INTRODUCTION

Many universities, research institutes, and medical centers are discipline-based. There are many calls to complement this model with integrative, interdisciplinary, and collaborative programs to better address societal challenges and to advance our basic understanding of natural systems (e.g., 1, 2). In areas with rapidly advancing knowledge as in so many of the sciences, we might expect networks of scholars to be fluid, disbanding and reforming in response to a quickly changing understanding of the world. In reality, departments and institutions often retain a historical rigidity that has less to do with organizing around communities of knowledge and more to do with the competitive advantages that accrue to those who can exploit the absence of change. This sort of rigidity would seem to be especially unfortunate as we think about science and technology education for sustainable development.

At the start of the 21st century scientific research is increasingly characterized by two basic ideas. First, disciplinary silos alone are not the best model for advancing knowledge. Today’s challenges demand a more flexible model that promotes ebb and flow from disciplinary to interdisciplinary endeavors, from narrowly reductionist to broadly integrative programs that might include natural, physical, and social sciences, the arts, humanities, engineering, business, and law. Second, this flexibility cannot be realized solely within most current academic organizational models. Instead we need collaborative networks that use computer and information technology (i.e., cyberinfrastructure) to take advantage of the mobility that is so common in today’s world. We must also educate people—young and old—to be able to work within and take advantage of such global networks.
Research and training programs form a spectrum from narrowly specialized disciplinary programs at one end to integrative at the other—the full spectrum works best to advance knowledge. Researchers and training opportunities may find their primary home in one portion or another of the spectrum, but all can benefit from interactions with other parts. If learning is the creative process by which new knowledge is discovered, how do we teach both faculty members and students that this process often means transcending single academic disciplines, even institutions? What should programs look like to allow students to master a body of scholarship, while accepting that disciplinary borders may be too constraining and that questions are often best answered through the intellectual fusion that comes from mastering knowledge as needed regardless of boundaries?

We need faculty members and students who think about knowledge-driven outcomes and how to achieve them within environments that may impose constraints on discovery. In addition, the humanities and social sciences bring important perspectives to the scientific enterprise. The scholarship that comes closest to achieving this vision requires networks of individuals who develop disciplinary and interdisciplinary ideas and then test them against widely different worldviews. In the parts of the world where education and research are separated into different institutions, there are even greater challenges to integrate education and research, and then to integrate across the disciplines.

Training programs are needed for students, faculty members, and non-university professionals who will work in just these sorts of networks. To be scientists in and for today’s world students must learn to be essentially “knowledge entrepreneurs,” discovering new knowledge while functioning in a broad, diverse network of scholars and institutions. Faculty members and mentors must learn to work in a different world than the one they may have been trained to confront. How can we make this happen given the conservative constraints of traditional research universities and research institutes?

This approach is particularly important in the context of sustainable development. For an issue that is global in scope and import, solutions will require advances within and connections between all areas of science, the humanities, and technology. The mission of the
National Science Foundation (NSF), which is to foster basic discoveries across all fields of science and engineering research integrated with science education at all levels, is congruent with these needs and approaches. Many projects funded by the NSF focus on questions of broad international concern that are important to sustainable development worldwide, including for example the spread of infectious disease, natural resource management, agricultural technologies, and computer and information technology that enable intellectual mobility. What follows are a series of NSF programs that address networking in diverse ways.

**EDUCATIONAL PROGRAMS**

NSF is committed to supporting the development of a globally-engaged scientific and technological workforce that will be prepared to succeed in a global knowledge economy. Because this is a core value for the NSF, international projects are a component of programs that support education more broadly, as well as those that are specifically designed to create an international experience. For example, the Research Experiences for Undergraduates program seeks to expand student participation in research that contributes to the NSF goal of developing a diverse, internationally competitive, and globally-engaged science and engineering workforce. Several of the projects funded through this program have international components, and the Nyanza Project in particular illustrates an interdisciplinary, international research training experience (3). The Nyanza Project, which is run on the shores of Lake Tanganyika in Tanzania, is a seven-week research training program for American and African students, with the goal of providing undergraduates, graduate students, and high school teachers with the skills to plan and conduct interdisciplinary research on the paleoclimatology, geology, limnology, aquatic biology and watersheds/conservation of tropical lakes. With funding from African sources and the NSF, 89 undergraduates, 24 graduate students, and 8 high school teachers from the U.S. and 58 African students (from Tanzania, Burundi, Zambia, Congo, Kenya, and Burkina Faso) have participated in the project over the last eight years.
Building capacity in cyberinfrastructure is critically important for scientists worldwide to conduct their research and educate their students. One example of how the use of cyberinfrastructure and collaborative networks is transforming traditional pedagogical approaches is the nanoHUB (4). The nanoHUB is a web-based initiative spearheaded by the Network for Computational Nanotechnology, a network of universities and researchers who work collaboratively to connect theory, experiments, and computation to advance the field of nanotechnology. The nanoHUB provides online simulation services as well as courses, tutorials, seminars, debates, and facilities for collaboration—the use of cyberinfrastructure tools to integrate nanotechnology research into education transcends many barriers. This resource registers more than a million visitors a month, with nearly half coming from a dozen different countries other than the U.S., including India, China, Korea, Taiwan, Japan, Singapore, Canada, and several European countries. Also, NSF’s International Research Network Connections Program is working with peer groups around the world to develop a global integrated network environment, and links to GÉANT and CLARA, the European and Latin American regional research and education networks.

The Pan American Advanced Study Institutes program brings U.S. and Latin American graduate students and post-doctoral fellows together to stimulate cooperation among researchers in the Americas in engineering and the mathematical, physical, and biological sciences. Recent topics have included ion nanobeams, advanced networking technologies for physics and astronomy, bioinspired nanoscience and molecular machines, and mathematical models of population dynamics. These short courses provide unique opportunities for students and investigators from the United States and Latin American countries to forge new connections and networks, and to explore new interdisciplinary fields of science and technology.

One last example of an educational program at NSF that promotes global engagement of students is the International Research Experiences for Students (IRES) activity, part of the Developing Global Scientists and Engineers Program. The IRES activity supports projects that create opportunities to introduce small groups of U.S. undergraduate and/or
graduate students to international science and engineering in the context of a research experience that also provides personal contacts on which to build future international collaborations. The goal is to provide U.S. student participants with a global perspective and opportunities for professional growth through international cooperative research training, networking, and mentoring. Current IRES projects offer opportunities in Japan, Thailand, Austria, Brazil and Costa Rica, in areas within engineering and the biological, mathematical, and physical sciences.

**RESEARCH PROGRAMS**

One of NSF’s long term investment priorities is to foster research that focuses on living sustainably on the Earth. Studies range from investigations of deep oceans to urban centers, and from basic energy science to climate science with the goal of improving our understanding of the links between human behavior and natural processes. As the world’s economies grow increasingly interdependent, international research partnerships are growing in importance. The ability to develop collaborations that create new value for the partners is often the limiting factor for progress in critical areas of science, engineering, and technology. NSF uses research grants to support the development of international partnerships that foster cooperation, build global research capacity, and advance the frontiers of science.

For example, within our own Directorate for the Biological Sciences, the **Plant Genome Research Program (PGRP)** supports collaborative research linking U.S. researchers with partners from developing countries to solve problems of mutual interest in agriculture, energy, and the environment, while building a global network of scientific excellence. The long-term goal of these collaborative efforts is a greater and sustained engagement with developing countries in plant biotechnology research. Since this aspect of the PGRP began in 2004, 17 projects in 10 countries (Bolivia, Brazil, Colombia, India, Mexico, Nepal, Nigeria, Peru, Philippines, Sri Lanka) have been supported, many of which include reciprocal exchanges of students and investigators. The research focuses on issues of local interest such as biotic and abiotic stress, and on local crops such as oil seed Brassica, rice, and chick peas. One of these collaborative projects has led to an international workshop
at which scientists from the U.S. and India joined together to develop an international initiative on using genomics technology to improve three legume species of agricultural and economic importance to both countries.

Also within the Directorate for the Biological Sciences, the **Ecology of Infectious Diseases (EID) Program** supports a number of interdisciplinary projects with collaborative links to countries in Africa, Mexico, the Caribbean, and Bangladesh. The goal of the EID program is to encourage development of predictive models and discovery of general principles for relationships between anthropogenic environmental change and the transmission and evolution of infectious agents. These problems frequently are global in nature, and the research requires international collaborations for successful outcomes. For example, one early EID project was designed to provide insights into the spread of tuberculosis, which has been exacerbated by the current AIDS epidemic in Africa. This project focused on bovine tuberculosis in the African buffalo population in the Kruger National Park, South Africa, and the spillover of this disease to cattle and humans living on the boundaries of the park. The results of the research, which found that the rate of spread during an epidemic can be highly determined by a few individuals (called “superspreaders”) that are responsible for most of the transmissions among individuals, have significant implications for disease management. To accomplish the goals of the project, a multidisciplinary team of U.S. and African scientists and students (including post-doctoral fellows, graduate students, and undergraduates), consisting of epidemiologists, microbiologists, veterinarians, ecologists, molecular biologists, and geneticists formed an international collaborative network—the students involved had an extraordinary opportunity to become engaged in a global problem through this research effort. As a result of their experiences, several of the students are continuing to work on international issues after receiving their degrees.

Over the last ten years, NSF has been working to build a network of materials research scientists in the developed and developing world. The **Materials World Network** is a global community of researchers and educators working across borders and
disciplines to accelerate materials discovery and design. Materials scientists are designing and engineering materials by building in special properties. Such new materials may help to increase energy efficiency, promote green manufacturing, improve health care, develop information and communications systems, and provide modern and reliable transportation and civil infrastructure. To maximize the global benefits, NSF joined with partners from abroad to establish the Network, which now reaches nearly every region of the world. The Network brings together a diverse community to address global challenges through materials research, technology, and education.

A new pilot program that NSF began last year is called **Partnerships for International Research and Education**, which supports the development of collaborative relationships between U.S. institutions and international organizations to advance research and education goals that could not be accomplished in the absence of the partnership. The first round of awards spanned a wide variety of research areas, all of which shared the common characteristic that success will require collaboration with foreign partners. These awards hold the promise of creating new models for international engagement through academic research, and will provide strong international research experiences for the students and post-doctoral fellows that will be involved in conducting the research.

**CONCLUSION**

The NSF invests in a wide variety of research and education efforts in its quest to fulfill its mission. Increasingly, in an era of globalization and interdisciplinary approaches, we need new paradigms in science and technology education that will enable the next generation to acquire not only the necessary skills and knowledge base to succeed, but also an appreciation for the international and interdisciplinary context within which science and technology operate. Creating a culture in which dynamic networks of individuals that span disciplines, institutions, and countries can form easily, enabled by cyberinfrastructure advances, will help these students become globally-engaged in a meaningful way. Only then can we hope to gain traction in solving the global challenges, including sustainable development, that confront the nations of the world.
ACKNOWLEDGMENTS

The introductory ideas for this paper were developed in conversations with Mark Jacobs, Jane Maienschein, Maxine Proctor, and Ronald Rutowski.

REFERENCES CITED

3. http://www.geo.arizona.edu/nyanza/
5. http://www.materialsworld.net/