prioritization on the development of capacity in nanotechnology. They receive funds from many of the federal agencies funding nanotechnology research and cooperate with industry on education, research, and development projects. In addition to efforts of individual institutions there have been several large-scale initiatives aimed at bringing a statewide strategic focus to California's nanotechnology efforts.

The California Institutes of Science and Innovation

The California Institutes of Science and Innovation (CISIs) were established in 2000 as a bold experiment to enhance and sustain economic development for the State of California. They were created to tackle demanding societal problems by harnessing technology-rich research that traverses conventional academic boundaries. As the result of a highly competitive and nationally peer-reviewed process, four institutes were selected and inaugurated. One of these four institutes focuses explicitly on nanotechnology, the California Nanosystems Institute, located at UCLA and UC Santa Barbara.[67, 68]

The California Nanosystems Institute (CNSI) is committed to pursuing research and innovation on nanosystems by bringing together the workforce of the future in nanotechnology. The goal of the institute is to harness the power and potential of collaborative research carried out at the nanoscale level for the State of California and to bring scientific and technological innovation into the state's economy. The CNSI is involved in closely coupled interactions with industry in order to identify realistic transitions of research into the industrial sector and to benefit from the feedback from industry into the research programs being initiated in the institute.

In addition to the efforts of the CNSI, each of the other three California Institutes of Science and Innovation also incorporates significant research in nanotechnology tailored to the research domains of each institute. The other three institutes are the California Institute for Quantitative Biomedical Research (QB3), the California Institute for Telecommunications and Information Technology (Calit2), and the Center for Information Technology Research in the Interests of Society (CITRIS).

The Western Institute of Nanoelectronics

In March 2006 another multi-institutional collaboration was launched among California partners, focusing on the pioneering field of "spintronics." The Western Institute of Nanoelectronics includes UC Berkeley and Stanford University, as well as the CNSI at UCLA and UCSB and multiple semiconductor companies. The program was launched with starting grants of $18.2 million: an industrial support total of $14.38 million and a matching $3.84 million UC Discovery Grant from the Industry-University Cooperative Research Program. Industry participants include Intel, IBM, Texas Instruments, Advanced Micro Devices, Freescale Semiconductor, and MICRON Technology.

Other California-Based Nanotechnology Research Initiatives

In 2004, Stanford's Center for Nanoscale and UC Berkeley's Center for Integrated Nanomechanical Systems became one of the NSF Nanotechnology Science and Education Centers. In addition to numerous federal grants, California has won many small technology grants and small business innovative research (SBIR) and small business technology transfer awards. Moreover, the state has many R&D facilities in the San Francisco Bay area (Silicon Valley) and Southern California (San Diego and Los Angeles).

In addition to the institutions mentioned above, other leading institutions involved in nanotechnology R&D in California include:

- Caltech Materials and Process Simulation Center
- University of Southern California Laboratory for Molecular Robotics
- Stanford Bio-X Center
- The Molecular Foundry at UC Berkeley
- Lawrence Berkeley National Laboratory
- NASA Ames Research Center
- The Focus Center Research Program

All of these institutions are potential venues for developing a globally comopetent and globally engaged workforce.

Globalization and the California Workforce

More than fifty countries now fund nanotechnology research. The most serious competitors to the United States are Japan, the United Kingdom, Germany, South Korea, Canada, China, and Singapore. For California to be globally competitive, its R&D and innovation institutions must actively compete with and attract investment from experts outside the U.S.

The highly technical workforce in California that supports its high-tech economy in semi-conductors and ICT fields is declining due primarily to two trends. The first is the growing presence of populations that are not currently prepared to enter four-year universities and the high-tech workforce. This is particularly a problem for California's Latino, African American, American Indian, and Pacific Islander students.[69] The second trend is that fewer foreign scientists and engineers are coming to the United States, as they are finding work in their home countries and elsewhere more attractive. This has ramifications both for technically trained employees and for foreign investment in companies run by immigrants. California faces the major challenge of providing a highly trained and globally competent workforce in the many potential applications of nanotechnology throughout several major economic sectors.

Education, Research, and Innovation

Several of the institutes involved in nanotechnology R&D include programs to prepare the state's students for the workplace of the future. The features of these programs include:

- Scientists working with high school students to attract them into STEM fields.
- University–community college collaborations to prepare students for nanotechnology jobs and transition community-college students into STEM majors in four-year institutions. This is especially important for attracting women and underrepresented minorities into these areas.

- The establishment of clubs, such as the Berkeley Nanotechnology Club, that bring students from science, engineering, business, law, and finance together to learn about and advance understanding of R&D and product commercialization.
- The development by the California university system of a plan to ensure that students travel abroad and that international cross-cultural experiences for S&E students are embedded in the curriculums.

California's Emerging Approach to Global Competence

Gretchen Kalonji, Director of International Strategy Development for the University of California, suggests that states undertake integrated approaches to collaborations in international research, education, and workforce development not only in nanotechnology, but across all fields of science and engineering. Working with select partner institutions worldwide as well as with governmental and industrial partners in California, the UC system has been exploring "Grand Challenges"[70] approaches for maximizing the contributions of public research universities to society. Elements include:

- Identifying major, interdisciplinary research challenges that are of vital importance to the health, welfare, and economic vitality both of California and partner regions.
- Pulling together new partnerships that include academia, governmental agencies, industry, and the nonprofit sector, both in California and in partner regions.
- Dramatically restructuring the educational experience of students to focus their energies on participating in multinational teams that contribute to the solution of these common, practical challenges.

The recently formed Canada–California Strategic Innovation Partnership (CCSIP) is emblematic of these new approaches. CCSIP was initiated by UC President Robert C. Dynes and by Canada's national science advisor, Arthur Carty, with the goal of catalyzing new collaborations that link the research, educational, entrepreneurial, and investment communities in both regions. Current working groups focus on challenges in the fields of stem cells and cancer, energy, information technology, nanotechnology, and infectious diseases. In parallel, a "Highly Qualified Personnel (HQP)" group is exploring new models for collaborative education, while an "IP and Venture Capital" working group is addressing mechanisms to overcome legal, financial, and structural barriers to cross-border research and investment. Spearheaded on the California side by the University of California, CCSIP is open to all of the research universities in California, to the "G13" group of the most research intensive universities of Canada, and to industrial partners in both regions. While this partnership is in its early stages, it shows considerable promise as a model whereby both Canada and California can leverage their respective strengths to create new long-term collaborations for mutual benefit.

Recommendations for Workforce Development

Both North Carolina and California, as outlined above, are seriously engaged in the business of ensuring a technically trained workforce in their states in order to compete for jobs and economic development opportunities in the global economy.

However, neither the planning documents cited nor the panels on these topics in the Sigma Xi workshop discussed "global competence" or "global sensibility," perhaps tacitly assuming that the foreign investments made in their states, the demographics of local communities, and the trade agreements made with other countries resolve the issue and that domain knowledge is all that is necessary. There was no clear grasp of the notion that a European or Asian company setting up facilities in the U.S. or in other countries might approach problems differently. But as stated earlier, and as evidenced by the flow of jobs outside the United States and those filled by non-U.S. citizens, companies will hire employees wherever they can find them. It is up to NSF and other federal funding agencies to assure that U.S. citizens can compete for jobs at all levels through a greater understanding of the cultural diversities in which international R&D and commerce are conducted.

The two recommendations below are aimed at beginning a dialogue between federal and state agencies, as well as industry and academia, to see how global competency skills can be explicitly considered at the state and local levels.

1. Develop state-based pilot programs that look at all levels of workforce development, from K–12 through continuing education, to see where global competency activities can be embedded into the education, research, and training processes
2. See how SBIR, ATE, and other federal programs can be better integrated into state strategic plans for S&E workforce development.

VIII. Summary and Conclusions

Economic globalization is a complex and dynamic concept. Economists are now beginning to examine both the basic elements and unforeseen consequences of globalization. Within the academic community there is a growing realization that the students, faculty, and researchers of tomorrow will need to be globally competent.

What this means for scientists and engineers is just beginning to be explored by the institutions that educate and train them and the industries that employ them. Many nations are investing time and resources into developing the four pillars of a knowledge economy: education and training, information infrastructure, economic incentive and institutional regimes, and innovation systems.

Will the U.S. take the bold leap forward to embrace globalization?

To date, the United States has successfully supported all four of these pillars, but some are being weakened by a declining S&E workforce. Countries such as China, India, and Japan are challenging U.S. preeminence in providing centers of excellence for high-tech research and development, and countries around the globe are competing to provide a highly skilled workforce that will meet the requirements of a globalized economy.

What is needed in the U.S., at minimum, is:

- Education and research institutions that embed global competence skills at all levels of training, starting with K–12 education and continuing throughout the life of the scientist or engineer.
- A change in the culture of U.S. educators, administrators, faculty, students, and the public to one where meaningful international collaboration is the norm rather than the exception.
- That states and regions ensure that their citizens possess the global competence to attract and retain domestic and foreign investment in high-tech industries and have a workforce that can work well either within the U.S. or abroad.
- A dynamic, flexible infrastructure that integrates science, engineering, and ICT to involve human and non-human resources that can tap into and actively participate in the creation of new knowledge and innovation wherever and whenever it is being generated.
- Mechanisms to build strong government, academic, and industry ties that bolster the U.S. system of innovation in a global environment.

Will the U.S. take the bold leap forward to embrace globalization? Will the U.S. be able to achieve the international sensitivity needed to understand and appreciate the nuances of the cultural diversity that are alive, well, and thriving around the globe? The United States has served as a model of knowledge and innovation that other nations continue to adapt for their own needs. Now it is up to us to take the next step forward—to provide the means of integrating students and engineers with science and engineering communities around the world so that the shared discovery of new knowledge and the translation of that knowledge into sustainable innovation can truly promote societal well-being.

Final Report Endnotes

1 Official statistics seem unavailable, but please see http://www.gyford.com/phil/writing/2003/01/31/how_many_america.php for some unofficial analysis.

2 Bikson, T. K. and S. A. Law. *Global Preparedness and Human Resources: College and Corporate Perspectives* (Santa Monica, CA: Rand Corporation, 1994).

3 http://www.nasulgc.org/CIP/Task%20Force/Call_to_Leadership.pdf

4 Downey, G. L., *et al*. The Globally Competent Engineer: Working Effectively with People Who Define Problems Differently, *Journal Of Engineering Education* 95 (April 2006), 1–16.

5 See, for example, National Academies, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (Washington, DC: National Academies Press, 2007) http://www.nap.edu/books/0309100399/html, and National Innovation Initiative, *Innovate America: Thriving in a World of Challenge and Change, 2004* http://www.innovateamerica.org/webscr/NII_EXEC_SUM.pdf.

6 Kuhn, T. *The Structure of Scientific Revolutions* (Chicago: University of Chicago Press, 1962).

7 Kishinami, T. and S. Kawanobe, presentation at "Assuring a Globally Science and Engineering Workforce Workshop," National Science Foundation, September 21, 2006.

8 Stiglitz, J. E. *Making Globalization Work* (New York: W. W. Norton, 2006), 4.

9 Friedman, T. L. *The World is Flat: A Brief History of the Twenty-first Century* (New York: Farrar, Straus and Giroux, 2005).

10 For a similar discussion see also Shirley Ann Jackson, The Nexus: Where Science Meets Society, *Science* 310, no. 5754 (December 9, 2005), 1634–1639.

11 Johnson, W. and D. Gray, presentations at "Assuring a Globally Engaged Scientific and Engineering Workforce," National Science Foundation, September 20, 2006.

12 Vaz, R., who cites studies by ABET, EC 2000 and Engineer 2020, presentation at "Assuring a Globally Engaged Scientific and Engineering Workforce," National Science Foundation, September 21, 2006.

13 Interview with Lester Thurow, *CIO Magazine*, December 15, 2003.

14 U.S. National Science Foundation, *2006 Strategic Plan*, http://www.nsf.gov.

15 Samarasekera, I., Keynote Address, "Assuring a Globally Engaged Science and Engineering Workforce Workshop," National Science Foundation, September 22, 2006.

16 National Science Foundation, *Science and Engineering Indicators 2006.*

17 OECD Main Science and Technology Indicators, 2003.

18 Thursby, M., presentation at "Assuring a Globally Engaged Science and Engineering Workforce Workshop," National Science Foundation, September 22, 2006.

19 See for example the 2003 OECD Programme for International Student Assessment, http://www.pisa.oecd.org/dataoecd/1/63/34002454.pdf.

20 Op cit, NSF Science and Engineering Indicators 2006, ch. 3.

21 Burland, D. M., M. P. Doyle, M. E. Rogers, and T. M. Masciangioli, eds. *Preparing Chemists and Chemical Engineers for a Globally Oriented Workforce: A Workshop Report to the Chemical Sciences Roundtable* (Washington, DC: National Academy of Sciences, 2004), http://books.nap.edu/catalog.php?record_id=11059

22 Ibid. p. 3

23 Johnson, W. and T. Hitmar, presentations at "Assuring a Globally Engaged Science and Engineering Workforce Workshop," National Science Foundation, September 20, 2006.

24 See, for example, a report by the Asia Society, *Math and Science Education in a Global Age: What the U.S. Can Learn from China, May 2006.* http://internationaled.org/mathsciencereport.pdf.

25 *NSF Science and Engineering Indicators, 2006*, Chapter 2, Highlights.

26 U.S. Bureau of Labor Statistics, Current Population Statistics (2000), Science and Engineering Indicators, 2006.

27 See the Report of the Lincoln Commission on the Abraham Lincoln Study Abroad Fellowships, http://www.nafsa.org/_/Document/_/lincoln_commission_report.pdf.

28 See the International Institute of Education Open Doors Web site at: http://www.iie.org. IIE reports that in 2006 the number of students traveling to non-English speaking and non-European countries increased significantly with increases to China, India, and Latin America showing significant gains. Non–social science STEM fields compose about 16 percent of students studying abroad.

29 See, for example, the NSF report *ATE Centers Impact, 2006–2007* http://www.atecenters.org.

30 http://www.globalseminar.org

31 http://www.openaguniversity.cgiar.org

32 Gray gives the example of a group in the Caribbean that found a niche in designing and producing hurricane windows and then selling them over the Internet. This niche allows the local residents to produce income for the community and at the same time to have a role in the "global economy." Another example is a group in Ecuador that helps fund its virtual university through the sale of orchids abroad.

33 http://www.gdlnamericas.org

34 http://www.wpi.edu/Academics/Depts/IGSD

35 http://tools.ecn.purdue.edu/ME/GEARE

36 Two specific NSF programs can be tapped to include more aspects of global competence or cross-cultural experiences for CC students in this vein. The first is the Course, Curriculum, and Laboratory Improvement (CCLI) Program in NSF's Division of Undergraduate Education, which can encourage CC-university relationships that include an international dimension and also foster the development of curriculums and facilities that meet the challenges of high-tech industries and begin to prepare future scientists and engineers in "global competence" skills. The second is the Advanced Technological Education (ATE) Centers Program, which can add a cross-cultural dimension by fostering education-industry partnerships with global companies (which it is already doing), and provide specific activities that will promote, in addition to basic skill sets, cross-cultural activities to build on the ability of technologists to work for foreign companies, to work in teams that are cross-cultural, and to work in foreign cultures.

37 NSF can explore this through its Advanced Learning Technologies and Social Sciences Programs.

38 For NSF this might include such programs as the Program on International Research and Education (PIRE), International Graduate Education, Research and Training (IGERT) Program, Developing Global Scientists Engineers, and other OISE awards. NSF can also see how these programs could be more effectively integrated into its disciplinary programs.

39 For NSF this might include Materials Research Centers, Nanotechnology Centers, Long-Term Environmental Research Centers, Supercomputing Centers, etc.

40 This section was prepared by Julio Ibarra, Steering Committee member and Chair of the Cyberinfrastructure Panel at the Sigma Xi workshop.

41 Star, S. L. and K. Ruhleder. Steps Towards an Ecology of Infrastructure: Complex Problems in Design and Access for Large-Scale Collaborative Systems, *CSCW '94 Proceedings of ACM*, 1994.

42 Robertson, D. S. *Phase Change: the Computer Revolution in Science and Mathematics* (New York: Oxford University Press, 2003).

43 Atkins, D. E., *et al*. *Revolutionizing Science and Engineering Through Cyberinfrastructure: Report of the National Science Foundation Blue-Ribbon Advisory Panel on Cyberinfrastructure* (Arlington, VA: National Science Foundation, 2003).

44 National Science Foundation, *Cyberinfrastructure Vision for 21st Century Discovery* (Arlington, VA: National Science Foundation, 2007). http://www.nsf.gov/pubs/2007/nsf0728/index.jsp

45 http://www.eu-egee.org/

46 http://www.rcuk.ac.uk/escience/default.htm

47 For a complete list of NSF-funded CI projects, please visit http://www.nsf.gov/od/oci/reports.jsp.

48 http://www.teragrid.org/about/

49 http://www.opensciencegrid.org/About

50 http://www.opensciencegrid.org/About/Education_and_Training

51 http://www.pragma-grid.net/

52 INT-0314015 and OCI-0627026

53 INT 0407508

54 http://prime.ucsd.edu/

55 California Institute for Telecommunication and Information Technology, http://www.calit2.net.

56 http://prius.ist.osaka-u.ac.jp/en/index.html

57 Annual Report of Institute for International Education (IIE) 2005, http://www.iie.org.

58 Initial funding from the Gordon and Betty Moore Foundation and subsequent funding from NSF.

59 See Kratz, T. K., *et al*. Toward a Global Lake Ecological Observatory Network, *Proceedings of the Karelian Institute* 145:51-62, in press.

60 http://www.nsftokyo.org/07handbk-j.html

61 For a state perspective, see Robert D. Atkinson and Daniel K. Correa, *The 2007 State New Economy Index: Benchmarking Economic Transformation in the States.* Information Technology Innovation Foundation and the Ewing Marion Kauffman Foundation, 2007. http://www.kauffman.org/pdf/2007_State_Index.pdf. Taking a series of 26 indicators in five categories—knowledge jobs, globalization indicators, economic dynamism, transform to a digital economy, and technological innovation capacity—states were ranked according to their abilities to generate new economic transformations. California ranked fifth, and North Carolina ranked twenty-fifth out of the 50 states.

62 National Academy of Engineering, The Engineer of 2020: Visions of Engineering in the New Century (Washington, D.C.: National Academies Press, 2004). http://books.nap.edu/catalog.php?record_id=10999

63 California, the most populous state in the United States, is a behemoth among state economies. If separated from the rest of the country, it would rank eighth in the world in terms of Gross Domestic Product with a Gross State Product of $1.55 trillion in 2004. California received about $15.7 billion in obligated federal R&D support and a total federal expenditure of $206 billion on all federal R&D in FY2002. The Department of Defense provided about a third of the R&D funding with The Department of Health and Human Services (HHS), the National Aeronautics and Space Administration, and the Department of Energy also providing resources. Fully 43 percent of its R&D funding goes to industry, and universities perform 18 percent of its R&D. North Carolina expended $1.4 billion in federal R&D in 2002, and had a total of all R&D expenditures of $5.1 billion. North Carolina's GSP is $337 billion. Universities perform 59 percent of federally funded R&D while industry performs only 11 percent. HHS is by far the biggest source of federal funding for North Carolina.

64 This section was prepared by Kathleen Kennedy, member of the Steering Committee and Chair of the Panel covering this topic at the "Assuring a Globally Engaged Science and Engineering Workforce Workshop," September 20, 2006.

65 To examine a copy of this plan and its revisions, see http://www.ncbiotech.org/biotechnology_in_nc/strategic_plan/index.html.

66 California Council on Science and Technology; *Nanoscience and Nanotechnology: Opportunities and Challenges in California;* Sacramento, CA; 2004. http://www.ccst.us/publications/2002NanoNc.pdf

67 http://www.cnsi.ucla.edu/

68 Each of the four multi-campus Institutes were charged with undertaking a highly multi-disciplinary set of research challenges that were sufficiently novel, valuable, and exciting to garner significant support from a variety of non-state sources. The State of California committed $100 million dollars of capital funding for construction of new buildings to each winning Institute, with the requirement that the Institutes demonstrate their value to society by attracting a 2 to 1 match from non-state sources. To date the CISIs have garnered collectively **close to a 5 to 1 match** in external support of their launch costs.

69 See the California Research Bureau and the CCST report, pp. 82–84.

70 A Grand Challenges approach is a method where "visionary" experts first identify the major problems that need to be addressed in a particular area of science and technology and then work through, hopefully in an innovative fashion, what players and resources can be applied to the problem to best assure that the problem will be resolved within a specific period of time. See, for example, Computing Research Association, *Grand Research Challenges in Information Security and Assurance*, Washington, DC., 2002 http://www.cra.org/Activities/grand.challenges/security/home.html or National Academy of Engineering, *Grand Challenges for Engineering*, Washington, DC, 2006, http://www.engineeringchallenges.org/

Appendix I: Workshop Agenda

Assuring a Globally Engaged Science and Engineering Workforce

NSF Headquarters – Stafford II, 5th Floor • September 20–22, 2006

Wednesday, September 20

9:00 – 10:15 Welcoming Remarks:
Philip B. Carter, *Executive Director, Sigma Xi*
Wanda Ward, *Deputy Assistant Director, Education and Human Resources Directorate*
Thomas A. Weber, *Director, Office of International Science and Engineering*

Charge to Workshop Participants: Wayne Johnson, *Vice President, University Relations, Hewlett Packard*

10:15 – 11:45 Panels

I. Global Engagement in a Virtual World
Organizer: H. Dean Sutphin, *Professor, Virginia Polytechnic and State University and Vice President for International Outreach, Virginia College of Osteopathic Medicine*
Participants: Molly Broad, *President, International Council on Distance Education and President Emeritus, UNC System*
Diana Oblinger, *Vice President, EDUCAUSE*
Nadarajah Sriskandarajah, *Professor, KVL and Project Leader, Global Seminar, Denmark*
David Gray, *Knowledge Management Coordinator, Latin America and the Caribbean Region, World Bank*

II. Industry Needs in a Global Ecosystem
Organizer: Daniel Marcek, *University Relations, Hewlett Packard*
Participants: John Spencer, *Program Manager, Academic and External Research Programs, Microsoft Research*
Patrick R. Antony, *Corporate Director, Enterprise-University Relations, Boeing Company*
Ray Almgren, *Vice President of Marketing and Academic Relations, National Instruments Corporation*
Discussant: Wayne Johnson, *Vice President, University Relations, Hewlett Packard*

12:00 – 1:00 Working Lunch – Roundtables

1:00 – 2:00 Poster Session I

2:00 – 3:30 Panels

I. Integrating Multinational Research into University S&E Curriculums – New Models
Organizer: Jeanne Narum, *Director, Project Kaleidoscope*
Participants: Gretchen Kalonji, *Director of International Strategy Development, University of California Office of the President*
Suresh Babu, *Senior Research Fellow, International Food Research Institute*

II. Mapping U.S. Global Engagement: Can It be Measured?
Organizer: Caroline Wagner, *Professor, Center for International S&T Policy, George Washington University*
Participants: Daniel Malkin, *Deputy Manager, Education, Science, and Technology, Sustainable Development Department, Inter-American Development Bank*
Rajika Bhandari, *Director of Research and Evaluation, Institute of International Education*
Barry Gale, *President, Gale International, LLC*

III. Building a Globally Competitive Biotechnology Community in North Carolina
Organizer: Kathleen Kennedy, *Vice President, Education and Training Program, NC Biotech Center*
Participants: William Bullock, *Director, Biotechnology Industrial Development, Department of Commerce, NC Biotech Center*
Kris Allsbury, *Coordinator, BioNetwork, NC Community College System*
Russ Lea, *Vice President, Research and Sponsored Programs, University of North Carolina System*
Christine B. Adamczyk, *Senior Scientist, U.S. Science and Education, GlaxoSmithKline*

3:30 – 5:00 Reconvene – Panel Chairs Report, Followed by Open Discussion

5:15 – 6:30 Sigma Xi Reception
Welcome by James Baur, *President, Sigma Xi*

Thursday, September 21

9:00 – 9:45 Keynote Address: Peter McPherson, *President and Exec. Officer, National Association of State Universities and Land Grant Colleges*

9:45 – 11:15 Panels

I. Entering the Workforce: Do Globally Engaged Undergraduate and Graduate Scientists & Engineers Fare Better?

Organizer: Mark Lazar, *Deputy Vice President for Scholarships, Training Programs, and International Operations, Institute of International Education*

Participants: Joseph Mook, *Chair, Mechanical and Aerospace Engineering, University of Buffalo*
Cheryl Matherly, *Associate Dean for Global Education, University of Tulsa*
Tricia Hitmar, *Human Resources North America, ABB*

II. What Information and Communications Technology Infrastructure Is Needed to Help Researchers Engage Globally?

Organizer: Julio Ibarra, *Executive Director of the Center for Internet Augmented Research and Assessment (CIARA), Florida International University*

Participants: Philip Papadopoulos, *Program Director, San Diego Supercomputer Center*
Paul Avery, *Professor, University of Florida*
Charlie Catlett, *Director, TeraGrid Project, Argonne National Laboratory*

11:15 – 12:00 Keynote: Globalization of Corporate R&D – Marie Thursby, *Executive Director, TI:GER®, Georgia Institute of Technology*

12:00 – 1:00 Working Lunch Roundtables

1:00 – 2:00 Poster Session II

2:00 – 3:30 Panels

I. Legal and Institutional Factors in Designing International Research Collaborations

Organizer: Vera Alexander, *Special Assistant on Fisheries and Oceans, University of Alaska Fairbanks*

Participants: Winston (Wole) Soboyejo, *Professor of Materials Science, Princeton University*
Takeshi Kishinami, *Vice President, International Affairs Division, Hokkaido University*
David Hitlin, *Professor of Physics, California Institute of Technology*
Virgil (Buck) Sharpton, *Vice Chancellor for Research, University of Alaska Fairbanks*

II. Faculty and Curriculum Challenges

Organizer: Juan Lucena, *Associate Professor, Liberal Arts and International Studies, Colorado School of Mines*

Participants: Gary Downey, *Professor, Department of Science and Technology Studies, Virginia Polytechnic and State University*
Dan Hirleman, *Head, School of Mechanical Engineering, Purdue University*
Richard Vaz, *Dean of Interdisciplinary and Global Studies Division, Worcester Polytechnic Institute*
Hung Tao Shen, *Professor and Chair of Department of Civil and Environmental Engineering, Clarkson University*

3:30 – 5:00 Reconvene – Panel Chairs Report, Followed by Open Discussion

FRIDAY, SEPTEMBER 22

8:30 – 8:45 Opening Remarks: Arden L. Bement, Jr., *Director, National Science Foundation*

8:45 – 9:15 Keynote Address: Indira Samarasekera, *President, University of Alberta*

9:15 – 10:45 Panels

I. THE INTERACTION BETWEEN DIVERSITY AND INTERNATIONALIZATION
Organizer: George Boggs, *President and CEO, American Association of Community Colleges*
Participants: Daniel Wubah, *Special Assistant to the President, James Madison University*
Eduardo Marti, *President, Queensborough Community College*
Grant Cornwell, *Vice President and Dean of Academic Affairs, St. Lawrence University*

II. SUSTAINING INNOVATION IN A GLOBAL ENVIRONMENT
Organizer: Peter McPherson, *Executive Director, NASULGC*
Participants: Anna Nilsson, *Science and Technology Attaché, Embassy of Sweden and Assistant Professor, Karolinska Institute*
Carl J. Sundberg, *University Lecturer and Coordinator, Science and Society, President's Office, Karolinska Institute*
Thomas Vaidhayan, *Chief Executive Officer, Aten Inc.*

III. NANOTECHNOLOGY R&D: THE VIEW FROM CALIFORNIA
Organizer: Anthony Waitz, *Managing Partner, QuantumInsight*
Participants: Arun Majumdar, *Almy and Agnes Maynard Chair and Professor, Mechanical Engineering, UC Berkeley*
Richard Helfrich, *Managing Director, Alameda Capital, LLC*
Jia Ming Chen, *Chief Operating Officer, Institute for Cell Mimetic Space Exploration, UCLA*

11:45 – 12:30 Reconvene – Panel Chairs Report, Followed by Open Discussion

12:30 Workshop Adjourned

Appendix II: Steering Committee, Keynote Speaker, and Panelists' Biographies

Steering Committee Members

Vera Alexander retired as Dean of the School of Fisheries and Ocean Sciences and Professor of Marine Science at the University of Alaska Fairbanks and now holds the title Professor of Marine Science and Dean Emerita at the University of Alaska Fairbanks. She also serves as the Director of the University of Alaska Coastal Marine Institute and of the Pollock Conservation Cooperative Research Center. She was born in Budapest, Hungary, grew up in England, and came to the United States in 1950 to enter the University of Wisconsin as a freshman. Originally planning to study chemistry, she became deeply interested in the biology of lakes and received B.A. and M.S. degrees in zoology in 1955 and 1962, respectively. In 1962 she moved to the University of Alaska. A new Marine Science Institute had been started, and she was accepted as the first marine science graduate student. She received her Ph.D. in marine science in 1965. She became a U.S. citizen in 1980.

Alexander is a Fellow of the American Association for the Advancement of Science, Fellow of the Arctic Institute of North America, and also a Fellow of the Explorers Club. She became a member of Sigma Xi in 1974. She has served on the National Research Council's Ocean Sciences and Polar Research Boards, and has chaired the Advisory Committee for the Ocean Sciences Division of the National Science Foundation. In 1999, she was awarded an honorary Doctor of Laws degree by Hokkaido University in Japan. She currently serves on the United States Marine Mammal Commission, the International Scientific Steering Committee for the Census of Marine Life, and the U.S. National Committee for the Census of Marine Life, and is serving second two-year terms as Chairman of the North Pacific Marine Science Organization (PICES) and President of the Arctic Research Consortium of the United States.

Julio E. Ibarra is Executive Director of the Center for Internet Augmented Research and Assessment (CIARA) at Florida International University. Ibarra oversees the university's Internet and Internet2 services and the AmericasPATH (AMPATH) project, which he created in 2000. Ibarra is the administrative and technical lead of Internet and Internet2 services for the university and is responsible for the strategic planning and development of the regional GigaPOP. Ibarra has been active in initiatives to advance networking and Internet technologies for the State of Florida. He serves on the Governor's IT Florida Task Force subcommittee on Infrastructure and Technology Development as a subject matter expert. He is co-author of the policy recommendation for the development of a Network Access Point (NAP) in South Florida to enhance the state's e-commerce opportunities with Latin America. Ibarra is the founder and director of AMPATH, a project to interconnect the research and education networks in South and Central America, the Caribbean, and Mexico to Internet2 connected networks. Ibarra has served as principal investigator for AMPATH over the past two years, successfully securing in excess of $1M in active equipment and collocation space in the NAP of the Americas, and a significant donation of bandwidth (450 Mbps collectively) from a major telecommunications carrier to begin the AMPATH project. Ibarra received the bachelor's and master's of science degrees in Computer Science from Florida International University.

Wayne C. Johnson is the Vice President for Hewlett-Packard Company's Worldwide University Relations, located at HP Laboratories in Palo Alto, California. He is responsible for higher education programs in research, marketing and sales, recruitment, continuing education, public affairs, and philanthropy. Johnson joined HP in July 2001 from Microsoft's University Relations department where he managed program managers and administrative staff across a customer base of 50 top-tier universities. He managed the development of formal Partnership Plans with each school and expanded the University Relations activities to include Latin American institutions. From 1967 to 2000, he held a variety of positions at the Raytheon Company in Lexington, Massachusetts, including National Sales Manager for Wireless Solutions, Manager of International Financing and Business Development in Wide Area Surveillance Programs, Manager of Administration and Strategic Planning, and Manager of Program Development and Operations for Technical Services.

Johnson received his B.A. in 1967 from Colgate University in Hamilton, New York, and his M.B.A. in 1971 from Boston College's Carroll School. He was an adjunct professor of management at Boston University from 1977 to 1999. Johnson currently manages an organization of 20 Program Managers and administrative staff working across 74 universities worldwide.

Johnson serves as a board member of the Institute for Women in Technology (IWT) and several oversight boards sponsored by the National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA). He has been recently appointed to the Accreditation Board for Engineering and Technology (ABET) Industrial Advisory Board and is a member of the Government-University-Industrial Research Roundtable (GUIRR).

Kathleen Kennedy is the Vice President of the Education and Training Program at the North Carolina Biotechnology Center. Prior to joining the Center, Kathleen was on the faculty at East Carolina University, where she was Director of the Biotechnology Training Program in the Department of Biology. At the Center, she oversees Center education programs, develops biotechnology-related curriculum materials, advises colleges on biotechnology education, and tracks biotechnology workforce training needs. She and her staff have produced *BioWork*, an innovative course for training bioprocess manufacturing technicians, as well as other publications on biotechnology careers and the related industrial skill and knowledge base.

Kennedy received her Ph.D. in molecular biology from Vanderbilt University and M.S. degree from the University of Texas at Austin in cell biology. Her undergraduate degrees were in journalism and English. She did post-doctoral research at the Biozentrum of the University of Basel, Switzerland. Her research areas have included membrane structure, bacteriophage structure and genetics, site-specific recombination, and the application of DNA hybridization technology to clinical diagnostics.

Gretchen Kalonji holds the position of Director of International Strategy Development for the University of California system. She is responsible for creating the first coordinated and comprehensive international strategy in UC history. Kalonji has developed creative approaches to internationalization and to the transformation of science and engineering education. At the University of Washington, where she held the Kyocera Chair in the Department of Materials Science and Engineering and was an active member of the African Studies faculty, she led a campus-wide effort to integrate collaborative international research activities into curricular pathways of students, across the disciplines and from freshmen to doctoral level. This initiative, entitled *UW Worldwide*, has been honored with multiple grants and awards, both in the United States and in partner regions. Before moving to Seattle, Kalonji served as Assistant and Associate Professor at MIT, from 1982–1990. Over the past 10 years, Kalonji has been the principal or co-principal investigator on more than $19 million dollars of related grants.

Kalonji's work, both in materials science and in educational transformation, has been recognized by numerous awards and honors, including the Presidential Young Investigator Award, the George E. Westinghouse Award from the American Society for Engineering Education, the Leadership Award from the International Network for Engineering Education and Research, and the National Science Foundation's Director's Award for Distinguished Teaching Scholars, the highest honor offered by NSF. Kalonji has held visiting faculty appointments at numerous universities and institutes around the world, including the Max Planck Institute (Germany), the University of Paris (France), Tohoku University (Japan), and Sichuan University and Tsinghua University (China). She serves on numerous national and international advisory boards and committees, particularly for projects and organizations focusing on innovations in education, equity and access in higher education, and international science and engineering. Kalonji has been called upon to give more than 115 invited lectures in institutions around the world.

Mark S. Lazar, Deputy Vice President for Scholarship Programs and International Operations at the Institute of International Education, oversees the work of the Institute's global network of offices around the world and supervises the scholarship and training programs that the Institute administers on behalf of corporations, foundations, individuals, international organizations, and U.S. government agencies. Programs include the Ford Foundation Global Travel and Learning Fund, the GE Foundation Scholar-Leaders Program, the Japan-IMF Fellowships, and more than a dozen Children of Employee scholarship programs for major international corporations including AIG, Harman International, and Lockheed Martin.

Lazar's portfolio also includes several science and technology initiatives to help increase global awareness in these fields. Programs include the NSF-funded Central Europe Summer Research Institute (CESRI), which supports U.S. graduate students in the sciences to complete summer research internships at Central European institutions and the Global Engineering Education Exchange (Global E^3), a consortium of more than 70 universities in the U.S. and abroad to promote study abroad in the fields of engineering.

Lazar holds master's degrees from New York University in urban planning and from Columbia University in European history. He has a bachelor's degree in history from the University of Wisconsin-Madison.

Juan Lucena is Associate Professor in Liberal Arts and International Studies and affiliated faculty member in the Center for Engineering Education at the Colorado School of Mines (CSM). He is also Boeing Company Senior Fellow in Engineering Education at the National Academy of Engineering and Visiting Professor in Science and Engineering Education at the Universidad de Las Americas in Puebla, Mexico. Lucena was a Distinguished Lecturer at the 2006 American Society for Engineering Education (ASEE) Annual Meeting and keynote lecturer at the 2004 National Conference on Engineering Education in Colombia. Trained in mechanical and aeronautical engineering (B.S. Rensselaer, 1987, 1988) and science and technology studies (Ph.D. Virginia Tech, 1996), he is principal investigator of the NSF-funded projects "Global Engineers: Ethnography of Globalization in Engineering Education, Hiring, Practices, and Designs" and "Enhancing Engineering Education through Humanitarian Ethics," which is developing a graduate curriculum in humanitarian engineering at CSM. He is author of *Defending the Nation: U.S. Policymaking in Science and Engineering Education from Sputnik to the War against Terrorism* (University Press of America, 2005) and co-developer of *Engineering Cultures*® multimedia courseware (with Gary Downey, Virginia Tech). Currently, he is co-authoring a book on *Engineers and the Metrics of Progress* and an article on the creation of transnational networks of engineering education.

H. Dean Sutphin is a professor of agricultural and extension education at Virginia Tech and the Vice President for International Outreach at the Virginia College of Osteopathic Medicine. Sutphin received bachelor's and master's degrees in Agricultural Education from the Virginia Polytechnic Institute and State University, and a Ph.D. in the field from The Ohio State University. Sutphin has served as Associate Dean and Director of Academic Programs at the Virginia Tech College of Agriculture and Life Sciences. Prior to this, Sutphin served as Professor, Associate Dean, Director of Academic Programs, and Department Chair of education at the Cornell University College of Agriculture and Life Sciences.

Sutphin has authored over 75 refereed articles, professional presentations, and scholarly manuscripts. Sutphin has envisioned, developed, and implemented several distance learning programs, including a multi-disciplinary, international distance education curriculum focused on the environment and sustainable food systems. The course is the U.S. 2000–2001 national award-wining course for the American Distance Education Consortium, linking live video and Internet to 36 institutions internationally. Sutphin was invited by the Vice President of the UN and Conference Chair for the UN World Summit on Sustainability in Johannesburg, South Africa, to demonstrate the Global Seminar for a gathering of 80,000 people and 1,000 to 2,000 members of the press.

Sutphin serves on the general Administration Board of the USDA Graduate School and has developed the Northeast Strategic Plan for Academic Programs for 12 states. Sutphin has led over 40 individual planning grants and projects totaling $3.1 million and has secured $400,000 in legislative funding for national competitive grants program with 12 projects awarded annually for 3 years.

Keynote Speakers

Arden L. Bement, Jr., became Director of the National Science Foundation on November 24, 2004, after serving as Acting Director since February 22, 2004. He joined NSF from the National Institute of Standards and Technology, where he had been director since December 7, 2001. As head of NIST, he oversaw an agency with an annual budget of about $773 million and an onsite research and administrative staff of about 3,000, complemented by a NIST-sponsored network of 2,000 locally managed manufacturing and business specialists serving smaller manufacturers across the United States. Prior to his appointment as NIST director, Bement served as the David A. Ross Distinguished Professor of Nuclear Engineering and head of the School of Nuclear Engineering at Purdue University. He was director of the Midwest Superconductivity Consortium and the Consortium for the Intelligent Management of the Electrical Power Grid.

Bement came to the position of NIST director having previously served as head of that agency's Visiting Committee on Advanced Technology, the agency's primary private-sector policy adviser; as head of the advisory committee for NIST's Advanced Technology Program; and on the Board of Overseers for the Malcolm Baldrige National Quality Award. Along with his NIST advisory roles, Bement served as a member of the U.S. National Science Board from 1989 to 1995. As NSF director, Bement now serves as an *ex officio* member of the NSB.

Bement also chaired the Commission for Engineering and Technical Studies and the National Materials Advisory Board of the National Research Council. He was a member of the Space Station Utilization Advisory Subcommittee and the Commercialization and Technology Advisory Committee for NASA, and he consulted for the Department of Energy's

Argonne National Laboratory and the Idaho National Engineering and Environmental Laboratory.

He currently serves as a member of the U.S. National Commission for UNESCO and serves as the vice-chair of the Commission's Natural Sciences and Engineering Committee. Bement holds an engineer of metallurgy degree from the Colorado School of Mines, a master's degree in metallurgical engineering from the University of Idaho, a Ph.D. in metallurgical engineering from the University of Michigan, honorary doctorate degrees from Cleveland State University, Case Western Reserve University, and the Colorado School of Mines, and a Chinese Academy of Sciences Graduate School Honorary Professorship. He is a member of the U.S. National Academy of Engineering and a fellow of the American Academy of Arts and Sciences.

PHILIP B. CARTER is Executive Director of Sigma Xi, The Scientific Research Society, a 60,000-member honor society for scientists and engineers with more than 500 chapters at academic institutions, government laboratories, and industry research centers. He is responsible for overall management of the Society's activities and operations and the administrative offices located in Research Triangle Park, North Carolina.

Recognized for teaching, research, and international initiatives, Carter came to Sigma Xi from North Carolina State University, where he is professor emeritus of microbiology and immunology, and from the not-for-profit Merck Foundation, where he was programs director of the Merck Childhood Asthma Network. From 1986–1989, he was associate vice chancellor for research at NCSU and director of the university's biotechnology program. He also served two years as Chair of the Faculty.

His expertise in microbial agents, such as anthrax, led to his chairing the steering committee for the Pentagon's Military Infectious Disease Research program. A native of Chicago, he earned B.S. and Ph.D. degrees from the University of Notre Dame and was a project leader in the immunology division of the Ames Company of Miles Laboratories, Inc. before joining the staff of the Trudeau Institute in Saranac Lake, New York, in 1971.

After a year as a visiting scientist at Oxford University in 1978, Carter joined the faculty at the University of Illinois at Champaign-Urbana as an associate professor and then moved to N.C. State in 1982 as a full professor. Associate editor of the scientific journal *Microbial Ecology in Health & Disease*, he has also served as president of the Association for Gnotobiotics and the International Association for Gnotobiotics.

M. PETER MCPHERSON is President of the National Association of State Universities and Land-Grant Colleges (NASULGC) and President Emeritus of Michigan State University. He chairs the board of Abraham Lincoln Study Abroad Commission, is the founding co-chair of the Partnership to Cut Hunger and Poverty in Africa, and is chairman of the Board of the International Food and Agricultural Development. McPherson also serves on the Board of Directors of Dow Jones.

He retired as President of Michigan State University in December 2004 after serving 11 years. From April to October 2003, he took leave from that position and served as the Director of Economic Policy in Iraq under the Coalition Provisional Authority. Prior to being named President of Michigan State, McPherson held senior executive positions with the Bank of America from April 1989 to October 1993.

From 1969 to 1989, McPherson held several governmental and private sector positions. He served as deputy secretary of the U.S. Treasury, with special focus on trade, tax, and international issues, from August 1987 to March 1989. He was the administrator of the Agency for International Development from 1981 to 1987. He has also been the chairman of the board of the Overseas Private Investment Corporation, a managing partner of a large Ohio law firm, and a special assistant to President Gerald Ford. From January 1977 to November 1980 he was a partner and head of the Washington office law firm of Vorys, Sater, Seymour and Pease. In 1964–1965, McPherson was a Peace Corps volunteer in Peru.

McPherson earned a bachelor's degree in political science from Michigan State University, an M.B.A. from Western Michigan University, and a J.D. from American University Law School. He holds honorary doctorates from Virginia State University, Mount St. Mary's College, and Michigan State University. McPherson has also been honored with the U.S. Presidential Certificate of Outstanding Achievement, the Secretary of State Distinguished Leadership Award, the Department of Treasury's Alexander Hamilton Award, the UNICEF award for "outstanding contribution to child survival," and the 1983 Humanitarian of the Year award from the American Lebanese League.

INDIRA V. SAMARASEKERA began her five-year term as the University of Alberta's twelfth president on July 1, 2005. She believes there are fundamental questions that need answering if Canada is to enhance its global competitiveness, among them: What will distinguish the world's great universities from the excellent ones in the 21st century? What do we need to do to ensure that students are receiving exceptional preparation to excel and be responsible citizens in our interconnected global environment? And how do we increase the translation of university research into public policy, private industry, and societal dividends that improve the quality of life?

Samarasekera is a member of the Prime Minister's Advisory Council on Science and Technology and the Public Policy Forum. In 2005, she was asked by the then–federal Industry Minister to sit on an expert panel, including BlackBerry inventor Mike Lazaridis and businessman Joseph Rotman, to advise the government on ways to ensure new technologies and services make their way to the marketplace.

Samarasekera is an Officer of the Order of Canada, a Fellow of the Royal Society of Canada, a fellow of the Canadian Academy of Engineering and a Fellow of the Canadian Institute of Mining, Metallurgy, and Petroleum (CIMM). Prior to coming to the University of Alberta, Samarasekera served five years as Vice President of Research at the University of British Columbia, where she was on the faculty for close to 30 years. Samarasekera has also served on Presidential Advisory Committees at MIT and Carnegie Mellon University.

Marie C. Thursby is currently a professor of strategic management and holds the Hal and John Smith Chair in Entrepreneurship at the College of Management, Georgia Institute of Technology, as well as an adjunct professorship in economics at Emory University. Before joining Georgia Tech, Thursby had been a member of Purdue University's economics faculty since 1988 and held the Burton D. Morgan Chair of International Policy and Management.

She is the founding director of a new graduate certificate program at Georgia Tech and Emory University called Technological Innovation: Generating Economic Results (TI:GER[sm]). Designed for doctoral students in science, engineering, and management and M.B.A. students from Georgia Tech, as well as J.D. and doctoral students in law and economics from Emory, the program connects integrated research in diverse technology fields with the business, legal, and organizational issues important for understanding commercialization of fundamental research. The program is funded by the National Science Foundation, the Alan and Mildred Peterson Foundation, and Hal and John Smith.

She has been a research associate of the National Bureau of Economic Research for fifteen years and serves on several major journal editorial boards, including *Management Science,* the *Journal of Technology Transfer,* the *Journal of International Economics,* and the *Review of International Economics.*

Thursby has published extensively on the economics of innovation, with particular emphasis on the industrial impact of university research, international R&D competition, and optimal license strategies. Other research interests include international economics and industrial organization, with a focus on how government policies and industry interact to determine competitiveness.

Panelists

Christine Boytos Adamczyk As a senior scientist at GlaxoSmithKline, Christine Boytos Adamczyk contributed to the discovery of antifungal agents and to the development of anticancer medicines for 22 years before taking on a new role in science education. Her undergraduate research at Merrimack College centered on medical technology and bacterial respiration. Her graduate research at North Carolina State University focused on microbial physiology. After 22 years of research and project leadership, she accepted a challenging new role in 1999 to create and direct GSK's U.S. Science Education programs, which now include "Sharing Science," the Center for Science Teaching and Learning, and the SPARK! program.

Her focus on improving science education includes collaborative efforts with the North Carolina Infrastructure for Science Education, the UNC DESTINY Traveling Learning Program, the Sally Ride Science Festivals, the Franklin Institute, Science in the Summer (AAAS), two MSP grants (NC-PIMS and TASC), the NC Museum of Natural Sciences, the Kenan Institute for Engineering, Technology and Science Teaching Fellows, and the Shodor Foundation. She believes that inquiry-based science learning is the key to our youth's success in our 21st-century society, as citizens and in the workforce. She enjoys the progressive, collaborative atmosphere that North Carolina brings to the advancement of science achievement in the K–12 schools, in academia, and in the business sector.

Ray Almgren, Vice President of Product Marketing and Academic Relations, leads the technical marketing operations for National Instruments along with the company's worldwide academic relations program. During his 18 years at National Instruments, Almgren has held positions in marketing, R&D, and applications engineering. His most recent roles include Vice President of Product Strategy, Director of R&D for the measurements product group, and Director of Software Marketing.

Throughout his career at National Instruments, Almgren has devoted significant effort to enhancing science and engineering education and inspiring students to pursue technical careers. He pioneered many of the company's academic and university relations programs, including the ROBOLAB project, which combines LEGO® MINDSTORMS® with LabVIEW to introduce robotics and control in grades K–12. In addition, Almgren is active in driving an annual giving program that creates scholarships for engineering students at the University of Texas at Austin, his alma mater.

Almgren currently is chair of the Texas Engineering and Technical Consortium and a member of the Government-University-Industry Research Roundtable sponsored by the National Academies. He serves on the ABET Industry Advisory Council, the School of Engineering Executive Board at Southern Methodist University, the Dean's Engineering Advisory Council at the University of Missouri-Columbia, the Advisory Committee for the Tufts University Center for Engineering Educational Outreach, the National EPICS Program Advisory Council at Purdue University, and the External Advisory Committee for the Electrical and Computing Engineering Department at UT Austin. In addition, he is a member of the IEEE Instrumentation and Measurement Society and the American Society for Engineering Education.

In 2004, Almgren was named an Outstanding Young Engineering Graduate of UT, an honor bestowed upon individuals age 40 and under for distinguished contributions in the realms of professional accomplishment, community service, and service to the UT College of Engineering. In 2005, he was a recipient of the Outstanding Young Texas Ex Award presented by the UT alumni association. Almgren serves as vice president and sits on the board of directors for the National Instruments Foundation, a private foundation focused on science and engineering education and research. Almgren graduated from UT Austin in 1987 with a bachelor's degree in electrical engineering.

Kris Allsbury is the Associate Director of the North Carolina Community College System BioNetwork. Her role is oversight of new community college biotechnology curriculums development throughout the NC Community College System, management of grants that play a key role in developing Biotechnology infrastructure, and support for system biotechnology economic development efforts. She has responsibility for the BioNetwork BioForum, BioNetwork Intellectual Property Issues, and the distance learning model for BioNetwork. She serves on the NC BPTC Industry Curriculum Committee, task forces analyzing industry needs, the distance learning development committee for the BTEC facility, the ECU Biotechnology Program Board, the NCCCS Virtual Learning Community committee, and the BioNetwork Technology Review Committee.

With over 30 years of extensive technical experience in the corporate, academic, and public sectors, she has done private consulting in staff development, database design, corporate training, software design, and Web site design. She served as Educational Program Coordinator at the North Carolina Supercomputing Center promoting mathematical modeling in the NC K–12 schools. She has written and managed several large grants from state and federal funding sources. Allsbury taught graduate and undergraduate instructional technology courses fulltime in the NC Central University School of Education and computer science courses at three other colleges in North Carolina and Wisconsin. Previously she has served on the technology development task force for an international educational philanthropy. She has presented at numerous state, national, and international conferences and was selected to serve on the NC Governor's Summit on Volunteerism, the Wisconsin Governor's Conference on Education, and the Wisconsin State Vocational, Technical, and Adult Education Leadership Identification Program. She has a University of Wisconsin master's degree in adult education, training, and development.

Paul Avery is a professor of physics at the University of Florida. He is the director of two Grid technology projects, GriPhyN and the International Virtual Data Grid Laboratory.

Suresh Chandra Babu is Program Leader for the Capacity Strengthening Program at the International Food Policy Research Institute in Washington, D.C., where as a senior research fellow he conducts research, outreach, and capacity-strengthening activities in the areas of global food and nutrition security. Prior to joining IFPRI in 1992 as a research fellow, Babu was a research economist at Cornell University in Ithaca, New York. He spent many years in southern Africa on various capacities. He was Senior Food Policy Advisor to the Malawi Ministry of Agriculture on developing a national level food and nutrition information system; an evaluation economist for UNICEF-Malawi working on designing food and nutrition intervention programs; coordinator of UNICEF/IFPRI food security program; and a senior lecturer at the University of Malawi. He currently serves as an adjunct professor of Indira Gandhi National Open University, New Delhi.

Babu currently heads IFPRI's Learning and Capacity Strengthening Program and coordinates its program on Global Open Food and Agricultural University. Since 1997, he has coordinated IFPRI's research and outreach efforts in Central Asian countries. He serves as a member of scientific and advisory Committees of Southern Africa Food Policy Network, African Capacity Building Foundation, African Forest Research Network, Millennium Ecosystem Assessment, IUCN's Commission on Ecosystem Management, and the World Agricultural Forum.

Babu received his Ph.D. and M.S. degrees in economics from Iowa State University and his MSc (agricultural economics) and BSc (agriculture) in universities in Tamil Nadu, India. He has conducted development research for bilateral and international organizations including the Food and Agricultural Organization (FAO) of the United Nations, the World Bank, UNCTAD, UNICEF, GTZ, and USAID.

Babu has authored or co-authored more than 80 refereed journal papers and book chapters. He is an associate editor of United Nations University's *Food and Nutrition Bulletin* and *Journal of Sustainable Development* and a member of the editorial board of the *African Journal of Food, Agriculture, Nutrition and Development.* He is the co-editor of the recent books *Food Systems for Improved Human Nutrition: Linking Agriculture, Nutrition, and Productivity* (Haworth Press, 2002); *Economic Reforms and Food Security in South Asia* (Haworth Press, 2005); and *Policy Reforms and Agriculture Development in Central Asia* (Springer, 2005).

Rajika Bhandari directs the Institute of International Education's research and evaluation activities and leads two major research projects—"Open Doors" and "Project Atlas"—that track and measure international higher education mobility at the U.S. and international level. She also designs and conducts evaluations for many of IIE's international education and professional exchange programs and is currently evaluating an Alcoa Foundation sustainability and conservation fellowship program and a Hewlett Foundation social sciences fellowship program in Latin America.

Before joining IIE, Bhandari was a Senior Researcher at MPR Associates, an educational research and consulting firm in Berkeley, California, that provides research and evaluation services to the U.S. Department of Education, state departments of education, and foundations. She also served as the Assistant Director for Evaluation at the Mathematics and Science Education Network at the University of North Carolina at Chapel Hill, where she directed research and evaluations of mathematics and science education pre-college and professional development programs. Bhandari also has substantial experience conducting educational research in the U.S. and in India on topics such as women and education in developing countries, immigrant parents' participation in children's education in the U.S., and adult education and lifelong learning.

George R. Boggs is President and Chief Executive Officer of the American Association of Community Colleges (AACC). He assumed the position in September 2000. From its Washington, D.C., headquarters, AACC represents over 1,100 associate's degree–granting institutions and some 10 million students. Boggs holds a bachelor's degree in chemistry from The Ohio State University, a master's degree in chemistry from the University of California at Santa Barbara, and a Ph.D. in educational administration from the University of Texas at Austin.

He has served on the Board of Directors of the California Association of Community Colleges, the Community College League of California, the Western Association of Schools and Colleges, and the American Association of Community Colleges, serving as Board Chair in 1993–1994. He served as a member of the Committee on Undergraduate Science Education of the National Research Council and has served on several National Science Foundation panels and committees. He has also served on the U.S. Department of Labor Committee on Skills Gap in the Workforce, and is a member of several other boards and committees. He has testified before both state legislative and Congressional committees on subjects related to higher education. He is the author of more than 50 articles and chapters in professional journals and books.

Boggs has been recognized by the Public Broadcasting System with its Terry O'Banion Prize for Teaching and Learning for "triggering the most significant educational movement of the past decade." He has been honored by the University of Texas as a Distinguished Graduate. He received the Professional of the Year Award for Motivational Leadership from the Leadership Alliance, the Harry Buttimer Distinguished Administrators Award from the Association of California Community College Administrators, the Marie Y. Martin Chief Executive Officer Award from the Association of Community College Trustees, the Stanley A. Mahr Community Service Award from the San Marcos Chamber of Commerce, the 2004 Paul A. Elsner Leadership Award by the Chair Academy, and the 2004 NISOD's International Leadership Award. The City of Vista, California, proclaimed January 15, 1994, as "Dr. George Boggs Day" in recognition of his community service. Boggs is listed in *Who's Who in America* and six other *Who's Who* directories.

Molly Corbett Broad, an economist and educator, is Professor of the Practice in the School of Government at the University of North Carolina at Chapel Hill and President Emerita of the University of North Carolina. She served as President of the 16-campus university from 1997 to 2006. The oldest public university in America, the university is a $6 billion-a-year operation that enrolls more than 196,000 students. UNC encompasses all of the state's public institutions that grant baccalaureate, graduate, and professional degrees, along with affiliated enterprises that advance the mission of the university, including the 11-station UNC Center for Public Television, the UNC Health Care System, the NC Arboretum, and the NC School of Science and Mathematics. UNC's chief executive officer is responsible for managing the affairs and executing the policies of the university and for representing the university to the NC General Assembly, state officials, the federal government, and other key university constituencies. She also served as the State Higher Education Executive Officer (SHEEO).

Before coming to UNC, Broad held administrative and executive positions at a number of universities, building a formidable reputation and gaining experience and expertise in finance, information technology, capital planning and construction, leadership development, and strategy. During her career, she has served as chief financial officer, chief operating officer and chief executive officer in several different universities. She was senior vice chancellor for administration and finance at the California State University system from 1992 to 1993, and was executive vice chancellor and chief operating officer from 1993 until her election as UNC President. Earlier in her career, Broad had served as the chief executive officer for Arizona's three-campus university system (1985–1992) and in a succession of administrative posts at Syracuse University (1971–1985), where she was manager of the Office of Budget and Planning, Director of Institutional Research and Strategic Planning, and Vice President for Government and Corporate Relations. In 1976, she took a one-year leave of absence to serve as deputy director of the New York State Commission on the Future of Postsecondary Education, a blue-ribbon panel charged with evaluating the organizational structure and financing of the state's two public university systems.

Broad earned a General Motors Scholarship to Syracuse University and graduated Phi Beta Kappa with a baccalaureate degree in economics from the Maxwell School of Citizenship and Public Affairs. She holds a master's degree in the field from The Ohio State University and a doctoral fellowship in economics from the Maxwell School of Syracuse University.

Active in an array of professional and civic organizations, Broad has written and spoken widely on strategic planning for higher education, information technologies, globalization, biotechnology, and K–16 partnerships. She is immediate past chair of the National Association of State Universities and Land-Grant Colleges (NASULGC) board of directors, past chair of the Internet 2 corporation board of directors, and past president for the International Council for Distance Education. She has served on the boards and executive committees of the Business–Higher Education Forum, the National Council on Competitiveness, the National Association of University System Heads, MCNC, the North Carolina Biotechnology Center, and the North Carolina Economic Development Board. She holds seats on the boards of RTI International (serving on the audit and compensation committees), the Institute for Defense and Business, the executive advisory boards of Monster.com, SunGard SCT, Mellon Foundation, the Association of Governing Boards Presidents' Council, and the Partnership for Public Service. A member of the First Centenary Consultative Committee for Fudan University in Shanghai, China, she also serves on the Parsons Corporation Board of Directors and its audit and nominating/governance committees.

William O. Bullock is Director of Biotechnology Industrial Development for the North Carolina Biotechnology Center (NCBC), a private nonprofit corporation located in Research Triangle Park, North Carolina, dedicated to providing long-term economic benefit to North Carolina through support of biotechnology research, development, and commercialization statewide. Bullock's direct efforts focus on facilitating life science company expansion within, and attraction to, North Carolina. He also works as a liaison with the North Carolina Department of Commerce (NCDOC) as part of his efforts to support the growth and development of the state's life sciences industry.

Prior to joining NCBC, Bullock most recently served as International Business Development Manager for Biotechnology within the International Trade Division of NCDOC. He was also Vice President of the biotechnology consulting firm BioAbility, where he directed numerous studies and client consulting projects in North America and abroad, including international biotechnology competitiveness benchmarking, economic development strategic planning, business plan development, technology assessments, and market research and analyses. Other prior experience includes business consulting for global pharmaceutical and biotechnology firms and six years in research, development, and marketing at Stratagene Cloning Systems in San Diego, California.

Bullock has written and presented extensively on a variety of topics related to commercial biotechnology, including economic development, business models, market research, regulation, agriculture, workforce development, strategic alliances, U.S./International biotechnology, and more. He received his undergraduate degree in cell biology and biochemistry from the University of California, San Diego, and undertook graduate training in biochemistry. In addition, he received an M.B.A. from the Kenan-Flagler Business School at the University of North Carolina, Chapel Hill.

Charlie Catlett is a Senior Fellow at Computation Institute at the University of Chicago and Argonne National Laboratory and Director of the NSF TeraGrid project, a $150 million initiative involving a distributed "Grid" of information technologies at eight major supercomputing centers and universities. Prior to joining Argonne in 1999, Catlett was Chief Technology Officer at the National Center for Supercomputing Applications, where he had worked since 1985. From 1999 to 2004, Catlett directed the State of Illinois–funded I-WIRE optical network project, deploying optical fiber infrastructure to interconnect ten locations in Illinois. From 1999 through 2004 he founded the Global Grid Forum, an international technical standards body with participants from more than 40 countries. With Larry Smarr, Catlett co-authored the seminal paper "Metacomputing" in 1992 in the journal *Communications of the ACM*, which initiated what would become the concept of "Grid" computing. In 1996 he was a co-investigator, along with Smarr as well as Rick Stevens, Dan Reed, and Ian Foster, of the $180 million NCSA Alliance project, in which the term "Grid" was first coined. Catlett is a Computer Engineering graduate of the University of Illinois at Urbana-Champaign.

Jia-Ming Chen is the Chief Operating Officer of the Institute for Cell Mimetic Space Exploration at the University of California, Los Angeles.

Grant Cornwell is the Vice President of the University, Dean of Academic Affairs, and Professor of philosophy at Saint Lawrence University. Nationally recognized for his work in defining liberal learning in a global environment, Cornwell is a member of the National Advisory Board for Liberal Education and Global Citizenship: The Arts of Democracy, a national three-year faculty and curriculum development initiative of the Association of American Colleges and Universities. Much of his current work on campuses is devoted to bridging international and multicultural studies and campus initiatives. He is also serving as a fellow in the National Learning Communities Project at the Washington Center for Improving the Quality of Undergraduate Education. He received the Outstanding Freshman Advocate award from the National Resource Center for Freshman Year Experience in 1995.

Cornwell earned his master's degree and Ph.D. from the University of Chicago. Most recently, Cornwell worked in the development of the new major in Global Studies. He has directed a number of large faculty development grants in global and intercultural studies, and teaches courses in African, Caribbean, and global studies. In the past, Cornwell has been awarded the Donald C. Faber Distinguished Scholar-in-Residence endowment from Miami University of Ohio and has served as a board member of the Great Lakes Research Consortium.

Gary Downey is Professor of Science and Technology Studies and affiliated faculty in the Department of Engineering Education at Virginia Tech. He was 2005–2006 Boeing Company Senior Fellow in Engineering Education at the U.S. National Academy of Engineering. He was distinguished lecturer on globalization, leadership, and diversity in engineering education at the 2006 meeting of the American Society for Engineering Education and keynote lecturer on the engineer as problem definer at the 7th World Congress of Chemical Engineering in 2005. Trained as a mechanical engineer (B.S. Lehigh University, 1974) and cultural anthropologist (Ph.D. University of Chicago, 1981), he is winner of Virginia Tech's 1997 Diggs Teaching Scholar Award for scholarship in teaching, 2003 XCaliber Award for instructional technology, and 2004 William Wine Award for career excellence in teaching.

Downey is principal investigator on three NSF-funded projects: "Engineering Cultures: Building the Global Engineer," "Engineers and the Metrics of Progress," and "Engineering Leadership through Problem Definition and Solution." He is author of *The Machine in Me: An Anthropologist Sits Among Computer Engineers* (Routledge, 1997), co-editor of *Cyborgs and Citadels: Anthropological Interventions in Emerging Sciences and Technologies* (School of American Research Press, 1998), and co-developer of *Engineering Cultures*® multimedia courseware (www.conted.vt.edu/engcultures).

David Gray is the LCR Regional Knowledge Management Coordinator of the World Bank in Washington, D.C. As Regional Coordinator of the Network, Gray is in charge of directing the Network's growth and presence in the Latin American and Caribbean Region, as well as establishing strategic alliances among institutions.

Richard W. Helfrich is a Managing Director of Alameda Capital, a venture fund in formation. Alameda is focused on the convergence of technologies from information technology or energy combined with advanced materials or life science. These combined technologies create new high-value products that enable profitable business growth while improving the quality of life. Helfrich currently serves on boards in the fields of medical equipment, alternative energy, communications, and semiconductors. Helfrich's interests are in improving economic growth and the quality of life through technology and a highly educated workforce.

Earlier Helfrich actively invested in the U.S. and managed the U.S. portfolio for a German venture fund. This fund covered communications, semiconductors, energy, and life sciences. Helfrich has served on more than 20 boards and founded several hardware companies. Helfrich's operational experience includes executive business and marketing roles in large companies as well as startups. One of those roles included a NASDAQ company turnaround and one startup he founded later became a prosperous NASDAQ company. At the start of his career Helfrich worked in the aerospace sector as an engineer and scientist at Northrop and Hughes (now part of Raytheon). Helfrich promotes public policy initiatives regionally and globally and participated on the California Nanotech Task Force. During 2005, Helfrich testified to the U.S. House Congressional Committee on Science and Technology promoting legislation to expand science education funding for K–12, reducing regulatory burdens for small business, and creating programs to encourage more new company spinouts from federally funded research. Over the last several years Helfrich has served on SBIR panels reviewing proposals from small businesses. Helfrich also participates on regional venture panels that review startup presentations and provides guidance to those businesses. Helfrich has taught business and marketing classes at UC Extension focused towards entrepreneurs. Helfrich's education includes an A.B. in physics, MSEE, and pre-med chemistry and biochemistry. Helfrich has authored numerous articles on business, marketing, and technology and spoken at dozens of conferences.

E. Dan Hirleman is currently Professor and William E. and Florence E. Perry Head of the School of Mechanical Engineering and Interim Director of Global Engineering Programs at Purdue University. Hirleman received his degrees from Purdue University, obtaining the B.S.M.E. degree in 1972 (graduating in three years with Highest Distinction, 4.00 GPA), the M.S.M.E. in 1974, and the Ph.D. in 1977. During that time Hirleman also spent a year doing research at the Technical University of Denmark in Copenhagen and a year on the technical staff at Hughes Aircraft Company. He received National Science Foundation and Howard Hughes Fellowships as a graduate student. In 1992–1993 he was a visiting researcher at the Technical University of Delft in Holland and an Alexander von Humboldt Foundation Fellow at Universität Karlsruhe in Germany.

Hirleman's contributions to education include teaching courses such as "Introduction to Engineering Design" (freshman), "Thermodynamics" (juniors), capstone design courses (seniors, including global distance projects), and "Combustion" (graduate). He developed new courses in "Measurements and Microcomputers" (required junior year) and "Laser Diagnostics" (graduate). Hirleman also received the Pi Tau Sigma Professor of the Year Award for teaching excellence. At Purdue he orchestrated development of the Global Engineering Alliance for Research and Education (GEARE), a bilateral program integrating domestic and international internships, study abroad, and multi-national design team experiences for engineering students with Germany (Universität Karlsruhe), China (Shanghai Jiao Tong University), and India (IIT Bombay). He serves on the steering committee for the Colloquia in International Engineering Education, was co-chair of the Engineering Education Conference co-sponsored by the American and Chinese Mechanical Engineering Societies held in Beijing in April 2006, and received the Achievement Award from the International Network for Engineering Education and Research (INEER) in 2006.

David Hitlin was appointed Professor of Physics at Caltech in 1986. He received his B.A. (1963), M.A. (1965), and Ph.D. (1968) degrees from Columbia University. His thesis, with C. S. Wu, was on the determination of shapes and sizes of deformed nuclei using high resolution spectroscopy techniques with muonic x rays. He was an Instructor at Columbia from 1967 through 1969. Although trained in experimental nuclear physics, he switched to elementary particle physics, moving to the Stanford Linear Accelerator Center as a Research Associate. He was appointed assistant professor of physics at Stanford in 1972, and moved to Caltech in 1979 as an associate professor.

Hitlin has been principal investigator of the Caltech High Energy Physics grant since 1994. He has served on the Program Advisory Committees of the Stanford Linear Accelerator Center, Fermilab, Cornell and Brookhaven laboratories, on the Argonne National

Laboratory Advisory Panel for High Energy Physics, on the DOE Technical Advisory Panel on the University Program and on the Fastbus Standards Committee. He was Chairman of SLUO, the Stanford Linear Accelerator Lab Users Organization, for three terms. He is currently a member of the High Energy Physics Advisory panel to the DOE and NSF. He is a Fellow of the American Physical Society.

Tricia Hitmar is the Director of People Development for ABB North America and is responsible for leading the region's talent management and development activities, executive leadership programs and forums, key learning and organization development initiatives, and change management activities related to One Simple ABB programs. She is also responsible for the human resources activities in the region's Information Systems organization. Previously, she was the business development manager and established ABB Robotics' first inventory management services business. In that role, she was the global product manager for the SmartSpares technology, set global pricing, was responsible for marketing the offering, and managed the project execution activities. She trained global counterparts, met with ABB customers around the world, and spoke internationally on the technology and services offering.

Hitmar also managed a multi-million-dollar profit center service business as director of training and documentation for the Robotics business. This was the largest center globally and provided operations and maintenance training to more than 3,000 customers annually in addition to producing extensive systems documentation materials for the operations and maintenance of ABB equipment. She served on a global team to implement best practices worldwide among the training and documentation centers. Hitmar originally joined ABB in 1997 in a human resources management role and was responsible for leading the HR activities for multiple business units including staffing, employee relations, international assignments, rewards and recognition, and employee development.

Prior to ABB, Hitmar worked for Eaton Corporation where she was a divisional human resources manager with responsibilities for the HR function in the divisions' operations located in China, Mexico, Taiwan, Thailand, and the United States. She was a human resources manager with United Technologies Corporation and a human resources supervisor with ITT Industries.

Hitmar earned an M.B.A. from Wayne State University in Detroit, Michigan, and a B.S.B.A. in Human Resources Management and Organizational Development from Bowling Green State University. She has also attended ABB's Executive Education Program at the Fuqua School of Business at Duke University.

Takeshi Kishinami serves as the Vice President of International Affairs and Facilities of Hokkaido University in Japan. Kishinami received the B.E., M.E., and Ph.D. degrees in engineering from Hokkaido University. He is currently a member of the Science Council of Japan and has previously served as Dean of the Hokkaido University Graduate School of Engineering. Kishinami's research interests include Digital Information Modeling and Technology, High Quality Information Modeling for Data Exchange between Design and Manufacturing, and High Level Data Modeling for Next Generation Computer Controlled NC Machine Tools. Kishinami is involved in Japanese efforts to increase the cosmopolitan and international character of its national universities.

Russ Lea has been serving as the Vice President for Research and Sponsored Programs at the University of North Carolina since April 1, 2001. For six years prior to his recent appointment, he served as Associate Vice Chancellor for Research at North Carolina State University. In his current capacity, Lea serves as the Chief Research Officer for the consolidated 16-campus UNC System. Lea's principal responsibilities include securing increased levels of external support from federal, state, and private sources; assisting campuses to develop policies and procedures; maintaining a sponsored program database accessible to the public; and promoting economic development and technology transfer. The position supports the Senior Vice President for Academic Affairs and interfaces with UNC Board of Governors and campus research officers to ensure that research policies and procedures are consistent with the academic, research, and public-service mission of the UNC System as it strives to serve its faculty, students, staff, and public.

Lea holds Ph.D.s from SUNY College of Environmental Science and Forestry and from Syracuse University. He serves on the editorial board for *Environmental Science and Policy Journal.* Lea has served on the boards of the NC Museum of Natural Sciences, Institute for Transportation Research and Education (ITRE), the Small Business Technology Development Center (SBTDC), NC IDEA, the Center for Transportation and Environment (CTE), the NC Global Transpark, and the NC Association for Biomedical Research (NCABR).

Arunava Majumdar received a B.Tech in Mechanical Engineering from the Indian Institute of Technology, Bombay (IIT-B), in 1985, and a Ph.D. in Mechanical

Engineering from the University of California, Berkeley, in 1989, for research conducted in the laboratory of Professor Chang-Lin Tien. After being on the faculty of Arizona State University (1989–1992) and University of California, Santa Barbara (1992–1996), he began his faculty appointment in the Department of Mechanical Engineering at the University of California, Berkeley, on January 1, 1997. He currently holds the Almy and Agnes Maynard Chair Professorship in the College of Engineering.

In addition to his faculty appointment, Majumdar serves as the Director of the Berkeley Nanosciences and Nanoengineering Institute. He is also a member of the Nanotechnology Technical Advisory Group to the President's Council of Advisors on Science and Technology (PCAST). He served as the founding chair of the ASME Nanotechnology Institute, and is currently a member of the Council of Materials Science and Engineering at the Department of Energy. He also serves on the editorial board of the *International Journal of Heat and Mass Transfer* and *Molecular and Cellular Biomechanics,* and is the editor in chief of *Micro/Nanoscale Thermophysical Engineering*.

Majumdar is a recipient of the Institute Silver Medal (IIT-B) (1985), NSF Young Investigator Award (1992–1997), ASME Melville Medal (1992), the Best Paper award of the ASME Heat Transfer Division of ASME (1993), Gustus Larson Memorial Award of the ASME (2001), and Distinguished Alumni Award from IIT-B (2002). He is a fellow of ASME and AAAS, and is a member of the U.S. National Academy of Engineering. Majumdar's research interests are in the broad area of mechanics and transport in nanostructured materials. Of particular current interest are phonon dynamics and transport in low-dimensional materials, materials and devices for thermoelectric energy conversion, transport and reactions in confined liquids (nanofluidics), chemomechanics of small and macromolecules with applications in chem/biosensing, and nanoscale imaging.

Daniel Malkin joined the Inter-American Development Bank in September 2005 as Deputy Manager of the newly created sub-Department of Education, Science and Technology. In the IDB, one of his main responsibilities is to mainstream human capital development and innovation policies as key components of national development agenda and IDB financial and technical assistance activities. He is in charge of overseeing technical support for operations in the S&T, ICT, and Education areas, to ensure that these operations contribute to the development of best S&T policy practices and foster the innovation performance of Latin American and Caribbean countries.

Prior to joining the IDB, Malkin headed the Science and Technology Policy Division of the OECD Directorate for Science, Technology and Industry (DSTI). His activities focused on the assessment of OECD Member countries' S&T and innovation policies and public support of R&D; the performance and governance of science and innovation systems; the development and mobility of human resources in S&T; and, more generally, the contribution of science and technology to productivity and economic growth. This work led to the formulation of recommendations to high-level officials in charge of science and technology in OECD countries.

Malkin graduated from the École Polytechnique in Paris. He completed his post-graduate studies as a Fulbright scholar at the University of California, Berkeley, and at the University of Pennsylvania (Wharton School).

Cheryl S. Matherly is Associate Dean for Global Education at the University of Tulsa.

Daniel Marcek is Deputy Director of Hewlett Packard (HP) University Relations and is responsible for development of HP strategy for and engagement with select university partners worldwide. He has been involved in managing HP's university relationships since 1997 and is responsible for a wide range of institutions—from small, Ivy League campuses to some of the nation's largest public universities. He is also focused on exploring international opportunities for partnership among government, industry, academia, and NGOs to develop higher education systems based on quality assurance mechanisms that foster systemic improvements to create new business opportunities for HP.

Marcek joined HP in 1990 as a member of R&D management and has since worked in technical customer relations, managed HP user groups, and designed quality standards for HP. He is a computer science graduate of the University of New Hampshire and has spent nearly 20 years in a variety of software and systems development roles.

Eduardo J. Martí was appointed President of Queensborough Community College on July 1, 2000. An experienced educator who has led several community colleges with distinction, Martí previously served for six years as President of Corning Community College of the State University of New York (SUNY), and for eight years prior, as President of SUNY's Tompkins Cortland Community College. Martí also served as Executive Dean of Tunxis Community College and Acting President of Middlesex Community College, both located in Connecticut.

Martí serves on the Board of the American Association of Community Colleges (AACC), the Board of Teachers College at Columbia University, the Board of the Cornell Institute for Community College Development, as well as the Community College Research Center Advisory Board of Columbia University, and on the Excelsior College Board. Additionally, he serves on the Board for the Hispanic Educational Telecommunications System (HETS) and the Board of Governors of the Council for Aid to Education. He has served as Past President of the Association of Presidents of Public Community Colleges of the State of New York, a member of the ACE Commission on International Education, Chair of the Small and Rural Commission of the American Association of Community Colleges, member of the Executive Committee of the American Association of Community College President's Academy, and member of the Commission on Secondary Education of the Middle States Association.

Three times a graduate of New York University, Martí holds B.A., M.S., and Ph.D. degrees in biology from the institution. He is the recipient of the Founders' Day Award from New York University and was named to the Honor Roll of the Phi Theta Kappa, the international honor society for two-year colleges. As the recipient of a Fulbright-Hays Seminars Abroad award, he spent June 2004 traveling in China with leaders of minority-serving institutions

Joseph Mook is Professor and Chair of the Department of Mechanical and Aerospace Engineering at the University at Buffalo, State University of New York. He is also the Associate Dean for International Education for the School of Engineering and Applied Sciences at the University at Buffalo. Mook's commitment to education is highlighted by several significant awards, including both a SUNY Chancellor's Award for Excellence in Teaching (the highest administration-selected teaching award in the SUNY system), and a Milton Plesur Award (the highest student-selected teaching award at the University at Buffalo). Mook's commitment to international engineering education has also received many honors, including election as the Chair of the Executive Committee of the Global Engineering Education Exchange (Global E3), the largest engineering education exchange network in the world, and a SUNY Chancellor's Award for Internationalization. In the past several years he has created a number of innovative study abroad and/or exchange programs for engineering students, and supported other internationalization efforts in engineering education.

Mook's research work spans topics in optimal estimation, system identification, and controls. Applications of his work include spacecraft and aircraft guidance and navigation, flight controls and automatic landing systems, several topics in ground vehicles, and even air separation plants. He has authored or co-authored approximately 100 publications and has served as primary investigator on dozens of sponsored programs from numerous sources, with the biggest support coming from NASA, Ford, the Navy, and the Air Force. Among other research awards, he is a Research Fellow of the Alexander von Humboldt Society of Germany and also of the Japanese Society for the Promotion of Science.

Anna S. Nilsson has spent the last ten years doing research and policy-work in the field of innovation and science-based companies. She has a Ph.D. in Medical Innovation and Organization as well as an M.B.A. In her present position as Science Attaché, she focuses on innovation policy and economic growth, specifically related to life sciences.

Nilsson is presently on sabbatical from the Karolinska Institute in Stockholm, where she has worked since 1998 and holds an Assistant Professorship. The core of the work has been to increase the understanding of overall trends and characteristics of science-based companies, particularly in biotechnology. In 1998 she created and co-directed the first course on science-based entrepreneurship in Sweden, which gained immediate popularity and is still ongoing, now with a focus on bio-entrepreneurship. During post-doc studies at Stanford University (2002–2003) she initiated and co-directed a copy of the course in collaboration with a professor at Stanford School of Medicine. Although she is now on sabbatical, she continues with her research, including supervision of Ph.D.-students within the field of bio-entrepreneurship. Nilsson gains working experience from industry, nonprofit organizations, and government agencies, as well as universities. She has a great interest in international relations and has spent many years studying and working in the U.S., Latin America, and Spain.

Diana G. Oblinger is Vice President for EDUCAUSE, responsible for the association's teaching and learning activities and the director of the EDUCAUSE Learning Initiative. Oblinger has held positions in business and academia: Vice President for Information Resources and the Chief Information Officer for the 16-campus University of North Carolina system, Executive Director of Higher Education for Microsoft, and IBM Director of the Institute for Academic Technology. She was on the faculty at the University of Missouri-Columbia and at Michigan State University and an associate dean at the University of Missouri. She is an adjunct professor of adult and higher education at North Carolina State University.

Known for her leadership in teaching and learning with technology, she has testified before the U.S. Senate Committee on Employment, Safety, and Training and the U.S. House of Representatives Subcommittee on Technology. She serves on a variety of boards, such as the NSF Advisory Committee on Cyberinfrastructure. Oblinger is a frequent keynote speaker as well as the co-author of the book *What Business Wants from Higher Education*, which received the 1999 Frandson Award for best literature in continuing education. She is editor or co-editor of seven books and the author or coauthor of dozens of monographs and articles on higher education and technology. Oblinger has received several awards for teaching, research, and distinguished service. She holds three degrees from Iowa State University and is a member of Phi Beta Kappa, Phi Kappa Phi, and Sigma Xi.

Philip Papadopoulos is Program Director of Grid and Cluster Computing and Acting Group Leader of Grid Development and Deployment at the San Diego Supercomputer Center. He is also an adjunct associate research professor of computer science at the University of California, San Diego.

Virgil (Buck) Sharpton serves as the Vice Chancellor for research at the University of Alaska Fairbanks.

Hung Tao Shen is a professor in and the Chair of the Department of Civil and Environmental Engineering, Clarkson University, Potsdam, New York. He was a Visiting Research Hydraulic Engineer at the U.S. Amy Cold Regions Engineering and Research Laboratory in 1983, and a Visiting Professor at Lulea University, Sweden, in 1990. In 1998, he was invited to visit Iwate University, Japan, as a Monbusyo Special Visiting Professor, and served as a Visiting Professor at the Hokkaido River Disaster Prevention Research Center. Shen was the Chair of the IAHR (International Association of Hydraulic Engineering and Research) Section on Ice Research and Engineering from 2000 to 2004. He helped to organize several international ice symposia for IAHR, and actively promoted international exchanges on freshwater and sea ice research. Shen also served as the Editor of the *Journal of Cold Regions Engineering* of the American Society of Civil Engineers (ASCE) from 1997 to 2002. He is a recipient of the Harold R. Peyton Cold Regions Engineering Award, the CAN-AM Civil Engineering Amity Award of ASCE in 2000, and the Larry Gerard Medal of CGU-Hydrology Section in 2001.

Shen has been active in international research and education exchanges. He has collaborated with researchers from many countries in Asia, Europe, and North America. He was a Visiting Scholar of the Committee on Scholarly Communication with the People's Republic of China in 1991, a member of the Board of Directors of A.I.T. Foundation from 1984 to 1990, an Advisor of China Institute of Water Resources and Hydroelectric Power Research, and a visiting professor of Sichuan University, Dalian University of Technology, and Ocean University of China. Currently, he is the Co-Director of the NSF-REU Site Program on Marine Science and Engineering in China, which has trained over 90 students in the areas of marine science and engineering.

Winston (Wole) Soboyejo was educated in England, receiving his doctoral degree from Cambridge University and his bachelor's degree from London University before moving to the United States in 1988 to become a research scientist at McDonnell Douglas Research Labs in St. Louis, Missouri. In 1992, he worked briefly as a Principal Research Engineer at the Edison Welding Institute before joining the engineering faculty of The Ohio State University in Columbus, Ohio. From 1997 to 1998, he was a visiting professor in the Departments of Mechanical Engineering and Materials Science and Engineering at MIT.

Soboyejo moved to Princeton University in 1999, where he currently serves as a professor of materials science. He is also the director of the U.S./Africa Materials Institute and the director of the Undergraduate Research Program at the Princeton Institute of Science and Technology of Materials. His research focuses on experimental studies of biomaterials and the mechanical behavior of materials. Current areas of interest include micromechanical machines, nanoparticles for disease detection, biomedical systems for prostheses, and cardiovascular systems, infrastructure materials, and alternative energy systems. In 1994, Soboyejo received an NSF Young Investigators award for his research in developing new ways of improving the fracture resistance of high temperature materials that may be used in airplanes currently being developed to travel at speeds much faster than the speed of sound.

John Spencer is a manager with Microsoft Research, a division of Microsoft Corporation. With 30 years of business, international business, and technology experience, Spencer's unique university relations and industrial partnership experience has focused primarily on developing academic, governmental, NGO, and industry relationships that develop, promote, enhance, and improve higher education in the United States and Latin America. He received a B.S. in business from the University of Central Florida and an M.B.A. in International Business from the American Graduate School of International Management (Thunderbird), in Glendale, Arizona.

Spencer was Commissioned 2nd Lt., Infantry, graduate of U.S. Army Aviation School–Helicopter School and served on active duty from 1967 through 1973. He retired from the Army Reserves in 1995 in Military Intelligence. From 1976 through 1994 he held positions with TRW, Inc., Revere Copper & Brass, Pullman Inc., ACI Consulting for Bell Laboratories and Argonne Laboratories, Hughes Helicopters Inc., and the McDonnell Douglas Corporation as an information technologist, developer, and systems manager. Spencer joined Microsoft after 12 years with McDonnell Douglas/Boeing. He is a member of the Corporate Members Council of American Society of Engineering Education, and the National Chairman of the Engineering Projects in Community Service (EPICS) at Purdue University. He is currently on the Deans Advisory Committee, Case Western Reserve University; Corporate Partners, Purdue University; Founding Board of Governors, R&D Center, University of Puerto Rico; and the Advisory Board, Alliance for Technology Learning and Society (ATLAS), University of Colorado, Boulder.

Nadarajah Sriskandarajah is responsible for Extension and Education Studies at Denmark's Royal Veterinary and Agricultural University. He is also a guest professor at the Swedish University of Agricultural Sciences in the area of environmental communication. With degrees from the University of Ceylon and the University of Sydney in animal sciences, Sri has worked within agri-environmental education and farming systems research at institutions in Australasia and Europe. He has been active for over two decades in designing experience-based curriculums and incorporating systems thinking in undergraduate and graduate education, mainly through his attachment to the University of Western Sydney, Australia. He has regularly interacted with colleagues in several land grant institutions in the U.S.

Sri has been leading the Global Seminar for six years at his Danish university, coordinating a cluster of five international classes from there. He also led a pilot program of international exchange study funded by the European Commission linking eight universities in Europe and Australia. Both of these programs had a strong focus on creating intercultural learning environments, the application of blended learning processes, and working with food and environmental problems in global contexts. Sri is an active member of Nordic and international networks in education and he is currently working on broadening the Global Seminar concept to incorporate the area of global environmental change and to include science and engineering faculties at universities in Asia, the Pacific, and Australia.

Carl Johan Sundberg serves as a project leader at the Centre for Medical Innovations at Karolinska Institute, with a focus on bio-entrepreneurship and science policy. He was appointed Science and Society Coordinator at the Office of the President in 1998. Sundberg has an M.D./Ph.D. degree from Karolinska Institute and works part-time as a scientist at the Department of Physiology and Pharmacology at Karolinska Institute. His research group is focused on physical activity and the molecular mechanisms of angiogenesis and mitochondrial biogenesis in human skeletal muscle.

He is also a licensed physician and part-time university lecturer in bio-entrepreneurship and heads the Unit for Bioentrepreneurship. Sundberg is the Course Director for several courses, among them "Human Physiology," "From Science to Business," "Medicine for Journalists," "Medicine for Decision Makers," and "Medicine/Drug Discovery for the Financial Industry." He is basic science editor of the *Swedish Medical Journal*, has been vice president of Euroscience, and was the founder and Chairman of Euroscience Open Forum 2004, a large international science conference. In 2005 he was awarded the European Commission's Descartes Communication Prize for Excellence in Science Communication. Sundberg is a board member of NsGene A/S.

Thomas K. Vaidhyan is Chief Executive Officer of Aten Inc.

Richard F. Vaz was born in Taunton, Massachusetts, in 1958. He received the B.S. (1979), M.S. (1984), and Ph.D. (1987) degrees in electrical engineering from Worcester Polytechnic Institute (WPI), specializing in signal analysis and communication theory. He has held professional positions with the Raytheon Company, GenRad Inc., and the MITRE Corporation in the areas of systems and design engineering. Since 1987 Vaz has been on the faculty of WPI, where he is currently Dean of Interdisciplinary and Global Studies, with oversight of WPI's worldwide network of 22 project centers at which more than 450 students per year complete degree-required academic projects. His teaching and research interests include service and experiential learning, engineering design and appropriate technology, and internationalizing engineering education. He has developed and advised interdisciplinary and technical student projects in Australia, England, Ireland, Italy, Morocco, Namibia, the Netherlands, Puerto Rico, Thailand, and Washington, D.C.

Vaz has published more than 40 papers and is the recipient of numerous teaching and advising awards, including the WPI Trustees' Awards for Outstanding

Teaching and for Outstanding Advising. He is a senior member of the Institute of Electrical and Electronics Engineers and was Program Chair of the IEEE 2004 International Symposium for Technology and Society. He is an active member of the American Society for Engineering Education, and since 2004 has served as a Senior Science Fellow of the Association of American Colleges and Universities, in which capacity he helps form recommendations for science and technology education nationwide.

Caroline S. Wagner specializes in science and technology and its relationship to innovation, policy, and society. Wagner is a Lead Research Scientist at the Center for International Science and Technology Policy, George Washington University, Washington, D.C. Under a grant from the Rockefeller Foundation, she is currently writing a book about international collaboration in science. Among her current advisory commitments, Wagner serves on the Advisory Board of Research on Knowledge Systems, a program of the International Development Research Centre of Canada. She was recently a Member of the United Nations Millennium Task Force on Science, Technology, and Innovation. She is a founding member of the Washington Science Policy Alliance.

Wagner joined GWU in 2005 after 12 years with the RAND Corporation in Washington, D.C., and Leiden, Netherlands. Prior to joining the RAND Corporation, Wagner was a Professional Staff Member for the United States Congress Committee on Science, Space, and Technology and before that, in the Congressional Office of Technology Assessment. She has also served as an analyst for the United States federal government specializing in comparative analysis of global developments in science and technology. This included a two-year assignment as an analyst at the U.S. Embassy in Korea. Wagner has consulted to the World Bank, the European Commission, the Organization for Economic Cooperation and Development, the U.S. National Science Foundation, and a number of governments. Wagner holds a doctorate from the University of Amsterdam, an M.A. from GWU, and a B.A. from Trinity University. She is the author of more than 20 reports on science, technology, and innovation, many of which can be found at http://www.rand.org.

Anthony Waitz has two decades of experience in management, strategy, and technology development. As a Managing Partner at Quantum Insight®, which he co-founded in 2001, he works with clients ranging from Fortune 500 companies to promising startups to prominent venture firms. Anthony also co-founded the MIT-Stanford-Berkeley Nano Forum, a nonprofit educational organization that has become the most respected group of its type in the Bay Area. Additionally, Waitz has been active in many other nanotech community activities, such as serving on Congressman Honda's Task Force on Nanotech, serving on the executive committee of Joint Venture, Silicon Valley's nano initiative, and authoring a chapter on commercialization of nanotech for a report to the California legislature.

Prior to focusing on emerging small technology, Waitz was a Director at Synopsys, Inc., where he had a number of different roles ranging from being responsible for the silicon IP strategy to running engineering for one of the business units. Waitz came to Synopsys through the acquisition of Silicon Architects, of which he was a co-founder. Silicon Architects' products were used in approximately 100 million products over the span of a decade. Waitz holds master's degrees from Stanford School of Engineering and the Stanford Graduate School of Business.

Daniel Wubah was born in Accra, Ghana, sometime in the second half of the 20th century. He attended high school at Accra Academy and then went to the University of Cape Coast for undergraduate studies where he majored in botany and education. He came to the United States in the early 1980s.

After graduate studies at the University of Akron, Ohio, and the University of Georgia, he worked as a postdoctoral fellow at the Environmental Protection Agency research lab in Athens, Georgia. He moved to Maryland when he accepted a position at Towson State University (now Towson University) in 1992. In 2000, he moved to James Madison University as the Associate Dean of the College of Science and Mathematics. Wubah is an anaerobic mycologist whose interest has shifted to academic administration. He is currently the Special Assistant to the President at JMU.

He has received several grants from federal and private agencies. In addition to serving on institutional committees, Wubah has been a member of several national committees, such as the panels at the National Science Foundation, National Institutes of Health, and the National Academies of Sciences.

Appendix III: References

Asia Society. *Math and Science Education In a Global Age: What the U.S. Can Learn From China*. New York: Asia Society, May 2006.

Atkins, D. E, *et al*. *Revolutionizing Science and Engineering Through Cyberinfrastructure: Report of the National Science Foundation Blue-Ribbon Panel on Cyberinfrastructure*. Arlington, VA: National Science Foundation, 2003.

Atkinson, R. D. and D. K. Correa, *The 2007 State New Economy Index: Benchmarking Economic Transformation in the States*. Washington, DC: Information Technology Innovation Foundation and the Ewing Marion Kauffman Foundation, 2007.

Bikson, T. K. and S. A. Law. *Global Preparedness and Human Resources: College and Corporate Perspectives*. Santa Monica, CA: Rand Corporation, 1994.

Burland, D. M., M. P. Doyle, M. E. Rogers, and T. M. Masciangioli, eds. *Preparing Chemists and Chemical Engineers for a Globally Oriented Workforce: A Workshop Report to the Chemical Sciences Roundtable*. Washington, DC: National Academy of Sciences, 2004.

California Council on Science and Technology. *Nanoscience and Nanotechnology: Opportunities and Challenges in California*. Sacramento, CA, 2004.

Downey, G, *et al*. The Globally Competent Engineer: Working Effectively with People Who Define Problems Differently, *Journal Of Engineering Education* 95 (April 2006): 1–16.

Friedman, T. L. *The World is Flat: A Brief History of the Twenty-first Century*. New York: Farrar, Straus and Giroux, 2005.

Jackson, S. A. The Nexus: Where Science Meets Society, *Science* 310, no. 5754 (December 9, 2005): 1634–1639.

Kratz, T. K. *et al*. Toward a Global Lake Ecological Observatory Network, *Proceedings of the Karelian Institute* 145:51–62, in press.

Kuhn, T. *The Structure of Scientific Revolutions*. Chicago: University of Chicago Press, 1962.

Lincoln Commission. *Global Competence and National Need: One Million Americans Abroad*. Washington, DC: Lincoln Commission, 2005.

NASULGC Task Force On International Education. *A Call to Leadership: The Presidential Role in Internationalizing the University*. Washington, D.C.: National Association of State Universities and Land Grant Colleges, 2004.

National Academies of Engineering. *Educating the Engineer of 2020: Adapting Engineering Education to the New Century.* Washington, D.C.: National Academies Press, 2005.

National Academies. *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*. Washington, D.C.: National Academies Press, 2007.

National Innovation Initiative. *Innovate America: Thriving in a World of Challenge and Change*, 2004.

National Science Foundation. *2006 Strategic Plan*. Arlington, VA: National Science Foundation, 2006.

National Science Foundation. *ATE Centers Impact 2006-2007*. Arlington, VA: National Science Foundation, 2006.

National Science Foundation. *Cyberinfrastructure Vision for 21st Century Discovery*. Arlington, VA: National Science Foundation, 2007.

National Science Foundation. *Science and Engineering Indicators 2006.* Arlington, VA: National Science Foundation, 2006.

North Carolina Biotechnology Center. *New Jobs for North Carolina—Update,* Research Triangle Park, NC: NC Biotechnology Center, 2004.

Robertson, D. S. *Phase Change: The Computer Revolution in Science and Mathematics*. New York: Oxford University Press, 2003.

DeVol, R. C. *et al*. *Biopharmaceutical Industry Contributions to State and U.S. Economies*. Milken Institute, October 2004.

Saxenian, A. Brain Circulation: How High-Skill Immigration Makes Everyone Better Off, *The Brookings Review* 20, no. 1 (winter 2002): 28–31.

Star, S. L. and K. Ruhleder, Steps Towards an Ecology of Infrastructure: Complex Problems in Design and Access for Large-Scale Collaborative Systems, *CSCW '94*. Proceedings of ACM, 1994.

Stiglitz, J. E. *Making Globalization Work*. New York: W. W. Norton, 2006.

Thurow, L. *Fortune Favors the Bold: What We Must Do to Build a New and Lasting Global Prosperity*. New York: Harper Collins, 2003.