Developing Evaluation Approaches to International Collaborative Science and Engineering Activities

WORKSHOP REPORT

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

Marie Curie

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Executive Summary

Background and Introduction

NSF's strategic plan clearly acknowledges the growing need for U.S. scientists and engineers to address questions of global scale and significance.[1] It also recognizes that applying the results of basic research to longstanding international challenges—such as epidemics, natural disasters, and the development of alternative energy sources—will require globally engaged investigators working collaboratively with agencies and organizations both within the United States and abroad.

The information included in this Executive Summary and full report resulted from a workshop conducted by Sigma Xi, The Scientific Research Society, on July 28 and 29, 2008, at the U.S. National Science Foundation (NSF) headquarters in Arlington, Virginia. The purpose of the workshop was to gather advice from experts on how to evaluate the impact of international programs that involve U.S. students, researchers, and educators in international scientific and engineering collaborations, such as those funded by NSF's Office of International Science and Engineering (OISE). The goal of the workshop was to help identify the unique contributions that international collaborations make to promoting excellence in scientific and engineering research and to use that information to develop monitoring and evaluation criteria for OISE programs.

Two specific types of programs were discussed. The first includes programs that focus on funding individual scientists and engineers to begin collaborative projects with international partners for the first time, such as NSF's International Research Fellowship Program (IRFP), which provides awards to individual postdoctoral scholars for up to two years of international research.[2] The second type of program discussed includes those that involve more complex collaborations across institutions and disciplines, both in the United States and abroad. One example is NSF's Partnerships for International Research and Education (PIRE), which awards up to $500,000 million per year for five years to Ph.D.-granting institutions and involves participants at all stages of their academic careers.

The workshop looked at developing ways to monitor and evaluate such programs in terms of the impact on individuals, institutions, and quality of research—and the extent to which those effects were unique to international collaborations. How do these international collaborations contribute to the creation of globally competent (and therefore globally competitive) scientists and engineers and science and engineering educational and research institutions, and how do they add to the knowledge environment? Effective assessments would be able to compare an international collaboration to a domestic project, measure a project's contributions to the overall goals of a funding program, evaluate its costs and benefits in terms of human and other resources, and measure the degree to which initial support from NSF led to sustained collaborations even after such funding ended.

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[1] National Science Foundation, *Investing in America's Future: Strategic Plan, FY 2006–2011* (Arlington, VA: National Science Foundation).

[2] See NSF's OISE Web site—http://www.nsf.gov/OISE—for a full description of all OISE programs.

The full report contains discussions and conceptual frameworks for each of the three levels and includes sections on appropriate methods, research agendas, and specific testable hypotheses. This summary provides a brief description of each level and the research questions that arose during the workshop.

Individual Level

Anecdotal evidence suggests that students and researchers who participate in international collaborative activities experience a unique set of challenges and opportunities that directly contribute to the knowledge, skills, and behaviors of a globally competent scientist or engineer. In turn, the added knowledge, skills, and behaviors have a direct impact on the career paths of these individuals. Identification of these key elements and their causal relationships is an empirical question.

The following research agendas provide a path for more explicitly assessing the contribution of international collaborations to the global competence of scientists and engineers:

- Examine what other science and engineering programs have done to evaluate the career development of students and faculty who participate in international programs. Support a series of pilot projects that will explore the short- and long-term effects of international experiences on career outputs and outcomes.
- Conduct studies that more fully identify the underlying motives for a scientist's or an engineer's desire for international collaboration. Identify possible correlations to previous experiences and level of education and career development. Previous studies can be used as a backdrop for developing motivational variables.
- Support research that seeks to identify the impact of international collaboration on the careers of scientists and engineers at all stages of their career development.
- Identify institutions (both four-year and graduate-degree-granting) and programs to use as models for developing best practices for international experiences. Support the development of systematic monitoring, assessment, and evaluation tools to compare the impact of international experiences across institutions and programs. As part of this project, develop consensus definitions of monitoring and evaluation terms and a common time line. Develop clear distinctions between those involved in the activities and the observers who are doing the monitoring and assessing.
- Support a series of research projects that explicitly link characteristics of global competence (such as curiosity, flexibility, and trust) to professional competence and the development of science and engineering knowledge, skills, and behaviors. Be able to identify experiences (such as putting students in an unfamiliar domestic environment or providing virtual learning opportunities) that might contribute to global competence among scientists and engineers without requiring travel abroad.

Institutional Level

In addition to advancing the career development of individual scientists and engineers, another underlying goal of NSF OISE is to enhance the capabilities of the institutions it supports to participate actively and continuously in international collaborations. Of particular importance is the ability of institutions to sustain, deepen, and expand existing international networks to meet new science and engineering challenges and opportunities around the globe. Developing the institutional flexibility to participate in cutting-edge research wherever and whenever it occurs will help to promote globally competent research and educational institutions. Both the funding institutions and the institutions that they fund were discussed in terms of how to develop evaluation criteria for tracking the impact of international collaborations on the institutions.

- Identify the appropriate level—university-wide, departmental, or somewhere in between—of an institution to study in order to measure the impact of a specific program on that institution. When an institution has multiple international projects simultaneously, how can the direct effects of specific projects like those supported by a PIRE or an IRFP grant be separated from other factors?
- Conduct studies of funded projects that examine the effect of the type of project on any changes in institutional development at the U.S. institution. Is there a difference between projects that involve only one researcher initiating a project abroad versus those that involve multiple researchers and multiple disciplines? Is there a difference in short-term versus long-term projects on institutional policies and practices? Taxonomies of project types need to be developed for all levels before comparisons can be made and impacts assessed.
- Conduct research to determine if the region of the world where the research is conducted and field of study affect the kinds of institutional changes that take place at the host U.S. institution. (An explanation of these differences is found in more detail on page 13 of this report.)

Knowledge Environment Level

The research areas below are intended to start the process of pinpointing the effects of international collaborations on the knowledge environment and the degree to which international collaborations add to the quality (of outputs and outcomes) of both "normal" science and "transformative research." Of the three elements that were discussed at the workshop, participants found that this was the most difficult to address.

- Conduct background research to determine what other agencies, institutions, and programs (both within and outside NSF) have done to evaluate their international science and engineering programs in terms of qualitative and quantitative impacts on discovery and innovation. One possibility is to compare the effects that an international component had within NSF disciplinary programs to those without an international component.
- Clearly identify learning styles, methods, techniques, and problem-solving approaches used outside the United States that might help advance science and engineering research. Which of these might facilitate productive research and lead to new discoveries and innovations?
- Develop prototypes of effective international collaborations at all levels of education and research, and include models of both short-term and long-term projects. This process should include a more detailed examination of what it means to produce better research "outputs" and "outcomes."
- Develop examples of discovery, innovation, and best practices that constitute transformative science, with a focus on those that involved international collaborations. Continue to refine the characteristics of transformative research.

Methods

Because of the dearth of quantitative and qualitative studies that directly measure the impact of international collaborations on science and engineering at all three levels, the methods that were suggested were primarily exploratory in nature. They are intended to define categories (taxonomies) more clearly and to suggest causal links, as well as to produce descriptive and explanatory models. Of particular interest was the development of models that examine the depth and breadth of science and engineering social and information networks that can be established, sustained, and expanded, and the use of both traditional and nontraditional means of communication (CIT) that intercultural science and engineering communications might require.

The discussion centered on the following groups of methods across all three levels:

- Surveys and longitudinal data collection
- Comparative case studies
- Interviews and focus groups
- Social and knowledge (communications) network analysis

Summary and Conclusions

Developing effective tools to evaluate such collaborations will take time and money. Participants arrived at the workshop with years of experience participating in, administering and evaluating international projects, but no one was able to offer existing long-term systematic evaluations or models that address all three of the levels of interest to NSF. At this point, most of the evidence remains anecdotal and unsystematic.

To address this shortcoming by doing everything suggested in the report would be quite time-consuming and expensive, and it would require the dedicated efforts of faculty and staff at various institutions for many years. The key recommendation is to develop some short-term feasible metrics that can be used to evaluate the impacts of IRFP and PIRE while studying some of the leading elements to develop more complex models in the future.

It also became clear at the workshop that specific programs such as PIRE and IRFP cannot be studied in a vacuum. Evaluations of their effectiveness must take into account other international activities that are taking place at institutions and the students and faculty involved in them. It was also noted that it is important to study the failures of international collaborations as well as the successes. Another point of agreement is that the impact of international collaborations will vary depending on the subject being studied and the region where the research is being carried out.

The discrepancy between the needs of industry and the needs of U.S. research institutions is another issue that remains unresolved. Industry wants competent U.S. scientists and engineers at all educational levels who are able to work, live, and operate effectively abroad for extended periods of time. Much of the research conducted by industry is applied research. It will result in the development of new products and new markets. Agencies such as NSF, however, want globally competent scientists and engineers to go abroad to conduct cutting-edge basic research and then return to the United States to teach and mentor others and advance U.S. contributions to the global process of research and development. One question that remains is what complementary and integrative roles different agencies and institutions involved in research play in developing global competence. This raises other questions as well, such as whether the process of evaluating international programs will be the same for all participants, including academic institutions and industry, or whether NSF should develop assessment tools that apply only to agencies with similar goals and strategies.

Next Steps

In order to develop a set of essential, feasible quantitative and qualitative monitoring and assessment tools for NSF OISE programs, the following steps should be taken:

- Determine what NSF and other governmental and nongovernmental agencies here and abroad have done to assess their international science and engineering programs. Identify key elements that can be adapted to NSF program evaluations.
- Prioritize the research agendas identified in this report and the lead NSF offices that might sponsor the research needed in these agendas.
- Develop several request-for-proposals based on these agendas that explore the development of monitoring and assessment tools at the individual, institutional, and scientific-research levels of analysis.
- Work with other agencies to develop a common set of evaluation standards.

I. Introduction

The information included in this report resulted from a workshop conducted by Sigma Xi, The Scientific Research Society, on July 28 and 29, 2008, at the U.S. National Science Foundation (NSF) headquarters in Arlington, Virginia. The purpose of the workshop was to gather advice from experts on how to evaluate the impact of international programs that involve U.S. students, researchers, and educators in international scientific and engineering collaborations, such as those funded by NSF's Office of International Science and Engineering (OISE). The sixteen invitees responded to a series of questions regarding the development of monitoring and assessment tools that could be used to assess three aspects of collaborative international research: (1) the impact of the collaboration on an individual scientist or engineer; (2) the impact on the institutions involved in the collaboration; and (3) the impact on the quality of science and engineering that resulted from the collaboration.[3] The primary purposes of the workshop were to help identify the unique contributions that international collaborations make to promoting excellence in scientific and engineering research and to use that information to develop monitoring and evaluation criteria for OISE programs. The workshop grew out of a 2006 conference that focused broadly on developing a globally competent U.S. science and engineering workforce.[4]

Two specific types of programs were discussed. The first includes programs that focus on funding individual scientists and engineers to begin collaborative projects with international partners for the first time. These programs are exemplified by NSF's International Research Fellowship Program (IRFP), which provides awards to individual postdoctoral scholars for up to two years of international research. The goal of the IRFP is to introduce scientists and engineers to collaborative international research early in their careers, thereby facilitating their ability to develop long-term relationships with colleagues abroad and giving them a global perspective on their field.

The second type of program discussed includes those that involve more complex collaborations across institutions and disciplines, both in the United States and abroad. One example is NSF's Partnerships for International Research and Education (PIRE), which awards up to $2.5 million per year for five years to Ph.D.-granting institutions and involves participants at all stages of their academic careers. PIRE is intended to help institutions in the United States build partnerships with foreign counterparts, with the goals of encouraging cutting-edge research, giving U.S. students international research experiences, and creating new models of international research collaboration.[5]

The workshop focused on developing ways to monitor and evaluate such programs in terms of the impact on individuals, institutions, and quality of research—and the extent to which those

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[3] Biographies of the invitees are included in Appendix I, and the questions that were developed can be found in Appendix II.

[4] Information about the 2006 workshop, its subsequent report, and an executive summary can be found on Sigma Xi's Web site: http://www.sigmaxi.org/global. The report—*Embracing Globalization: Meeting the Challenges to U.S. Scientists and Engineers*—includes some 90 recommendations to funding agencies and research institutions to help ensure that the U.S. workforce will be able to thrive in a global environment.

[5] There are other OISE programs that resemble IRFP and PIRE, but participants were asked to focus on these two. For a complete description of all OISE programs see: http://www.nsf.gov/OISE.

effects were unique to international collaborations. Effective assessments would be able to compare an international collaboration to a domestic project, measure a project's contributions to the overall goals of a funding program, evaluate its costs and benefits in terms of human and other resources, and measure the degree to which initial support from NSF led to sustained collaborations even after such funding ended.

There are a number of stakeholders—Congressional committees, NSF management, OISE management and program staff, and the Primary Investigators of NSF grants that have an international research or education component—with interests in insuring that NSF funds the most promising proposals. Only long-term monitoring and assessment tools can measure the real impact that international collaborations have on the U.S. science and engineering enterprise. Such evaluations contribute to the internal and external accountability that all government agencies have to these stakeholders and, indeed, to the American taxpayer.

II. Background

> *Increasing international competition and workforce mobility, combined with a surge in international collaboration in science and engineering research, continue to alter the science and engineering landscape worldwide. To lead within this broader global context, the U.S. science and engineering workforce must build greater capacity for productive international collaborations.*
> —NSF Strategic Plan

NSF's strategic plan clearly acknowledges the growing need for U.S. scientists and engineers to address questions of global scale and significance.[6] It also recognizes that applying the results of basic research to longstanding international challenges—such as epidemics, natural disasters, and the development of alternative energy sources—will require globally engaged investigators working collaboratively with agencies and organizations both within the United States and abroad. As recent economic and social trends have indicated, the global economy involves an interconnected web of economic and social networks that impact stakeholders throughout the world. An economic or political crisis in one country has economic, social, and political reverberations around the globe, often with unintended consequences. Now, more than ever, the role that international scientific collaborations and science diplomacy can play to fully meet the challenges and opportunities of advancing discoveries in health, food supply, energy, and environment, and even developing new models of economic development, takes on added significance in the coming decades of the 21st century.

The goal is clear. One problem, however, is that as scientists and engineers use advanced technology to build increasingly complex systems, it becomes more difficult to evaluate their progress toward that goal. Disciplines often have their own evaluative criteria, and these can be hard to compare and contrast to other fields of research. International collaborations add further difficulty by involving different cultures, metrics, and even definitions of "successful."

The workshop attempted to grapple with these important but complex issues by developing criteria for measuring the effectiveness of international collaborations on three levels:

[6] National Science Foundation, *Investing in America's Future: Strategic Plan, FY 2006–2011* (Arlington, VA: National Science Foundation).

1) The impact on an individual researcher
2) The impact on the institutions involved
3) The impact on the quality of the research produced

The following sections will address each of these three levels.

III. The Individual

Defining Global Competence

> *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.*
>
> —Indira Samarasekera[7]

An individual who chooses to participate in international exchanges and collaborations is assumed to return with new attitudes and beliefs that contribute to "global competence." One definition of global competence is "having an open mind while actively seeking to understand cultural norms and expectations of others, leveraging this gained knowledge to interact, communicate, and work effectively outside one's own environment."[8] Gary Downey has applied this definition specifically to engineers, describing a globally competent engineer as one who has "the knowledge, ability, and predisposition to work effectively with people who define problems differently than they do."[9]

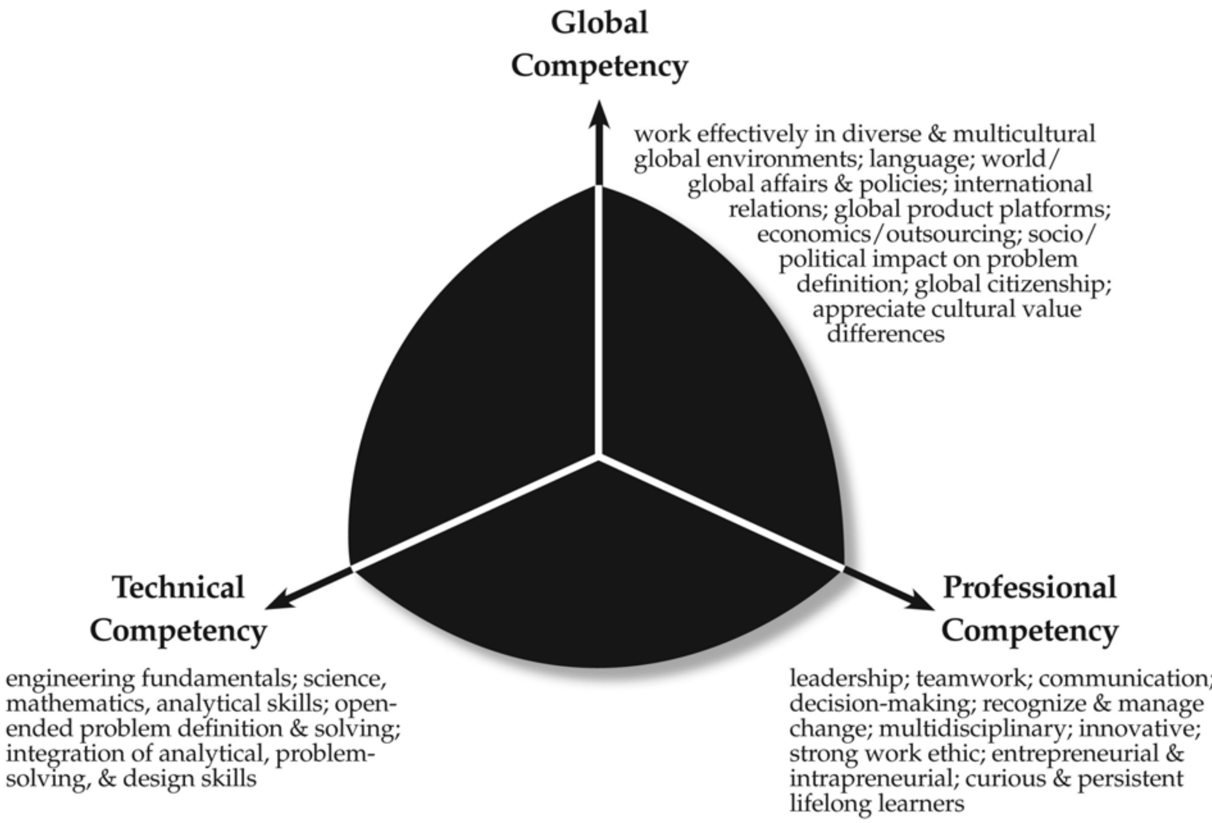
One aspect of the discussion at the workshop focused on whether a person really develops intercultural or global competence during a particular international collaboration. One way to approach this question is to look at global competence as a process that begins with an initial experience in a foreign setting and progresses to the ability to participate effectively in environments around the world. Many researchers might take part in the first steps of this process, but it is possible that only a few will have the leadership skills and knowledge to be able to cooperate in a truly global environment.

In general, students who travel abroad are assumed to acquire or strengthen a number of traits, including openness, curiosity, empathy, trust, and the ability to operate in different cultural settings. Measuring these traits is not easy, however, and it is even more difficult to quantify the differences between those students who take part in international collaborations and those who do not. For individuals involved in science and engineering, another important question is how international collaborations will result in the acquisition of knowledge, skills, and behaviors that strengthen their ability to engage in scientific discovery and innovation.

[7] Keynote Address, 2006 Workshop on "Assuring a Globally Engaged Science and Engineering Workforce," September 24, 2006.
[8] Hunter, B., *et al.*, "What Does It Mean to Be Globally Competent?" *Journal of Studies in International Education* 10 (Fall 2006), 267–285.
[9] 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.

Discussion

FIGURE I: ATTRIBUTES OF THE GLOBAL ENGINEERING PROFESSIONAL



Source: Proceedings of the International Research and Education in Engineering (IREE) 2007 Grantees Conference: Summary and Recommendations, Y. Chang and E. D. Hirleman, April 2008, available at https://engineering.purdue.edu/GEP.

At the outset of the workshop, participants noted that above all else, students and researchers should be technically and professionally competent in their fields of study. As Figure I indicates, global competency involves applying professional and technical competencies to a broader and more complex international environment. Together, these capabilities are what is expected of a scientist or engineer in the 21st century. The degree to which international collaborative experiences enhance or contribute to these attributes is an empirical question.

While there was agreement on the importance of these skills, there was a noticeable distinction between industry representatives and academics regarding the kinds of individuals and behaviors desired. Industry representatives were interested in the development of global collaborations at all levels of higher education—from community college to postgraduate programs—because there are a variety of tasks and job skills at each level. Moreover, industry representatives want employees from the United States to be able to travel, work, and live abroad for extended periods of time. Academic representatives expressed more interest in ensuring that individuals return to the United States to create new opportunities for themselves and others. One way to classify these differences is that industry may view the movement of

U.S. scientists and engineers to other countries as “brain circulation,” whereas others view it as “brain drain.”

During the course of the workshop, the following types of knowledge, skills, and behaviors were discussed. These can be used as a way to compare those scientists and engineers who have had collaborative international experiences with those who have not.

Knowledge

- Knowledge of new methods or techniques not available in the U.S.
- Access to information not available elsewhere or not in English-language journals
- Understanding of different languages and cultures
- Understanding of the different economic, social, and political systems that govern laws and regulations relevant to science and engineering, such as intellectual-property laws
- Knowledge of differences in finance, international standards, global product platforms, and marketing

Skills

- Use of new information technology, including software, hardware, equipment, and facilities
- Use of nontraditional means to gather, analyze, and communicate research
- Ability to discern cultural differences in laboratory rules and dynamics
- Ability to develop and expand sustainable international science and engineering networks
- Ability to lead and produce “transformative science” in environments other than one’s own

Behaviors

- Operate effectively in foreign environments
- Operate comfortably in foreign environments (e.g., eat native food and live without additional accommodations)
- Participate in additional international or global experiences in the United States and abroad
- Access media that report on international happenings (e.g. internationally oriented newspapers, foreign journals, and foreign-policy journals)
- Publish in foreign journals, participate in international conferences, teach or conduct research abroad for extended periods, publish with authors from outside the United States
- Obtain non-U.S. patents or licenses

FIGURE II: IMPACTS ON THE INDIVIDUAL OF INTERNATIONAL SCIENCE AND ENGINEERING COLLABORATIONS

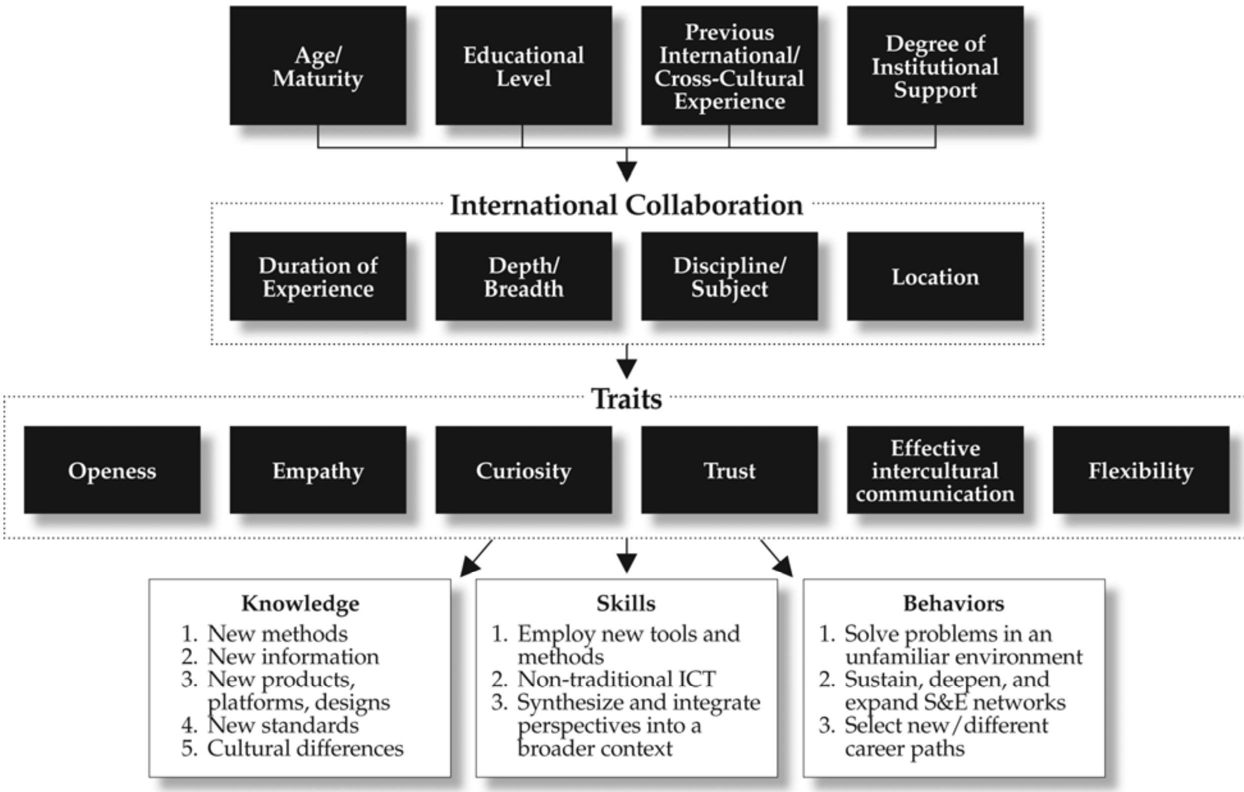


Figure II summarizes the discussion about impacts on the individual experiencing international collaborations by 1) delineating differences among the types of scientists and engineers participating in international collaborations; 2) identifying differences among the types of collaborations that may affect the outcomes and outputs of the collaboration; and 3) linking the traits that were discussed with possible knowledge, skills, and behaviors that result from the collaborations.

Individual Differences

Some variables that might influence the results of the international experience include the age and maturity of that person and the educational and professional level they had attained at the time of the experience. Whether the person was an undergraduate or senior research professor, for example, will influence the person's motivations or goals for participating. In addition, where the individual previously participated in international teams, or even that person's country of origin and international travel experiences, can often influence the degree of comfort and success achieved by the international experience. Finally, whether the individual's home institution actively supported the experience or put up hurdles to clear before he or she could collaborate might also influence the type of international experience that person had and the short- and long-term outcomes.

Collaboration Types

Not all research or educational experiences are alike, and these differences can affect the impacts of the experience on the individual. For example, some are of short **duration** and include just one international event, while others can take place over several years. In addition, in some experiences the host institution might be minimally involved, providing primarily logistical support for access to information, for example. Other experiences can involve large multidisciplinary, multinational teams that have day-to-day contact with each other and provide mutual support and key contributions. Thus, the **depth and breadth of the science or engineering networks** established by the teams can also have an impact on the opportunities made available to the individual participant.

The **discipline or subject area as well as the region of the world where the experience took place could** also influence the outcome. A physics experiment with access to CERN facilities in Europe provides a very different work environment from in-depth biodiversity field studies in varying types of ecosystems. Working in developing countries can introduce unique challenges and prompt the use of creative coping skills more so than working in cultures similar to that of the United States. Similarly, working in highly developed countries with very different cultures and language structures from the United States (such as Japan or China, for example) also produces its own set of unique challenges.

The different types of experiences will influence not only the impacts on the individuals participating in them, but also the institutions supporting them, and the quality of science and engineering outcomes and outputs that result.

Linking Traits with Specific Science and Engineering Knowledge, Skills, and Behaviors

Post-travel surveys of students traveling abroad indicate the development of a series of attitudes and beliefs, including openness and trust in others. The most interesting research challenge is to link the kind of traits associated with travel-abroad experiences to specific science and engineering knowledge, skills, and behaviors. Workshop participants mentioned several times that international collaborations help to develop cooperative and willing "world citizens,' but it is the role of NSF and other institutions to identify the science and engineering contributions catalyzed by such traits.

Methods

Several methods were mentioned that can help begin to measure the impact that international collaborations have on students and researchers. These include:

- Surveys: The Intercultural Development Inventory (IDI) and the Beliefs, Events, and Values Inventory (BEVI) were mentioned as tools to examine changes in certain traits exhibited by those who have international experiences.[10] However, these indices do not directly relate such traits to science and engineering competence. Additional surveys would need to be developed or adapted from other evaluations to link the traits measured with science and engineering knowledge, skills, and behaviors.

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[10] For a description of the IDI, see http://www.mdbgroupinc.com/idi_background.htm. For a description of the BEVI, see http://www.forumea.org/research-bevi.htm.

- Longitudinal data collection: The development of methods and tools to track individuals as their careers progress could provide a means to analyze the effect international experiences have on career paths and success. These tools might include automatic data-collection tools that could be used by subjects to report on career changes.
- Interviews: Responses gathered from qualitative interview questions could root out metrics that could be used to measure how international collaborations enhance an individual's scientific or engineering career.
- Case studies and focus groups: These could help identify differences between types of international projects and between individuals who do and do not take part in international collaborations.
- Studying IRFP and PIRE: These programs provide interesting comparisons and can be used to assess the impact of international experience on individuals, both those who have international experience early in their careers (IRFP), and those who are involved in established networks of collaboration at various stages of their careers (PIRE). Similar metrics can be used to assess the effect of international collaboration as long as type(s) of experiences can be clearly defined.

Issues and Research Agendas

What are the Sample Populations?

More than 200,000 U.S. students study abroad each year, but very few of them specialize in science or engineering. At this point, we do not really know what types of experiences our undergraduate or graduate students in science, technology, engineering, and mathematics (STEM) fields are having. Moreover, we do not know what percentage of educators and researchers who are not students take part in international collaborations. This is true both for scientists and engineers receiving NSF grants and for the science and engineering population as a whole.

It may be useful to conduct "before-and-after" studies of those who take part in international collaborations, but there must also be measurements that compare these individuals with those who do not take part in such collaborations. Otherwise, there is no way of knowing whether international projects make a unique contribution to science and engineering outcomes. One suggestion at the workshop was that virtual international learning experiences that take place within the United States might help develop some of the same knowledge, skills, and behaviors as travel abroad. This possibility raises the question of whether face-to-face collaborations in foreign settings provide a unique set of elements that no other experience can replicate.

Another problem concerns postdoctoral researchers, assistant professors, and others early in their careers. Is taking part in international collaborations a hindrance for them, or does it contribute to long-term career success?

Research Area 1: Support research that seeks to identify the impact of international collaboration on the careers of scientists and engineers at all stages of their career development.

Motivations

There are a number of possible motivations for a student or researcher to pursue international opportunities, including previous international travel, family ties to a specific region, enhancing a resume, or working with leading researchers abroad. These motivations might depend in part on an individual's stage of career development and level of education.

Research Area 2: Conduct studies that more fully identify the motives for international collaboration. Identify possible correlations to previous experiences and level of education and career development. Previous studies can be used as a backdrop for developing motivational variables.

Time Line

It is important to conduct longitudinal studies that measure the effects of international collaborations in both the long term and the short term, and the degree to which one international experience led to others. This raises the question of identifying the appropriate length of time to use when measuring the effect of international collaborations on career development (outcomes) as opposed to career productivity (outputs).

Research Area 3: Examine what other programs have done to evaluate the career development of students and faculty who participate in international programs. Support a series of pilot projects that will explore the short- and long-term effects of international experiences on career outputs and outcomes.

Research Area 4: Identify academic institutions (both four-year and graduate-degree-granting) and specific programs to use as models for developing best practices for international experiences. Support the development of systematic monitoring, assessment, and evaluation tools to compare the impact of international experiences across institutions and programs. As part of this project, develop a consensus of terms and a common time line. Develop clear distinctions between those involved in the activities and the observers who are doing the monitoring and assessing.

Linking Global Competence Traits to Science and Engineering Knowledge, Skills, and Behaviors

As stated previously, there has been a lot of discussion regarding the meaning of global competence in terms of specific traits and skills, but these discussions have usually not directly addressed how global competence relates to the professional development of scientists and engineers. It is important to examine how international experiences prepare scientists and engineers to operate in a global environment.

Research Area 5: Support a series of research projects that explicitly link global competence traits to professional competence and the development of knowledge, skills, and behaviors. Be able to identify experiences (such as putting students in an unfamiliar domestic environment or providing virtual learning opportunities) that might contribute to global competence among scientists and engineers without requiring travel abroad.

Testable Hypotheses

Throughout the workshop, participants were asked to develop specific, testable hypotheses that would be measured either quantitatively or qualitatively and used to examine the unique contributions that international collaborations provide. Hypotheses that might be used to measure the impact of collaborations on the individual level include:

H1: The earlier a student participates in a meaningful international collaborative experience (ICE), the more likely it is that he or she will stay in the field/earn an advanced degree/attain professional and technical competencies.
H2: Students with ICE on their resume are more likely to get hired by industry or pursue an academic career.
H3: Scientists and engineers with ICE are better able to create, expand, and sustain international networks than those without it.
H4: Scientists and engineers with ICE use different information technologies and other tools to collect, analyze, and disseminate information than those without it. These include nontraditional tools.
H5: Scientists and engineers with ICE develop a unique set of knowledge, skills, and behaviors that those without ICE lack.
H6: Students with ICE make different career choices within and outside STEM fields than those with no ICE.
H7: Students with ICE are more productive (produce higher-quality output) during their careers than those without ICE.
H8: Globally competent scientists and engineers are better able to participate in "transformative" science and engineering. (See Section V.)

Individual Career Development

There are many variables that affect an individual's career, apart from any international research or educational experiences the individual may have. Family circumstances, institutional barriers, the economy, and even international politics can play direct and indirect roles in career choices. Still, as some of the workshop participants noted, international experiences lay the groundwork for the development of individuals who, over time, will develop the cultural sensitivities necessary to operate in a global environment. Locating good models of international engagement, identifying what types of experiences work best, and integrating international experience into programs that result in globally competent scientists and engineers is a daunting challenge, but it is one that NSF and others must undertake to ensure that international programs produce the desired results.

IV. Institutional Development

In addition to advancing the career development of U.S. scientists and engineers, another underlying goal of NSF OISE is to enhance the capabilities of the institutions it supports to participate actively and continuously in meaningful international collaborations. Of particular importance is the ability of institutions to sustain, deepen, and expand existing international networks to meet new science and engineering challenges and opportunities around the globe. Both the funding institutions and the institutions that they fund were discussed in terms of how to develop evaluation criteria for tracking the impact of international collaborations on the institutions.

These goals raise the question of what it means to be a globally competent institution. How can a college, university, or other academic or research institution actively support its faculty, staff, and students in participating in a global science and engineering environment?

Discussion

Some institutions already have active international programs; other institutions are just beginning to develop them. There are several components to a mature global-engagement program. These include receiving outside funding from NSF and other agencies that support international research and education; contributing the institution's own human, financial, and infrastructure resources to support international programs; and the encouragement of a global culture both on campus and off by the institution's leadership. At a globally competent institution, international science and engineering experience would be the rule, not the exception. As with individual career development, creating globally competent institutions is a long-term, evolutionary process that will take place over not just years, but decades.

A number of benchmarks can be used to track an institution's progress toward global competence in terms of impacts on institutional policies and practices, outreach activities, and evaluation activities. These include:

Institutional policies and practices:

- Inclusion of global competence issues within an institution's vision, mission, and strategic priorities
- Curriculums with a global perspective and international emphasis
- Courses that integrate language skills with technical science and engineering subjects, including a joint language/science and engineering degree
- Mandatory requirements for students to travel as part of the degree-granting process at all levels
- Providing orientation, mentoring, and other activities for students before, during, and after international programs
- Flexibility to deal with the dynamic environments and different standards and values that are involved in dealing with different cultures
- New centers, multidisciplinary studies, and other academic changes that integrate global activities within the institution
- Backfilling for teachers' positions for those who participate in international projects abroad
- Developing incentives in terms of promotions and tenure that encourage foreign engagement in science and engineering activities

Outreach:

- The ability to develop, sustain, and expand international science and engineering networks and the information technology and other infrastructure needed for such activities
- Cross-institutional programs with foreign counterparts, including shared credit- and degree-granting standards
- Inviting foreign faculty to lecture at the institution
- Outreach to the broader public to explain the impact of international programs on the quality of science and engineering

Monitoring and evaluation:

- Consciously attending to and measuring the impacts of multiplier effects brought about by international science and engineering programs

- Consciously attending to and measuring the impacts of international experiences on career choice and development of its science and engineering faculty and alumni

One major issue underlying the process of attaining the goal of global competence is how NSF programs, such as PIRE and IRFP, affect the ability and motivations of institutions to achieve this goal.

FIGURE III: INSTITUTIONAL LEVEL

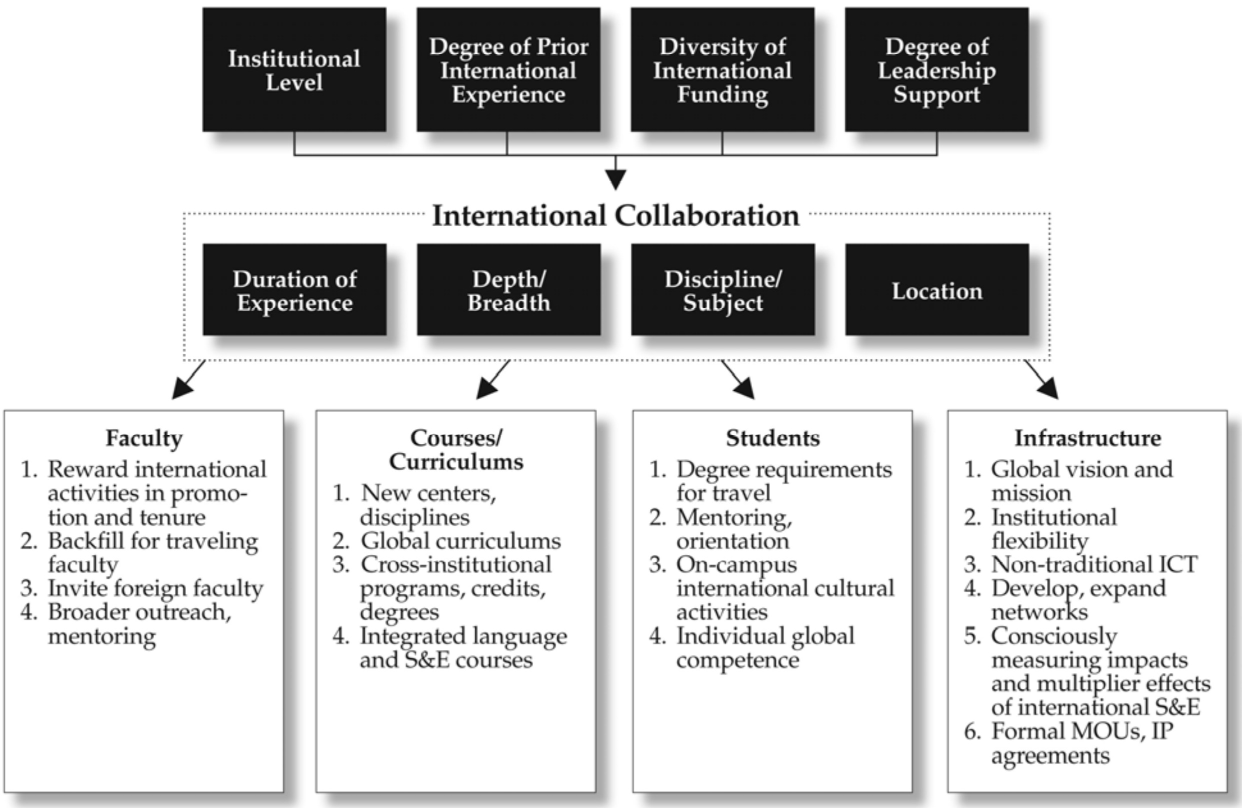

Figure III summarizes the discussion and organized institutional behaviors according to their effects on faculty, students, courses and curriculums, and basic institutional infrastructures.

Methods

Evaluating the degree to which NSF programs directly impact an institution's development is a very complex issue, as many institutions already have international programs. This is especially true of those institutions that are at the forefront of scientific and engineering research. Therefore, workshop participants suggested ways that comparisons could be made between those institutions that receive NSF funding and those that do not. These methods include:

- Social and communication network analyses to examine the degree to which science and engineering networks that resulted from NSF funding were sustained, expanded, and deepened
- Comparative case studies across different projects that would examine similarities and differences in impacts depending on the type of research and where it was conducted

- Focus groups of award recipients that would more clearly identify both specific institutional impacts and institutional barriers to the development of global-engagement programs
- Comparisons across institutions to see which characteristics of a globally engaged institution were enhanced or changed due to specific projects

Issues and Research Agendas

There are several other issues involved in trying to measure the impact of specific NSF programs on the institutions being funded. One such issue is determining the level of the institution to evaluate. Should it be at the level of the entire university or college, or should it be a narrower focus, such as at the school, department, or center level?[11]

Research Area 1: What is the appropriate level of an institution to study in order to measure the impact of a specific program on that institution? When an institution has multiple international projects simultaneously, how can the direct effects of a PIRE or IRFP grant be separated from other factors?

Another question raised regarding institutional change was NSF's motivations in funding specific projects. Will NSF fund the best research within a global environment, or will it act as a catalyst for new institutions to initiate international research projects? Understanding the answer to this question is important for assessing what and how much institutional development occurred.

Research Area 2: Conduct studies of funded projects that examine the effect of the type and the duration of the project on any changes in institutional development at the U.S. institution.

One final problem is that whereas some organizations track international exchanges, there is no group that specifically examines the institutional changes that take place when institutions are involved in international science and engineering projects.

Research Area 3: Conduct research to determine if the region of the world where the research is conducted and field of study affect the kinds of institutional changes that take place at the host U.S. institution. As discussed on page 13, an individual may be influenced by the region of the world and the subject area where research is being discussed. US institutions may also have to make different kinds of arrangements depending upon whether the partnering institution is located in a developing country with currency, visa, and other restrictions or a developed one with strong financial and social support systems. Similarly, institutions will also be influenced on the degree of investment needed depending on the field of study. Institutional arrangements with CERN, for example, would be very different in terms of infrastructure support compared to doing biodiversity field research is Botswana.

[11] Some surveying has been done of the impact of international experiences on students at the institutional level. See, for example, Green, M. F., *et al.*, *Mapping Internationalization on U.S. Campuses: 2008 edition* (Washington, DC: American Council on Education), http://www.acenet.edu/programs/international/mapping2008.

Testable Hypotheses

Any testable hypothesis here assumes the ability to place institutions along a spectrum of international engagement, from those that have no or minimal international involvement to those with extensive international programs. These hypotheses can be used to assess the impact of specific programs, such as IRFP and PIRE, on a given institution. Generally, institutions with extensive international experience:

H1: are better able to develop, sustain, and expand international research and education networks to meet research and education challenges.
H2: have developed more flexible infrastructures to adapt to changing arenas for cutting-edge and high-risk areas of research.
H3: have developed new and nontraditional means to communicate data and research findings of international projects.
H4: are more likely to develop multidisciplinary, multicultural research settings with a global emphasis on their campuses.
H5: are more likely to develop curriculums with an international component and to stress learning foreign cultures and languages.
H6: will have a higher retention rate in STEM fields.
H7: will have a higher percentage of students seeking further education in STEM fields.
H8: will have a higher job-placement rate for their students.

V. Improved Science and Engineering Knowledge Environments

Discussion

Participants in the workshop agreed that assessing the impact of international engagement on the quality of science and engineering research is a very difficult task. There seems to be an underlying assumption that international collaborations such as IRFP and PIRE provide unique enhancements to conducting research and creating educational environments that domestic experiences do not provide. It is also assumed that people seek out these experiences for the unique opportunities they offer in terms of access to new equipment, facilities, expertise, data, and phenomena. Finally, there is an assumption that international collaborations provide opportunities to participate in transformative research, whenever and wherever it may occur.[12] Participants expressed the view that many issues in science and engineering are inherently global issues and cannot be successfully addressed without international collaborations. A globally competent science and engineering community, then, is one that avails itself of opportunities for new discoveries, knowledge, and innovation regardless of location.

The United States is now just one actor in an ever-expanding global research community. Other nations are increasingly funding high-risk, high-payoff research and creating international research consortia. The question for the United States is how to use the nation's resources to ensure a high return on investment in international science and engineering collaborations.

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[12] For an initial discussion of "transformative" research, see National Science Board, *Enhancing Support of Transformative Research at the National Science Foundation* (Arlington, VA: National Science Foundation), May 7, 2007.

Answering that question requires the development of a set of metrics that measure the impact of international collaborations on the quality of science and engineering knowledge and education. What new opportunities does working with foreign colleagues offer U.S. scientists and engineers? What methods can be used to track the unique effects of such collaborations? Do they, in fact, lead to "better" science and engineering? One note: It may require a long timeframe to track the contributions of international collaborations to advancing and changing science and engineering in the United States.

Some of the possible benefits of international collaborations that were discussed are:
- New methods for solving problems
- New approaches to learning
- New equipment, tools, and facilities
- Access to experts
- Access to new information
- Access to phenomena (such as a specific geological site, species, ecology, or weather pattern)
- Creation of new "consumers" or "markets" for knowledge
- Understanding of international standards or culturally laden rules for creating and disseminating knowledge
- New intellectual property, such as foreign patents, licenses, publications, citations, and recognition
- A broader societal, political, or economic impact

Aspects relating to "transformative" science that could be explored might include:
- Peer recognition of cutting-edge or innovative science and engineering
- New subfields within a discipline
- New interdisciplinary foci
- New technologies
- Paradigm shifts
- More and/or better publications in peer-reviewed journals
- Awards and grants from diverse sources

FIGURE IV: KNOWLEDGE ENVIRONMENT LEVEL

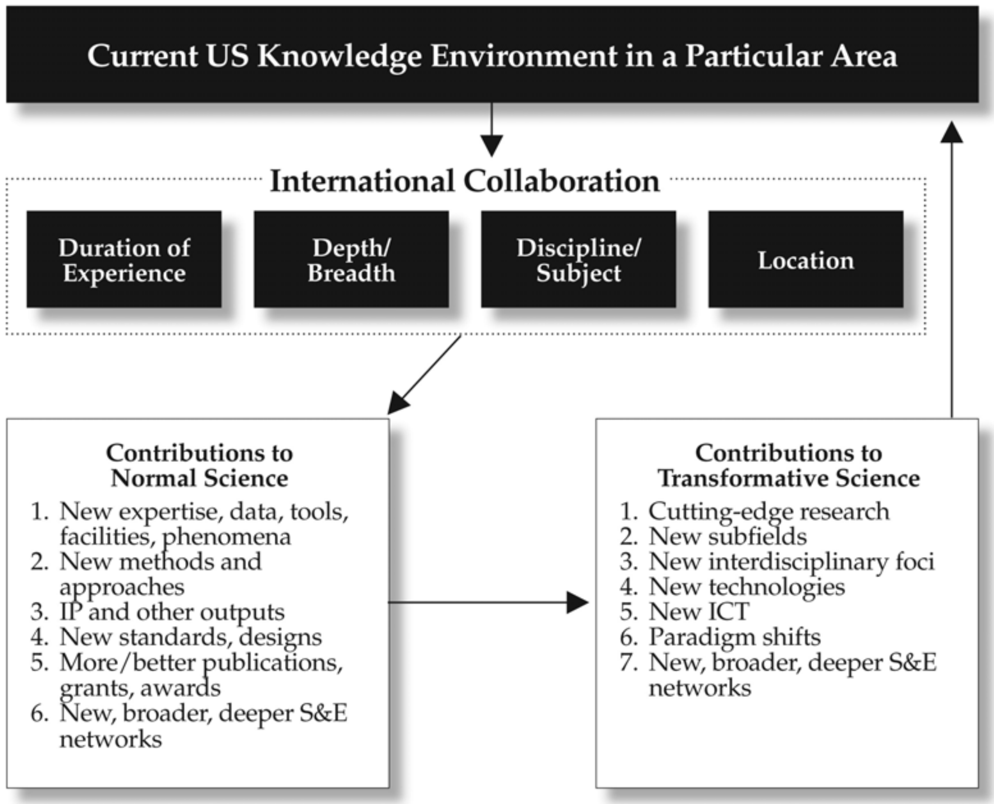

Figure IV provides a conceptual framework for visualizing how international research collaborations contribute to both "normal" and "transformative" science. These contributions contain both science "outputs" and "outcomes," although many of the reports addressing the nation's loss of its competitive edge focus on outputs, such as patents, publications, citations, and relative research and development expenditures.[13] New metrics are needed to measure the effects of U.S. participation in the global science and engineering environment and how that participation affects the quality of the science and engineering that the nation produces.

Methods

Participants suggested several methods for beginning the process of defining and refining aspects of research that are uniquely improved by international collaboration. Preliminary research must be done to develop categories and comparative samples for all types of these collaborations, from single, short-term initial visits to long-term, complex, multidisciplinary, multinational projects. Among the methods suggested are:

- Creation of an initial glossary of evaluation terms so that project evaluators would be operating with the same working definitions
- Interviews with participants in these projects to help answer the question: What in this work could not have happened if it were not international?

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[13] See, for example, National Science Board, *Research and Development: Essential Foundations for U.S. Competitiveness in a Global Economy*, available at http://www.nsf.gov/statistics/nsb0803/start.htm.

- Focus groups of participants in similar and dissimilar projects to focus on specific elements of knowledge outcomes and outputs
- Case studies of specific projects that delineate similarities and differences between program designs and evaluation criteria. It is important to note whether the approach used is inductive or deductive.
- Knowledge-network analysis, including the use of new or nontraditional ways of generating, analyzing, and communicating information

Issues and Research Agendas

The research areas below are intended to start the process of pinpointing the effects of international collaborations on the knowledge environment. Of the three elements of impact, this was the most difficult to address.

Research Area 1: Determine what other agencies, institutions, and programs (both within and outside NSF) have done to evaluate their international science and engineering programs in terms of qualitative and quantitative impacts on discovery and innovation. One possibility is to compare the effects that an international component had within NSF disciplinary programs to those without an international component.

Research Area 2: Clearly identify learning styles, methods, techniques, and problem-solving approaches used outside the United States that might help advance science and engineering research. Which of these might facilitate productive research and lead to new discoveries and innovations?

Research Area 3: Develop prototypes of effective international collaborations at all levels of education and research, and include models of both short-term and long-term projects. This process should include a more detailed examination of what it means to produce better research "outputs" and "outcomes."

Advances in information technology, among other factors, have contributed to the acceleration of new discoveries and the development of new fields and new paradigms. Still, it remains a long-term process for "normal science" to become "transformative science."

Research Area 4: Develop examples of discovery, innovation, and best practices that constitute transformative science, with a focus on those that involved international collaborations. Continue to refine the characteristics of transformative research.

Testable Hypotheses

Compared to research collaborations based in the United States alone, international research collaborations will result in:

H1: access to new information, expertise, tools, facilities, and/or phenomena not found in the United States.

H2: development of new methods, technologies, and approaches to problems.

H3: use of nontraditional and new ways to record and analyze data and communicate research findings.

H4: understanding of new standards, designs, and intellectual-property approaches not found in the United States.