Evaluation of the National Science Foundation's Partnerships for International Research and Education (PIRE) Program

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Executive Summary

At the turn of the century, the National Science Board (NSB) noted that "international boundaries have become considerably less important in structuring the conduct of research and development" in science and engineering fields (S&E) (NSB, 2001). NSB called for increased U.S. government commitment to international S&E research and education, and acknowledged the National Science Foundation's (NSF) leadership role in international S&E research and education activities (NSB, 2001).

NSF's Partnerships in International Research and Education (PIRE) program, which funded its first cohort of projects in 2005, reflects NSF's commitment to international partnerships that can help address critical S&E questions. PIRE funds projects across a broad array of scientific disciplines, in an effort to catalyze long-term, sustainable international partnerships for collaborative research and education that will prepare a cadre of students and early-career researchers for strong leadership and engagement in global science and engineering. Projects support intellectually substantive collaborations between U.S. and foreign researchers in which the international partnership is essential to the research effort.

To better understand the results of its investment in PIRE, NSF contracted with Abt Associates to conduct an evaluation of PIRE. We designed the evaluation to examine the value added when U.S. researchers engage foreign collaborators in shaping and implementing a research agenda through PIRE, specifically to: examine the research produced by projects funded by the PIRE program; measure the research and career outcomes for PIRE participants; explore the perceived effects of PIRE on U.S. and foreign institutions; and document the contributions of PIRE to addressing societal challenges.

The evaluation used existing and primary data sources and descriptive, comparative, and quasi-experimental methods to provide information on outcomes in four key areas:

- **Research outcomes**, including the quantity and quality (i.e., citation impact) of projects' publications, and the percentage of foreign coauthors of these publications;
- **Participant experiences** during and after the project, in particular the nature of project-related activities conducted outside the U.S., collaborations between U.S. and foreign participants both during and subsequent to project participation, and perceived benefits and challenges of PIRE;
- **Role of U.S. institutional policies and practices** surrounding international faculty and student engagement and how these policies and practices affected—or were affected by—the PIRE project; and
- **The potential contributions of PIRE to global societal challenges** that may require international cooperation and coordination.

A central component of the evaluation methodology was the construction of a matched comparison group of NSF-funded projects that were not required to include an international collaboration and that were matched to PIRE projects along a set of key criteria such as award amount and duration.

The evaluation found evidence that PIRE is furthering its objectives: to promote opportunities for U.S. scientists and engineers to engage in international collaborations that enhance research excellence; to provide international research and educational experiences for U.S. students and faculty that will prepare the U.S. science and engineering workforce for global engagement; to strengthen the capacity of U.S. researchers and institutions to build and sustain international

partnerships; and to support partnerships that promote excellence in science, engineering and education.

Specific Findings

Research Outcomes

- Across PIRE journal articles the mean field normalized citation impact (NCI) was 1.8 and the journal NCI was 1.3, reflecting a higher than average impact of these articles relative to the impact of an average journal article (the average field and journal NCI =1).
- There were no statistically significant differences between PIRE and the comparison group in the quantity or quality of research produced. However, PIRE publications had a significantly higher proportion of foreign contributions per journal article measured both as the percentage of foreign institutions per article and the percentage of foreign authors per article.
- At the participant level, there were no significant differences in annual number of post-onset publications between PIRE and comparison Principal Investigators (PIs). However, among postdocs, PIRE participants had, on average, a larger number of post-onset annual publications and these publications had a larger impact. PIRE graduate students also had a higher average number of annual post-award publications than their comparison group peers.
- PIRE PIs' post-onset publications had, on average, a statistically significant higher percentage of non-U.S. institutional affiliations among authors than comparison PIs' post-onset publications.

Participant Experiences

- A greater proportion of PIs, postdoctoral researchers (postdocs), and graduate students in PIRE projects traveled outside the U.S. than participants in comparison projects. For each group, the percent was well over three-fifths among PIRE participants and less than one-quarter among participants in comparison projects. Further, PIRE postdocs and graduate students were more likely than their counterparts in comparison projects to have traveled abroad to conduct research.
- Collaboration with individuals within the U.S. was commonly reported by both PIRE and comparison PIs, postdocs and graduate students, however, PIRE participants were more likely to collaborate with individuals based primarily outside the U.S.
- PIRE PIs and graduate students were more likely to report maintaining these international collaborations than comparison project participants, and commonly these relationships continued to focus on research-related exchanges.
- PIRE postdocs, graduate students, and undergraduates would recommend their peers engage in international research and education because of the benefits associated with working with and learning from international collaborators, cultural and social exchange; enhanced professional networking, and skills and knowledge developed as a researcher. Challenges were not commonly mentioned by respondents.
- Undergraduates who traveled outside the U.S. for PIRE-related research were more likely to have collaborated with foreign faculty, senior- or postdoctoral-level researchers or graduate students rather than with foreign undergraduate students.
- Among undergraduate respondents who traveled outside the U.S. for PIRE-related research, the majority reported that their participation in the project yielded a range of personal benefits. Most commonly reported among these was an understanding of how scientists work on real problems (81 percent), followed by tolerance for obstacles faced in the research process (71 percent), self-confidence in their field of study (69 percent), and clarification of a career path (67 percent).

- Foreign senior investigators (FIs) were less likely than U.S.-based investigators to have traveled internationally during their participation in the PIRE project (48 percent). Among those who traveled abroad, the majority traveled to the U.S. (78 percent).
- Among most FIs, PIRE was not the first international research collaboration with a U.S.-based partner; 82 percent reported working with a U.S.-based individual on research prior to their participation in the PIRE project.

Institutional Context

- Institutional representatives reported that their institutions support international research and education initiatives through a variety of mechanisms, and the majority indicated that policies and practices mostly facilitated graduate and undergraduate participation in international opportunities.
- Institutional representatives found that PIRE aligned well with existing institutional goals for internationalization.

  A greater number of representatives described institutional factors that support undergraduate and graduate student involvement in education and research activities abroad than the number that described barriers to such involvement. However, more representatives mentioned barriers to undergraduate than graduate student participation in international opportunities.
- The majority of administrators responded that PIRE had not resulted in any changes in policies or practices related to undergraduate or graduate education in science, technology, engineering and mathematics (STEM) fields (32 respondents). Among the 14 responses that credited PIRE with effecting change, many indicated that faculty, students and administrators had increased awareness of the value of international research experiences for students.

Societal Impacts

- The three most frequent types of benefits of PIRE described by senior investigators were insights about the natural environment (43 percent of PI responses, 24 percent of FI responses); technological advances that would benefit society (21 percent of PI responses) and PIRE's promotion of cross-cultural exchange (18 percent of PI responses, 32 percent of FI responses). Specific examples included scientific advances in sustainable energy, conservation, understanding climate change, and mitigating hazards from disasters.
- Senior investigators (74 percent of PIs and 78 percent of FIs) noted that their PIRE project has advanced knowledge or led to discoveries that might help address global challenges in health, environmental and other areas in which solutions appear unlikely to emerge from the efforts of one nation acting alone. Asked how their PIRE project could help address these challenges, the mechanism that senior investigators most often mentioned was that PIRE projects leveraged the expertise, resources, and perspectives of a range of international researchers.
- PIs and FIs indicated that findings from their PIRE project could inform policy and planning, provide tools or technologies applicable to global challenges, and provide improved academic models for educating the next generation of researchers. The characteristic of PIRE that lead investigators most commonly mentioned as contributing to addressing global challenges is the ability to leverage the expertise, resources, and perspectives of a range of international researchers.

1. Introduction

At the turn of the century, the National Science Board (NSB) noted that "international boundaries have become considerably less important in structuring the conduct of research and development" in science and engineering (S&E) fields (NSB, 2001). NSB called for increased U.S. government commitment to international S&E research and education, and acknowledged the National Science Foundation's (NSF) leadership role in international S&E research and education activities (NSB, 2001).

The Office of International Science and Engineering (OISE) is NSF's hub for international research opportunities for U.S. scientists and engineers. Operated within OISE, the Partnerships in International Research and Education (PIRE) program, which funded its first cohort of projects in 2005, reflects NSF's commitment to international partnerships that can help address critical S&E questions. Dr. Jon Strauss, a member of the NSB and former Chairman of NSB's Task Force on International Science, cited PIRE in his Congressional testimony as an example of a federal program that fosters innovative research and education by creating cross-border collaborations between U.S. scientists and engineers and international colleagues (Strauss, 2009).

PIRE funds projects across a broad array of scientific disciplines, in an effort to catalyze long-term, sustainable international partnerships for collaborative research and education that will prepare a cadre of students and early-career researchers for strong leadership and engagement in global science and engineering. Projects support intellectually substantive collaborations between U.S. and foreign researchers in which the international partnership is essential to the research effort.

To better understand the results of its investment in PIRE, NSF contracted with Abt Associates to conduct an evaluation of PIRE. We designed the evaluation to examine the value added when U.S. researchers engage foreign collaborators in shaping and implementing a research agenda through PIRE, specifically to:

- Examine the research produced by projects funded by the PIRE program;
- Measure the research and career outcomes for PIRE participants;
- Explore the perceived effects of PIRE on U.S. and foreign institutions; and
- Document the contributions of PIRE to addressing societal challenges.

1.1 Overview of the Study

The evaluation used descriptive and matched comparison analyses to: examine the quantity and quality of research produced by the PIRE program and its participants; measure the research and career outcomes for PIRE participants; and document how PIRE is perceived as changing the way U.S. institutions support international research and educational collaborations. The evaluation was designed to answer the following research questions:

1. What is the quantity and quality of the publications that PIRE projects have produced?
2. How does the quantity and quality of publications produced by PIRE projects—that are required, by definition, to include an international collaboration—compare to the quantity and quality of publications produced by similar NSF-funded projects that do not require an international collaboration?

3. (a) What are the research outcomes for PIRE participants (PIs, postdoctoral researchers and graduate students)?
   (b) What are the program experiences and educational or career outcomes of PIRE PIs, postdoctoral researchers, and graduate and undergraduate student participants?

4. (a) How do the research outcomes for PIRE PIs, postdoctoral researchers, and graduate students compare to those of similar participants in similar NSF-funded projects that do not require an international collaboration?
   (b) How do the program experiences and educational or career outcomes of these PIRE participants compare to similar participants in this comparison group of NSF-funded projects?

5. How do international affairs representatives at PIRE lead PIs' institutions perceive the effects of PIRE on their institutions' policies and practices for supporting international research and educational collaborations?

6. What are the program experiences of foreign senior investigative partners in PIRE and how do they perceive the effects of PIRE on their research and educational practices and those of their institutions?

7. How have PIRE projects contributed to research that may inform global societal challenges?

To answer these questions, the evaluation relied on extant data as well as data collected via surveys designed specifically for this evaluation.

The 59 PIRE projects awarded as of June 2013 were included in the evaluation; NSF had made 12 awards in 2005, 20 in 2007, 15 in 2010 and 12 in 2012. These projects range in size from relatively small, bi-national consortia (e.g., two U.S. and two non-U.S. institutions in one foreign country) to large, multi-national, multi-institutional awards (e.g., a dozen U.S. institutions and 11 non-U.S. institutions representing eight foreign nations). Many are multi-disciplinary, combining, for example, the expertise of econometricians with researchers in fluid dynamics; and, notably, many feature partnerships between academic and industrial or non-profit institutions. The comparison group of projects was constructed from non-PIRE, NSF-funded projects in which an international collaboration is not required. Project-level characteristics of the PIRE projects were used to identify the comparison set of projects.

1.2 Context of the Study

International partnerships in S&E are vital both for understanding critical science and engineering problems, and for advancing discoveries in STEM fields. Through international networks of scientists, resources can be shared and ideas can be developed, tested, and implemented across traditional boundaries (NSB, 2008). Such partnerships can also serve as an important tool in broader international diplomacy efforts. Policymakers also note that including developing nations in collaborative efforts can promote self-sufficiency and encourage international participation beyond S&E research alone (NSB, 2008). These collaborations are complex. Recently, a workshop convened by the U.S. National Academy of Sciences explored the role that culture, administrative, and legal considerations play in international research collaborations (National Research Council, 2014).

> *Science and engineering partnerships can strengthen international relationships and… promote basic scientific values such as accountability, meritocracy, transparency, and objectivity.*
>
> *—NSB, 2008*

NSB recognized this globalization of S&E research and education, in concert with the associated opportunities and challenges for the U.S., in a 2010 publication highlighting globalization trends (NSB, 2010). Further, the potential of science policy and science diplomacy to meet international challenges was highlighted by participants at a workshop convened by the National Research Council to discuss the importance of international science engagement and global science cooperation, and the value of providing opportunities and incentives for U.S. researchers to engage in science in an international arena (National Research Council, 2011).

Engagement in international collaboration is important for U.S. scientists' continued prominence in the global research community and capacity to gain insight into international research advances (NSB, 2001). An active role in international collaborations means that the U.S. can expect to reap benefits not otherwise realized. Recent research found that when U.S. and U.K. researchers engaged in collaborations, the impact of their resulting research significantly increased (as measured by citation rates), especially for U.S. corresponding authors (Luo et al., 2011). Similarly, a recent bibliometric analysis found that papers written by collaborators from multiple countries were cited more than those with authors from a single country (Adams, 2013). Additional benefits of international collaboration may include increased access to physical resources and funding; additional opportunities to benefit from the expertise of collaborators; and access to populations, records, historical materials, and circumstances that provide "natural experiments" (Goodnow, 2008). International collaborations can facilitate expansion of U.S. markets and promote opportunities for international economic exchange (NSB, 2001). Finally, international networks of scientists can more easily share resources and develop, test, and implement ideas across traditional boundaries (NSB, 2008).

Although policy-makers and funding agencies have emphasized the increasing need for U.S. S&E researchers to become globally engaged with their counterparts in other countries, little research has systematically examined the effectiveness of programs explicitly designed to foster international collaboration. Recent studies have, however, documented that participants in programs designed to promote international S&E collaboration report acquisition of knowledge and skills, as well as plans to engage in international collaborations in the future. For example, an evaluation of NSF's International Research Experience Program (IREP), a program for undergraduate and graduate students in five of NSF's Science and Technology Centers, found that students who engaged in an international research experience reported gaining technical, communication, and language skills; developed an appreciation for cultural differences; and felt that their research experience would "create opportunities for future international collaboration" (Spencer, 2008).[1] An evaluation of the Research Internships in Science and Engineering (RISE) program reached similar conclusions. RISE supports undergraduate students' summer internships in German higher education institutions. Researchers found that the majority of RISE student participants developed a greater understanding of German culture, the vast majority reported an increased desire to travel abroad, and about one in four alumni reported returning to Germany at some point after the internship, either to visit or to pursue work/study opportunities (Institute of International Education, 2009). Finally, an evaluation of NSF's International Research and Education in Engineering (IREE) pilot program also found that program participants, especially graduate and postdoctoral students, reported acquiring new research

[1] Begun in 2005 by NSF's Office of Integrative Affairs, the IREP program invited Science and Technology Centers (STCs) to apply for funding to (1) provide students at STCs with an international research experience; (2) establish or strength an international collaboration that would enhance the STC's mission; and (3) provide students a more international experience at their home STC. From the five STCs selected, 36 graduate students and 6 undergraduates traveled to 18 countries, for stays lasting approximately 2 to 3 months. The program ended in 2008.

capabilities, and that they planned to continue collaborations with their international counterparts at the end of their program experience (Flattau et al., 2009).

Some recent evaluations of other NSF programs have employed rigorous quasi-experimental design to construct appropriate comparison groups to investigate the project-related career outcomes for program participants related to a matched comparison using propensity score matching for the IRFP (Martinez, Epstein, et al., 2012) and EAPSI (Martinez, Neishi, et al., 2012b) programs. These studies found that a large proportion of participants continued their international collaborations beyond the fellowship period (for both programs). In comparison to their matched peers who did not receive a fellowship, fellows in both programs produced a larger number of publications co-authored by a collaborator in a foreign institution, although the difference was larger for the IRFP than the EAPSI program, which offers a shorter fellowship period (Martinez et al., 2012a; Martinez et al., 2012b). The proposed evaluation will further our understanding of the role of programs in fostering international research collaborations, and the productivity and influence of such collaborations.

1.3 PIRE Program

The PIRE program makes competitive awards for up to five years of funding to U.S. scientists and engineers who partner with individuals and institutions outside the U.S. to implement a program of research and education. Classes are funded in an alternating two-year, three-year cycle so that two classes of awards are active at any given time. The first class of funded projects was 2005, so their funding ended in 2010 to 2011; the second class was funded two years later, and ended in 2012. However, there have been some no-cost extensions. The third class was funded in 2010 and the fourth in 2012. Across these first four cohorts the program made a total of 59 awards (two of which were renewals of prior PIRE awards). For the first two PIRE competitions, the maximum funding per award was $2.5 million (up to $500,000 per year). These restrictions were removed for the 2010 and 2012 cohorts; the result was an approximate doubling in the amount of per-award funding across the five year grant period. PIRE is one of NSF's "cross-cutting" programs open to researchers within and across any of the disciplines NSF typically funds through its directorates.

PIRE grantee institutions must provide professional development opportunities for U.S.-based researchers, especially those early in their career, including postdoctoral fellows and graduate and undergraduate students. A significant aspect of the opportunity for U.S. participants is on-site research experience at an international laboratory, whether university-, industry- or government-based. PIRE funding can be used to support the costs of U.S.-based participants in the international collaboration; foreign partners contribute funding from their own sources, such as NSF's counterpart agencies in other countries.

For PIRE competitions, NSF has limited the number of proposals that each lead institution can submit. Starting with the second PIRE competition, NSF has used a multi-stage proposal process, in which institutions first submit a preliminary proposal and NSF then selects which of these are invited to submit a full proposal. Up to four external reviewers (identified based on the proposed research areas) rate each PIRE proposal along a 1 (poor) to 5 (excellent) scale; subsequently, reviewers meet in panel to discuss each proposal and recommend to NSF which proposals are "not competitive," "competitive," or "very competitive." NSF program officers make the final award recommendations (subject to the available budget and approval by NSF management). These award recommendations take into account both panel recommendations and other factors such as the geographic and disciplinary balance across the portfolio of awards as well as participation by PIs traditionally under-represented in science and engineering, and institutions from states that typically receive a lower share of NSF funding.

The PIRE program has historically received the largest share of NSF's Office of International Science and Engineering (OISE) programming budget: for example, in FY 2011, the PIRE program had a budget of approximately $18.7 million, representing 38 percent of OISE's total budget (NSF, 2012).[2] The objectives of the PIRE program are to: promote opportunities for U.S. scientists and engineers to engage in international collaborations that enhance research excellence; provide international research and educational experiences for U.S. students and faculty that will prepare the U.S. science and engineering workforce for global engagement; and strengthen the capacity of U.S. researchers and institutions to build and sustain international partnerships.

Notable changes to the program since its inception include changes to scale and scope. In the 2005 and 2007 PIRE cohorts, budgets were capped at $2.5 million, but beginning with the 2010 cohort, these budget limitations were removed (NSF, 2004, 2006, 2007, 2009). In addition, starting with the 2010 cohort, grantees had to propose a project of sufficient scope that its effects would extend beyond an individual PI's research group to the participating U.S. institutions by strengthening institutional capacity for sustained international engagement. For the 2012 PIRE cohort, NSF tailored its first objective (to support international collaborations that enhance research excellence) to focus on international partnerships that would support excellence in science, engineering and education to "inform the societal actions needed for environmental and economic sustainability and sustainable human well-being" (NSF, 2011). NSF also suggested a host of potential partner agencies, both domestic and foreign, that could provide additional funding. Finally, to support foreign investigators from developing countries who were working with U.S. PIRE grantees, NSF partnered with USAID to establish the Partnerships for Enhanced Engagement in Research (PEER) Science program. Together, PIRE and PEER are jointly funding collaborations between U.S. investigators and their counterparts in developing countries where science and engineering capacity is emerging (USAID, 2013).

[2] In comparison to OISE's other investments, PIRE received nearly twice as much as OISE's next largest investment priority, namely a combined $10.6 million allocated to three international programs for students and early career researchers: International Research Experiences for Students (IRES); East Asia and Pacific Summer Institutions (EAPSI); and International Research Fellowship Program (IRFP).

2. Methodology

For the evaluation of PIRE, we used a combination of existing and primary data sources and descriptive, comparative, and quasi-experimental methods to explore four key areas:

1. Research outcomes, including the quantity and quality (i.e., citation impact) of projects' publications and the percentage of foreign coauthors of these publications;
2. Participant experiences in the (PIRE or comparison) project, in particular, the nature of project-related activities conducted outside the U.S., collaborations between U.S. and foreign participants both during and subsequent to project participation, and perceived benefits and challenges of PIRE;
3. The role of U.S. institutional policies and practices surrounding international faculty and student engagement and how these policies and practices affected—or were affected by—the PIRE project; and
4. The potential contributions of PIRE to global societal challenges, in particular, challenges that may require international cooperation and coordination.

A critical part of the evaluation methodology was the construction of a matched comparison group of NSF-funded projects that were not *required* to include an international collaboration and that were matched to PIRE projects along a set of key criteria such as award amount and duration.

This chapter provides a brief overview of the data sources and analytic methods; the construction of the comparison group; survey sampling and response rates; and characteristics of the respondents. Volume 2 of this report provides additional technical detail on the data sources and methods.

2.1 Data Sources

Exhibit 2.1 summarizes the data sources used to address each of the evaluation's research questions. In this section, we briefly describe each of these data sources.

2.1.1 NSF Administrative Data

NSF maintains administrative data at the aggregate level in relational databases for active and expired awards funded under current and former NSF programs and at the individual award level, including proposals and annual and final reports. We used the following NSF administrative data:

- Award databases: To construct the comparison group of non-PIRE projects, we queried NSF award databases to identify candidate comparison projects that met specific criteria such as the funding directorate, award duration, type and grant amount.
- Program solicitations: Having identified candidates, we used program solicitations as well as candidate and PIRE projects' proposals and annual and final reports to perform additional screening against other key matching criteria.
- Annual and final reports: We used annual and final reports to collect characteristics of individual PIRE and comparison projects and participants including PI-reported publications resulting from the project (to inform bibliometric analyses) and the names of project participants and their institutions (to construct survey sampling frames).[3]

[3] Participants listed by a PI in an annual and final report did not necessarily receive funding directly from the PIRE (or comparison) award to the PI(s). For example, graduate students might have had graduate fellowships to support their participation in the project; some undergraduate students had participated as part of a separate, NSF-funded Research Experience for Undergraduates (REU) grant to one or more PIs.

Exhibit 2.1: Research Questions for the Evaluation of NSF's PIRE Program

Research Questions		Project or Participant Level	Survey Data								Analyses
			NSF Administrative Data	PI and co-PI	Postdoc	Graduate Student	Undergraduate	Foreign Investigator	Institutional Representative	Bibliometric Data	
RQ 1.	What is the quantity and quality of the publications that PIRE projects have produced?	Project	X	X						X	Descriptive
RQ 2.	How does the quantity and quality of publications produced by PIRE projects—that are required, by definition, to include an international collaboration—compare to the quantity and quality of publications produced by similar NSF-funded projects that *do not require* an international collaboration?	Project	X							X	Descriptive Comparative
RQ 3.	(a) What are the research outcomes for PIRE PIs, postdoctoral researchers, and graduate students? (b) What are the program experiences and educational or career outcomes of PIRE PIs, postdoctoral researchers, and graduate and undergraduate student participants?	Participant	X	X	X	X	X			X	Descriptive Comparative
RQ 4.	(a) How do the research outcomes for PIRE PIs, postdoctoral researchers, and graduate students compare to those of similar participants in similar NSF-funded projects that *do not require* an international collaboration? (b) How do the program experiences and educational or career outcomes of PIRE participants compare to similar participants in this comparison group?	Participant	X	X	X	X				X	Descriptive Comparative Quasi-experimental
RQ 5.	How do international affairs representatives at PIRE lead PIs' institutions perceive the effects of PIRE on their institutions' policies and practices for supporting international research and educational collaborations?	Project							X		Descriptive
RQ 6.	What are the program experiences of foreign senior investigative partners in PIRE and how do they perceive the effects of PIRE on their research and educational practices and those of their institutions?	Participant	X					X			Descriptive
RQ 7.	How have PIRE projects contributed to research that may inform global societal challenges?	Project		X				X			Descriptive

2.1.2 Survey Data

The study included survey data collection from six respondent groups including current or former participants and administrators from each PIRE project's sponsoring institution who did not participate directly in the projects:

1. Principal and co-Principal Investigators (PIs) in PIRE and comparison projects;
2. Postdoctoral participants (postdocs) in PIRE and comparison projects;
3. Graduate student participants in PIRE and comparison projects;
4. Undergraduate student participants in PIRE projects;
5. Foreign investigators (FIs, i.e., non-U.S. personnel at a level equivalent to a U.S. PI) in PIRE projects; and
6. Administrative representatives from lead PIRE institutions.

Surveys of participants included questions about international travel, types of research and educational activities, and the nature of collaborations with foreign personnel both during and after their participation in the project. We asked PIRE participants about their perception of the benefits and challenges of PIRE, and PIRE PIs and FIs about any potential contributions of the PIRE project to global societal challenges. From administrative representatives, we sought information about institutional policies and practices related to international research and education by faculty and students, how these policies might have facilitated or hindered PIRE activities, and whether the PIRE award had led to any changes in policy or practice.

2.1.3 Bibliometric Data

For each of the 59 PIRE projects and 55 matched comparison projects, bibliographic information for journal articles (i.e., authors, year of publication, article title, journal name and volume) was identified from lists of publications that PIs submitted to NSF in annual reports. These records were then submitted for comparison by Thomson Reuters Scientific staff to records in the Web of Science databases.[4] For each PI-reported record that matched a record in the Web of Science, we asked Thomson Reuters to provide the following data (see Definitions, below):

- Field normalized citation impact (NCI);
- Journal normalized citation impact (NCI);
- Percentage of foreign institutions per article;
- Percentage of foreign authors per article (for articles published 2009 or later);
- Percentage of foreign institutions per article citing PIRE/comparison publications; and
- Percentage of foreign institutions per article cited by PIRE/comparison publication(s).

To investigate research outcomes for individual participants in PIRE and comparison projects, we collected the names of PIRE PIs, postdocs and/or graduate students, and when possible, email addresses and/or a bibliographic record for a selected "seed publication" when no email address was

[4] Although investigators disseminate their research in publications other than peer-reviewed journal articles, we restricted certain analyses of research outcomes to the data available on articles indexed in articles in Thomson Reuters' Web of Science. We discuss the limitations of this restriction in Section 2.6.

available in NSF data. Thomson Reuters attempted to find publications on which participants were authors by matching the participant's name and/or email address and using seed publications when available to disambiguate individuals with identical or similar names. Searches covered publications published in 2000 or later. For each article matched to a participant, Thomson Reuters provided:

- Bibliographic data for each article published in 2000 through 2014 on which the participant was a coauthor;
- Field normalized citation impact (NCI) per year, for each year from the year of publication through 2013;
- Journal normalized citation impact (NCI) as of 2013;
- Percentage of foreign institutions per article; and
- Percentage of foreign authors per article (for articles published 2009 or later).

Analyses of research outcomes for participants were restricted to articles co-authored by a PIRE or comparison project participant (PI, postdoctoral researcher, or graduate student). Articles were classified into two time periods:

- Post-onset: those published in or subsequent to a participant's first year of participation in the PIRE or comparison project (note that these publications could include articles or reviews that did not result directly from the PIRE or comparison project); and
- Pre-onset: those published in the years prior to a participant's first year of participation in the PIRE or comparison project.

For participants who completed a study survey, we used the year in which the respondent reported first working on the project as the "onset" year. For survey non-respondents, we used the award start year. By definition, pre-onset publications did not result from participation in the project; post-onset publications could include both articles that resulted directly from the PIRE project and those that did not. Furthermore, some participants had no pre-onset publications, some had no post-onset publications, and some had neither. (See Volume 2 for results of participant-level matching.)

2.2 Constructing the Counterfactual

For each of the 59 PIRE projects awarded in the 2005, 2007, 2010 and 2012 cohorts, we attempted to identify a similar NSF project that *did not require* an international collaboration, but which was similar to its corresponding PIRE project along other key criteria, following a series of iterative steps. First, we generated candidate awards from the NSF directorates that most closely matched the PIRE award's research area; had an award amount (including any supplementary funding) within 20 percent of the PIRE award's amount; had award start and end dates within 12 months of those of the PIRE award; were funded as continuing grants; and had a duration (including any extensions) within 12 months of the PIRE project's duration (or expected duration for active projects). Next, using award abstracts, proposals, and annual and final reports, we screened each candidate project further to ensure that:

- The project was funded by an NSF program whose primary purpose was research (in contrast to programs focusing on, e.g., training, workforce diversity or equipment or infrastructure).
- The project included at least two different participating institutions (U.S. or foreign).
- The project included at least one graduate student.

- The PI was not a current or former PIRE PI.
- The applicable program solicitation(s) either encouraged applicants to propose an international collaboration; mentioned international collaboration as an option; or did not mention international collaboration at all. [5]
- In addition, we carefully scrutinized the candidate's award's abstract, annual reports, and the CVs of PIs, co-PIs and senior personnel to identify candidate projects where the research area(s) was similar to the PIRE award. To make this determination, we looked for evidence from award abstracts, reports and CVs of senior personnel that the comparison project would require types of knowledge or expertise similar to that required by the PIRE project.

If multiple candidates meeting these criteria were identified, the comparison project that best matched the research focus of the corresponding PIRE award was selected. Finally, if no comparison award was eligible, we attempted to generate new candidates (i.e., the first step) by including additional directorates (if likely to yield viable new candidates) in the search query and:

- Allowing the start and end dates of candidate projects to be within 24 months of the PIRE award (n=10 comparison projects);
- Allowing the duration of candidate projects to be within 24 months of the total PIRE duration (n=7 comparison projects);
- Allowing the candidate award amount to differ by up to 25 percent of the PIRE amount (n=5 comparison projects); and
- Including standard grants as an eligible award type (n=10 comparison projects).

We identified a matching project for 55 of the 59 PIRE projects from a population of approximately 1,500 projects that met step one criteria. Volume 2 summarizes the resulting characteristics of the matched pairs of projects. For four of the PIRE awards, no matched comparison project was found. To protect the identity of the selected comparison projects and personnel, we withheld the award numbers, project titles, institutions, and other identifying characteristics from NSF.[6]

2.3 Sampling, Locating Respondents, and Response Rates

To construct the sampling frames for the online surveys, we obtained names and institutional affiliations of PIRE and comparison project participants from PI-submitted annual reports. For PIRE and comparison projects, we selected a census of PIs postdoctoral researchers, graduate students and foreign investigators identified from annual project reports. We selected a sample of undergraduates proportional to the number of undergraduates participating in each PIRE project, and a convenience sample of institutional administrators from lead PIs' institutions (i.e., from the PIRE award's sponsoring institution).

We refer to all participants who were primarily based at a U.S. institution at the time of participation as "U.S.-based" participants. This designation is unrelated to participants' actual citizenship. Thus, a

[5] An NSF program that disallowed international collaborations would have been ineligible but no such program was encountered.

[6] The purpose of the comparison group was to evaluate PIRE against a counterfactual, not to provide direct comparisons of the outcomes of any individual comparison project to its matched PIRE project. Withholding the comparison project identities helped ensure participation in the evaluation by comparison project personnel.

U.S. postdoctoral participant in PIRE or a comparison project could have been a U.S. citizen or not. Likewise, a "foreign investigator" was defined based on his or her primary institutional affiliation: if this institution was outside the U.S. the individual was a foreign investigator, regardless of actual citizenship. (Note that project participants were not necessarily receiving funding directly from the project in which they participated.)

2.3.1 Respondent Group

Individual participants were classified based on their "status" (as faculty, postdoc, or student) when they first participated in the project. We based this classification on their reported status in the earliest annual report in which they were listed: for example, if an individual participated as both a postdoctoral researcher and a graduate student, the individual was classified as a graduate student participant. During survey fielding, we reclassified individuals as needed based on screening questions in the survey. For example, two individuals identified as graduate student PIRE participants in our sample indicated that they had been undergraduates when they first participated in the project. We reclassified these individuals and invited each to complete the PIRE undergraduate survey. We excluded respondents whom we determined were ineligible for the survey (e.g., individuals who indicated that they were not official co-PIs or foreign graduate students).

2.3.2 Locating Respondents

We supplemented existing contact information from annual reports with information publicly available via internet searches (e.g., departmental web pages) and by asking PIs to provide the most recent email address (or other contact information) for both current and former participants. To identify institutional administrators, we asked lead PIs to nominate up to two appropriate administrative officials who would be familiar with the PIRE award (e.g., a director of international affairs, or vice provost for research); searched institutional web sites for names of officials in administrative offices; and allowed administrators invited to complete a survey to indicate an alternative official who might be better suited to complete the survey.

2.3.3 Response Rates

Exhibit 2.2 summarizes the response rates for each survey. We sent an emailed survey invitation and link to each targeted sample member and six reminder emails. For PIs and FIs, we also mailed letters to institutional addresses to encourage survey participation. During survey fielding, we determined that some sample members were ineligible for the survey; we excluded them from response rate calculation and analyses. (Misclassified respondents were invited to participate in the survey corresponding to their correct respondent group.)

Exhibit 2.2: Sample Size and Response Rates for Study Surveys

Respondent Group	PIRE		Comparison	
	Sample Size	Response Rate	Sample Size	Response Rate
Lead PIs	59	71%	55	62%
All PIs	293	58%	205	56%
Postdocs	211	55%	235	50%
Graduate Students	531	54%	705	47%
Undergraduates	735	40%	NA	NA
Foreign Investigators	251	47%	NA	NA
Institutional Administrators	59	78%	NA	NA

Sources: Annual reports submitted by PIs to NSF; study surveys.

Notes:

Sample size is equal to the number of eligible respondents. The response rate indicates the percentage of this sample that completed a survey. Because it is impossible to verify that the intended recipient has received an emailed survey invitation, response rates include sample members who may not have received the survey invitation.

Lead PIs and institutional administrators for PIRE projects had the highest response rates (71 and 78 percent) and undergraduates had the lowest (we had particular difficulty finding a valid email address for undergraduates). In general, response rates for comparison respondent groups were lower than for the corresponding PIRE groups.

2.4 Respondent Characteristics[7]

Roughly one-quarter to one-third of PIRE and comparison PIs and post-docs were female. Among graduate and undergraduate students, 40 to 45 percent were female. Only 19 percent of FIs were female. Less than one-fifth were members of racial or ethnic groups traditionally under-represented in science and engineering.

The majority of participants reported that their primary field of research (or the field in which they were pursuing an undergraduate or graduate degree) was in the sciences, mathematics or engineering. Notably, 24 percent of PIRE PIs reported that their primary research field was in engineering and 14 percent that it was in the social sciences; in both cases, the percentage was twice that of comparison PIs. A greater proportion of comparison PIs were in the natural sciences or mathematics.

On average, postdoctoral researchers reported participating for just under two years in the project (PIRE or comparison). Undergraduate and foreign senior investigators each reported an average of nine months of participation. Graduate students took part in a PIRE project for an average of 31 months (just over 2.5 years), whereas graduate students in comparison projects reported an average duration of more than 35 months (just under 3 years).

[7] We did not conduct statistical tests of significance for apparent differences between PIRE and comparison group characteristics reported here.

Exhibit 2.3: Characteristics of Participants

	PIs		Postdocs		Graduate Students		Under-graduates	FIs
	PIRE	COMP	PIRE	COMP	PIRE	COMP	PIRE	PIRE
Demographic characteristics								
Female[1]	23%	25%	36%	27%	41%	40%	45%	19%
Member of minority group traditionally under-represented (URM) in S&E[2]	10%	16%	17%	15%	17%	16%	20%	NA
Primary field of research/field of study[3]								
Natural Sciences or Mathematics	61%	81%	82%	83%	60%	70%	65%	77%
Engineering	24%	12%	12%	15%	31%	22%	24%	18%
Social Sciences	14%	7%	6%	<1%	9%	8%	4%	5%
Health	<1%	0%	0%	<1%	0%	<1%	2%	0%
Humanities, Arts, Business/Management or Other	NA	NA	NA	NA	NA	NA	4%	NA
Average duration, in months, of participation in the project (standard deviation)[4]	12 (11.0)	12 (10.2)	23 (13.2)	22 (13.1)	31 (20.4)	35 (18.8)	9 (11.9)	9 (11.5)

Sources:
Percent female, Percent URM: PI survey, Items H3-H5; Postdoc survey, Items F3-F5, Graduate survey, Items F3-F5; Undergraduate Survey, Items G3-G5; FI Survey, Item G4 (percent female).
Primary research discipline/field of study: PI survey, Item E3; Postdoc survey, Item D2; FI Survey, Item A12. Primary field of graduate degree: Graduate survey, Item A3; Primary major field for bachelor's degree: Undergraduate survey, Item A7.
Duration: PI survey, Items A3-A7; Postdoc survey: Items C1, C1a, C1b; Graduate student survey, Items C1, C1a, C1b; Undergraduate survey: Items B7, B7a, B7b; FI survey: Items A3-A7.
Notes:

1 Percent female: PIs: PIRE N=163, missing=7; Comparison N=112, missing=2. Postdocs: PIRE N=113, missing=9; Comparison N=113, missing=8 . Graduate students: PIRE N=278, missing =7; Comparison N=323, missing=8. Undergraduates: N=286, missing=4; FIs: N=104, missing=18.

2 Percent URM: Survey respondents who reported race/ethnicity as Black/African-American, Hispanic, American Indian/Alaska Native, Native Hawaiian/other Pacific Islander were classified as traditionally under-represented minorities (URM). PIs: PIRE N=162, missing=8, Comparison N=112, missing=2; Postdocs PIRE N=111, missing=11, Comparison N=112, missing=9; Graduate students: PIRE N=278, missing=7, Comparison N=323, missing=8. Undergraduates: N=283, missing=7.

3 Primary research discipline: PIs: PIRE N=170, Comparison N=114; Postdocs: PIRE N=114, missing=8, Comparison N=113, missing=8; FIs: N=121, missing=1. Primary field of study for graduate degree: Graduate students: PIRE N=285, Comparison N=331; Primary major field for bachelor's degree: Undergraduates: N=246. A list of disciplines classified as natural sciences, mathematics, engineering, social sciences and health is in Volume 3 of the report. Only undergraduates had the option to indicate that their major field for their bachelor's degree was in Humanities or Arts or in Business or Management; PIs, FIs, postdocs and graduate students could select from natural sciences or mathematics; engineering; social sciences; or health.

4 Duration, PIs: PIRE N=168, missing=2, Comparison N=114; Postdocs: PIRE N=107, missing=15, Comparison N=108, missing=13; Graduate students: PIRE N=275, missing=10, Comparison N=327, missing=4. Undergraduates: N=207, missing=2; FIs: N=121, missing=1. For PIs and FIs, the duration in months was calculated by multiplying the percent time a PI reported spending on the project by the elapsed time between the reported first date of participation and the date on which they last contributed to the project. In active projects, we set the date of last contribution to the project for participants who reported that they were still contributing to the project to the survey reference date.

2.5 Analysis Methods

2.5.1 Analyses of Research Outcomes (Chapter 3)

Analyses of publication outcomes (quality, quantity, and international collaborations) were conducted at the project level (i.e., for projects as a whole including all journal articles reported by the PI as resulting from the project), and at the participant level (i.e., analyzed separately for each of three types of project participants: PIs, post-docs, and graduate students). At the project and participant levels, analyses included: (a) a descriptive analysis of outcomes for PIRE projects (or PIRE participants), and (b) comparative descriptive analyses of the differences between PIRE and comparison projects (or between PIRE and comparison group participants). At the participant level, analyses also include (c) an impact analysis comparing outcomes for PIRE and comparison participants.

Descriptive analyses

The descriptive analyses show the distributions of key publication outcomes across PIRE projects (Research Question 1) or PIRE participants (Research Question 3). The descriptive statistics reported include the mean, standard deviation, minimum, maximum and quartiles (25^{th} percentile, median, 75^{th} percentile) for each outcome. Where informative, we also include graphical displays that provide a more fine-grained illustration of these distributions than indicated by quartiles. At the project level, these analyses included all PIRE projects where at least one publication record was identified by Thomson Reuters' Web of Science (51 PIRE projects). At the participant level, these analyses included all PIs, postdocs and graduate students who had at least one post-onset publication identified in the Web of Science (265 PIs, 135 postdocs and 181 graduate students).[8] (Note that articles published post-onset may have resulted from activities other than participation in the PIRE project.)

Descriptive comparative analyses

We also include descriptive comparative analyses to show *differences* in research outcomes for PIRE and comparison projects (Research Question 2) and participants (Research Question 4). A comparison project was identified for 55 of the 59 PIRE projects. However, at the project level, these descriptive comparative analyses included only the subset of 45 matched pairs of projects *where each project within each pair had at least one journal article identified in the Web of Science*. Ordinary least-squares (OLS) regression analyses included the outcome as the dependent variable; independent variables included a group indicator (i.e., 1=a PIRE project; 0=a comparison project) and dummy variables to account for the matched pairs of projects.

At the participant level, we conducted a descriptive comparative analysis of the percentage of foreign affiliations among co-authors of participants' post-onset publications. These analyses included only participants from within matched project pairs *who had at least one post-onset and at least one pre-onset publication indexed in the Web of Science*. The analysis used ordinary least squares regression models that included a group indicator (PIRE=1, COMPARISON=0) and dummy variables representing the matched pairs of projects; these participant-level analyses also controlled for the pre-onset measure of the outcome (e.g., percentage of foreign institutions per publication per participant).

Impact analyses of participant-level outcomes

To estimate the impact of PIRE on participant-level research outcomes (Research Question 4), we used a quasi-experimental, comparative interrupted time series (CITS) design to compare outcomes of

[8] Post-onset publications are those published in the year of or after the start of participation in the project; see Definitions. See Volume 2 for further details on matching of project publications and project participant names to the Web of Science records.

PIRE participants to those of matched participants from the group of comparison projects (see Volume 2 for technical details). We applied this method to test the impact of PIRE on two research outcomes—the number of publications and the field normalized citation impact (field NCI) for post-onset publications.[9] We conducted separate analyses for PIs, postdoctoral researchers and graduate students. For each group, we matched PIRE participants to corresponding participants from comparison group projects on their first year of project participation and attempted to limit the analysis sample to participants who were statistically equivalent on both number of publications and average field NCI per year for publications prior to the onset of project participation.[10] The CITS analysis for each group included four years of pre-onset data and multiple years of post-onset data.

A CITS analysis is similar to a difference-in-difference model with data at multiple "pre-treatment" and "post-treatment" time points. The analysis calculates the difference between (a) the pre-post difference in the outcome measure for PIRE participants and (b) the pre-post difference in the outcome measure for comparison project participants.

Data from participants in comparison projects—who were producing publications in the same years as their PIRE counterparts—acts as a control for factors external to PIRE that could have affected publication productivity or citation impacts (e.g., macroeconomic trends affecting research and development efforts in general, independent of any effects of PIRE on research outcomes). Data from participants prior to the onset of their participation in a project (PIRE or comparison), acts as a control for factors related to time-invariant differences between participants that could affect the research outcomes independent of the effects of PIRE participation on these same outcomes (e.g., differences between participants' research disciplines are well known to affect publication trends and it is reasonable to assume that the effect of research discipline is stable across time). By controlling for two potential sources of observed differences in research outcomes that are independent of PIRE, the CITS method reduces the number of plausible alternative explanations for observed differences, and increases confidence that differences likely result from the effect of PIRE.

We note three important caveats about the analyses of research outcomes:

- The size of analysis samples differs for the descriptive, comparative and impact analyses. That is, at the project level, as a result of taking into account the matched project pairs and restricting the sample to projects with at least one publication indexed in the Web of Science, the sample for comparative analyses includes just the 45 matched pairs of PIRE and comparison projects. At the participant level, comparative samples include only participants within matched pairs who had at least one pre-onset and one post-onset publication indexed in the Web of Science (PIs: PIRE N=204; comparison N=168 in 54 matched project pairs; postdocs: PIRE N=48; comparison N=55 in 34 matched project pairs; graduate students: PIRE N=36; comparison N=56 in 45 matched project pairs).[11]

[9] Post-onset articles are those published after the participant had begun participating in the PIRE or comparison project. Pre-onset articles are those published prior to this onset of participation. (See Section 2.1.3: Data Sources, Bibliometric Data.)

[10] We defined baseline equivalence for annual number of publications and field NCI per year as a standardized difference in pre-onset means between the two groups of less than .25 standard deviations. We established equivalence for all respondent groups on each measure with one exception: the PI analysis sample was not equivalent for number of pre-onset publications per year, but was equivalent on the pre-onset mean field NCI per year.

[11] A pair of matched projects from the total of 55 was dropped if there were no respondents with pre- and post-onset publications in one or both of the members of a pair of projects. For example, if a PIRE project

- Unlike the quasi-experimental impact analyses, the descriptive comparative analyses do not allow any inferences about the underlying causes of observed differences in research outcomes: that is, from these analyses, we cannot conclude that the differences in research outcomes were caused by the PIRE program.
- In addition, because the impact analyses are quasi-experimental rather than experimental, attributions of differences in research outcomes to the PIRE program must acknowledge the possibility of alternative explanations. We discuss this third caveat in more detail below (see Section 2.6: Limitations).

2.5.2 Analyses of Participant Experiences (Chapter 4)

We conducted both descriptive and descriptive comparative analyses of primary survey data. Descriptive analyses included both quantitative and qualitative methods. For continuous variables we report means, standard deviations and, where informative, other characteristics of variation around the mean such as the median, minimum, maximum and inter-quartile values. For categorical and dichotomous variables, we report frequencies in terms of number and percentages. Missing data were excluded from these calculations. Where possible, we re-coded responses to "other, specify" response options into an existing response provided; if the response did not fit an existing response option we counted it as "other." For open-ended survey items, we used *NVivo* software to explore similarities and differences across respondents and identify and summarize key themes that emerged from these data. We identified emergent themes inductively using an iterative coding approach in which we generated potential themes from an initial review of a subset of responses and then applied these themes to the entire set of responses, iterating between generating themes and coding responses against those themes.

To compare the experiences of PIRE and comparison PIs, postdocs, and graduate student participants, we also conducted descriptive comparative analyses for selected outcomes. These analyses used ordinary least squares (OLS) regression analyses with the outcome as the dependent variable; independent variables included a group indicator (i.e., 1=a PIRE project; 0=a comparison project) and dummy variables to account for the matched pairs of projects (N=55). Because we matched projects on criteria such as award amount, duration, award start and end years, and research area(s), controlling for these pairs effectively controls for these matching criteria.

Although these comparative analyses provide a test of the statistical significance of differences between PIRE and comparison participants' outcomes, these analyses do not support inferences about the underlying cause of these differences. Differences may or may not have resulted from participation in the PIRE program or the programs represented by the comparison group.

2.5.3 Analyses of Institutional Policies and Practices for International Research and Education (Chapter 5)

Analyses of the PIRE institutional administrator survey data (as well as some data collected from PIs about their institutions) include both quantitative and qualitative descriptive analyses like those described above for participant experiences. Where useful, we include direct quotations to illustrate key themes. (We have deliberately censored the names of individuals, institutions, and geographic locations to protect the anonymity of respondents and their institutions.)

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had one postdoc who had pre and post onset publications but the matched comparison project had a postdoc with no pre-onset publications, the pair of projects was dropped from the analysis for postdocs.

2.5.4 Analyses of Societal Impacts (Chapter 6)

To summarize data bearing on the potential contributions of PIRE to global societal challenges, we conducted primarily qualitative data analyses of open-ended survey responses to illuminate key themes as well as variation or notable divergence from these themes. We include direct quotations (with censoring to protect anonymity of respondents) where meaningful.

2.6 Limitations

Below, we describe three key limitations of the study and how these suggest caution in interpretation of the study findings. These key limitations are:

1. In a non-experimental study like this one, there is a risk that omitted variables, rather than the PIRE program itself, may be responsible for any observed differences between PIRE and non-PIRE outcomes.

2. The sole source of participant information – annual and final reports to NSF – often lacked contact information, and in some instances names of participants were also missing, particularly the names of participants from institutions other than the lead PI's.

3. We obtained lower than expected survey response rates and did not have data needed for a non-response bias analysis or weighting of the survey data for non-response.

4. Our methods for assessing research outcomes based on bibliometric data are limited by the following:

    a. We could only obtain bibliometric data for peer-reviewed journal articles;

    b. We used citation indices as one indicator of the "quality" of publications, despite the fact that citation indices are influenced by factors other than the underlying quality of the research; and

    c. The bibliometric data matching procedures we used likely reflect some omissions or inaccuracies in the reference data listed in PIs' annual reports and the fact that more recent PIRE and comparison projects have had less time to accrue publications and citations.

2.6.1 Non-Experimental Comparison Group

The most rigorous estimates of the impact of PIRE on outcomes of interest would come from a study in which the PIRE and comparison group were determined using random assignment. Because award decisions for past cohorts of the program had already been made when the evaluation was planned, random assignment of applicants to treatment (receive a PIRE award) or control (do not receive a PIRE award) was infeasible. Even if the evaluation had been conducted prospectively (i.e., prior to award decisions), it is unlikely that random assignment would have been feasible given NSF's proposal and award procedures.[12] We also determined that the most rigorous quasi-experimental designs were not possible (e.g., a regression discontinuity design, or propensity score matching of awarded to non-awarded PIRE proposals based on pre-award characteristics).[13] Instead, we

[12] Even in merit-based programs, it is possible to conduct a random assignment study if there are a greater number of equally qualified applicants than available funding or award openings. However, NSF's proposal review includes consideration of both intellectual merit and broader impacts, and program officers exercise discretion in making awards to meet other foundation-wide objectives (e.g., such as increasing the representation of awards to under-represented minorities or institutions).

[13] Further discussion of the rationale for the study design is included in Volume 2.

constructed the strongest possible non-experimental comparison group using available data sources (i.e., other NSF awards), and matching a comparison project to each PIRE project as closely as possible across criteria thought to most strongly influence project outcomes (e.g., award amount, duration, research field(s), year of award onset). Nevertheless, as with any non-experimental comparison group, the possibility remains that we did not take into account some other set of factors that cause the outcomes of PIRE and the comparison group to differ. This risk (sometimes called "omitted variables bias") means that the majority of our reported findings do not rule out alternative explanations for differences between PIRE and comparison group performance. As a result, we urge caution in interpreting differences between PIRE and the comparison group. It is possible, for example, that pre-existing differences in the PIs and other individuals in the PIRE and comparison group are responsible for differences in the project- and participant-level outcomes, and that these differences may have occurred even in the absence of the PIRE program.

One exception to this caveat is our analysis of the research outcomes of PIRE participants relative to those of comparison group participants. This analysis used a robust quasi-experimental comparative interrupted time series design. These analyses not only take advantage of the project-level matching of comparison and PIRE projects, but also matched individual participants on pre-project characteristics associated with the outcomes.

2.6.2 Incomplete Participant Information in Annual Reports

The primary—and to our knowledge, only—sources of the names of individual participants in PIRE and comparison projects were annual and final reports that PIs submit to NSF. However, for many such participants, these reports lacked contact information necessary to invite the participant to complete a study survey. In addition, without an email address for a participant, it was difficult to match participant names to publications in the Web of Science on which they were potential co-authors. Especially for researchers with common names, disambiguating multiple authors with the same (or highly similar) name becomes difficult without a unique identifier such as an email address. We attempted to collect email addresses by conducting internet searches and by asking co-PIs to provide contact information for participants listed in the annual reports. Several also supplied the names (and when possible, an email address) of additional participants who had been omitted from these reports. The lack of participant contact information was especially serious for undergraduates: of 735 undergraduate participants in our survey sample, we were unable to locate an email address for 196 (more than 25 percent).

2.6.3 Survey Response Rates

Despite providing multiple prompts to encourage survey participation, we obtained lower than expected response rates for postdoctoral researchers, graduate students, FIs and undergraduates. In particular, just 40 percent of the undergraduate sample completed a study survey. Part of the reason for lower-than-expected response rates stemmed from the fact that NSF lacks a systematic mechanism for collecting program participants' contact information other than annual project reports, and no mechanism for keeping track of program "alumni" whose participation in a program has ended. Although former graduate students or postdocs often remain in academia and can be found via their affiliation with a university, undergraduates and other former participants in NSF programs who go on to jobs in industry are difficult to locate. As a result, the survey responses we received from former participants likely over-represent those who remained in academia (e.g., undergraduates who enrolled in graduate school) and under-represent participants now working in industry. Moreover, because we could not identify data on the characteristics of sample members (e.g., demographic characteristics) we were unable to perform a non-response bias analysis. It is possible that survey respondents differ

systematically from non-respondents and we suggest caution in interpreting the survey findings from these groups.

2.6.4 Methods For Assessing Research Outcomes

A key objective of the evaluation was to compare the quality of research produced by PIRE to the quality of research produced by the comparison group. We used measures of citation impact to represent the quality of research in spite of the well-known limitations of citation impacts as a measure of quality (Bornmann et al., 2008; Leydesdorff, 2008; Moed, 2005; Pendlebury, 2009). Nevertheless, given the sheer number of publications included in the evaluation, we judged that an alternative, such as expert review of publication quality, was not feasible. Instead, we have attempted to follow the principles of the "Leiden Manifesto" (Hicks et al., 2015) by including additional measures that align with the PIRE program's key goals to stimulate research collaboration between U.S.- and non-U.S.-based researchers (e.g., the percentage of foreign co-authors per paper); by using normalized citation indices to account for variation across research disciplines in publication and citation trends; and by clearly describing the analytic procedures and their limitations.

Investigators disseminate their research in a variety of forms and venues, including book chapters, conference papers, open-access journals and repositories (e.g., *arXiv*), and peer-reviewed journals. However, because citation data were not readily available for other types of publications, we limited our analyses of research outcomes in this study to articles in peer-reviewed journals that are indexed in Thomson Reuters' Web of Science. Restricting the data to peer-reviewed journal articles may be particularly problematic for disciplines such as computer science or mathematics, in which researchers rely less heavily on journal articles than on conference proceedings and online repositories. We note, however, that among the 59 PIRE projects and 55 comparison projects, only 6 projects in the evaluation (3 PIRE, 3 comparison) were CISE-related, and 2 (PIRE) were mathematics-related. Nevertheless, some projects never intended to produce peer-reviewed journal articles, but rather, focused on contributing other resources such as data repositories, software, and similar products for dissemination; for these projects, our focus on journal articles excludes their primary research products.

We also excluded articles in journals not indexed in the Web of Science for which citation data may have been available elsewhere (e.g., from Scopus or Google Scholar). Thomson Reuters was unable to match a small proportion of journal articles listed in PIs' annual reports to existing records in the Web of Science despite indexing the journal in which the article was published. (See Volume 2 for more detail regarding the bibliometric data matching.) In particular, among the more recently awarded PIRE and comparison group projects (i.e., those with award onset in 2012 or later), annual reports were more likely to have fewer publications (of any kind) listed, and those identified in the Web of Science had had less time to accrue citations.

Because of these limitations, we encourage caution when interpreting the findings reported for research outcomes based on the available bibliometric data. However, we note that we found no statistically significant differences between the proportion of PIRE and comparison projects' publications that were matched to the Web of Science.

3. Research Outcomes

PIRE seeks to enable research at the leading edge of science and recognizes the value of international partnerships in addressing critical science and engineering questions. Thus, a primary focus of the evaluation was to explore the research outcomes of PIRE projects and to understand how these outcomes compared to research outcomes of non-PIRE NSF projects. In this chapter we describe the quantity and quality of research produced by PIRE projects (and PIRE participants), as well as measures of international engagement in this research. We also examine whether and how these research outcomes differ from those of a matched comparison group of projects and for matched participants within the matched pairs of projects. Specifically, the findings address the following research questions:

- RQ 1. What is the quantity and quality of the publications that PIRE projects have produced?
- RQ 2. How does the quantity and quality of publications produced by PIRE projects—that are required, by definition, to include an international collaboration—compare to the quantity and quality of publications produced by similar NSF-funded projects that do not require an international collaboration?
- RQ 3a. What are the research outcomes for PIRE participants (PIs, postdoctoral researchers and graduate students)?
- RQ 4a. How do the research outcomes for PIRE PIs, postdoctoral researchers, and graduate students compare to those of similar participant groups in similar NSF-funded projects that do not require an international collaboration?

At the project level, we report both descriptive analyses (Research Question 1) and comparative analyses (Research Question 2) that take into account the one-to-one matching of PIRE and comparison projects. At the participant level, we report descriptive findings for research produced by PIRE PIs, postdocs and graduate students from the onset of their participation in the project forward (i.e., post-onset publications); we present a descriptive comparative analysis of the contributions of foreign co-authors to PIRE and comparison project participants' post-onset publications, taking into account matched pairs of projects; and finally, we present impact analyses of the effects of PIRE on PIs,' postdocs,' and graduate students' post-onset publications. These impact analyses use data from participants' pre-onset and post-onset periods to estimate the difference in the pre-post differences in research productivity and quality between these three groups of PIRE and comparison participants.

Specific research-related measures we report include the:

- Total and average annual number of peer-reviewed journal articles published;
- Citation impact measures of these articles (field NCI and journal NCI);
- Relative contribution of authors based at foreign institutions to these articles;
- Extent of foreign co-authorship in the research that is *cited by* PIRE and comparison projects' publications; and
- Extent of foreign co-authorship of research that *cites* PIRE and comparison projects' publications.

Findings in this chapter are drawn from annual reports submitted by projects to NSF and the Thomson Reuters' Web of Science database. We describe the data sources and the analysis methods used more fully in Chapter 2 (with supplementary technical details in Volume 2 of the report).

Key findings include:

- Across PIRE projects, there is variation in research productivity. Six projects reported no publications and two others had no publications indexed in the Web of Science. Across the 51 PIRE projects with publications recorded in the Web of Science, the average number of publications was 24.
- Across PIRE journal articles the mean field NCI was 1.8 and the journal NCI was 1.3, reflecting a higher than average impact of these articles relative to the impact of an average journal article (the average for each NCI measure=1).
- There were no statistically significant differences between PIRE and the comparison group in the quantity or quality of research produced. However, PIRE publications had a significantly higher proportion of foreign contributions per journal article measured both as the percentage of foreign institutions per article and the percentage of foreign authors per article.
- At the participant level, there were no significant differences in annual number of post-onset publications between PIRE and comparison PIs. However, among postdocs, PIRE participants had, on average, a larger number of post-onset annual publications and these publications had a larger impact. PIRE graduate students also had a higher average number of annual post-award publications than their comparison group peers.
- PIRE PIs' post-onset publications had, on average, a statistically significant higher percentage of non-U.S. institutional affiliations among authors than comparison PIs' post-onset publications.

3.1 PIRE Projects' Publications

Findings used references submitted by PIs in annual and final reports. As described in Chapter 2, we excluded publications other than journal articles from these analyses.

3.1.1 Number and Quality of Publications

PIRE projects varied considerably in terms of research productivity, as measured by their output of journal articles.[14] PIRE-supported research resulted in a project average of 24 articles but the mean is skewed by the relatively small number of projects with much higher numbers of articles (the median is 22 articles).

The average impact of research published by PIRE was larger than average, measured by either field or journal NCI. Exhibit 3.1 indicates that the distribution of the citation impacts is skewed; for example, the median field NCI across PIRE journal articles is 1.09, but the 95th percentile is 5.78. Thus, although half of these publications have an NCI higher than 1.09, 5 percent have a field NCI that is more than five times that of the median.

[14] For some PIRE projects, particularly those involving research related to computer and information sciences, using journal articles to examining research output underestimates their contributions, since these projects did not plan to publish research reports in journals, but rather were designed to produce resources such as data repositories and software accessible to a broad community of researchers. Moreover, not all PIRE projects intended to produce journal articles, but rather, set out to establish resources available to the broader research community (e.g., data repositories).

Exhibit 3.1: Key Bibliometric Indicators for Articles Produced by PIRE Projects (N = 1,399 articles)

Bibliometric Indicator	N of Articles with Data[a]	Minimum	Q1[b]	Median[b]	Q3[b]	95th Percentile[b]	Maximum	Mean	SD[c]
Number of articles per project[d]	1,399	0	2	22	42	70	88	23.7	23.5
Field NCI	1,339	0.00	0.35	1.09	2.19	5.78	45.05	1.82	3.04
Journal NCI	1,368	0.00	0.27	0.80	1.74	4.11	40.67	1.30	1.89
Percentage of authors at non-U.S. institutions	1,153	0.0%	0.0%	28.6%	60.0%	100.0%	100.0%	32.7%	32.5%
Percentage of non-U.S. institutions	1,398	0.0%	0.0%	43.7%	61.2%	100.0%	100.0%	36.7%	31.5%

Sources: Annual reports submitted by PIs to NSF; Thomson Reuters' Web of Science

Notes:

[a] Of the 1,399 articles identified in the Web of Science, field NCI data were available for 96 percent, journal NCI for 98 percent, percentage of foreign authors for 82 percent (unique author affiliations are only available in the Web of Science for articles published in 2009 or later), and percentage of foreign institutions for nearly 100 percent.

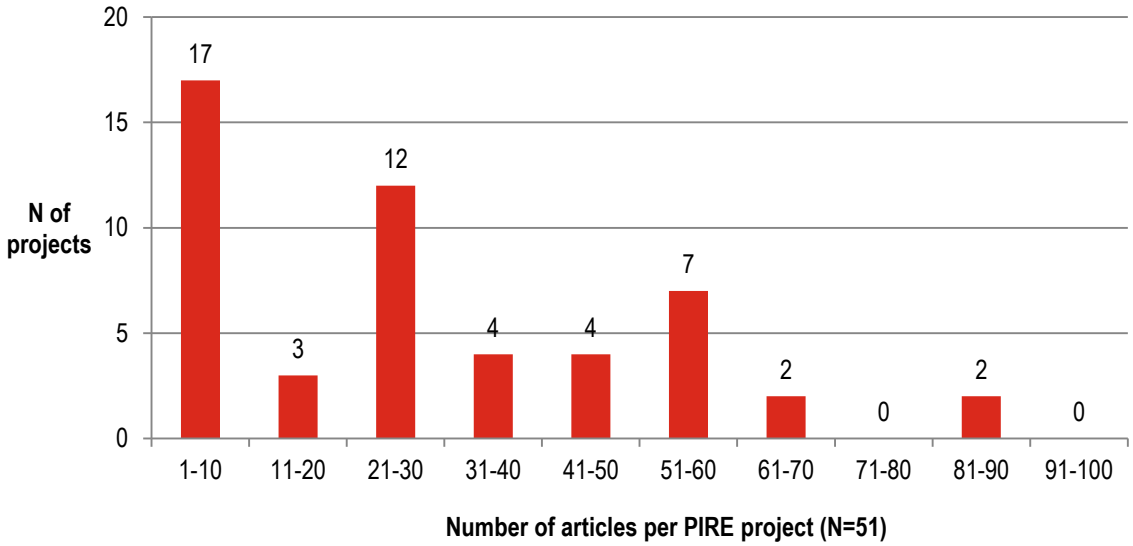
[b] Q1, the first quartile, indicates the value of the 25th percentile for the given indicator (75 percent of the articles have values greater than the Q1 value). The median indicates the 50th percentile (half of the articles have values greater than the median). Q3, the third quartile, indicates the value of the 75th percentile (25 percent of the articles have values greater than the Q3 value shown). At the 95th percentile, 5 percent of articles have values greater than shown. Taken together, the quartiles and 95th percentile illustrate the degree to which the distribution of an indicator is skewed (or not).

[c] SD=standard deviation

[d] Some PIRE projects never intended to produce journal articles, but instead produced data repositories, software and similar resources accessible to researchers but not reflected in bibliometric counts of published articles.

Across PIRE projects, the distribution of the number of journal articles is positively skewed, such that a small minority of projects produced a large number of publications, with most producing a small total number of publications (Exhibit 3.2 shows a more fine-grained illustration of this distribution than Exhibit 3.1). Of the 51 PIRE projects with at least one journal article matched to Web of Science data, 11 (22 percent) produced 51 or more articles, with two of these producing more than 80. Most projects (17 projects; 33 percent) produced up to 10 peer reviewed journal articles (i.e., matched to Web of Science records); another 23 projects (45 percent) produced between 11 and 50 articles.

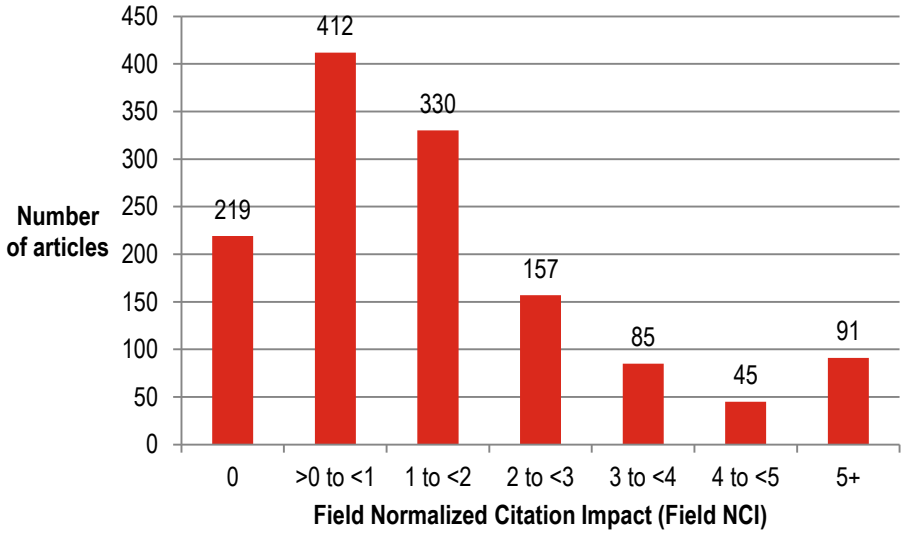
Exhibit 3.2: Distribution of Number of Journal Articles per PIRE Project (N=51 projects)



Sources: Annual reports submitted by PIs to NSF; Thomson Reuters' Web of Science
Notes: Of the 59 PIRE projects in the study, 8 had no journal articles identified in the Web of Science. These 8 projects include 6 (5 from the 2012 PIRE cohort, 1 from the 2010 cohort) that reported no journal publications by the time data were collected and 2 projects (1 from the 2012 cohort, 1 from the 2007 cohort) where none of the reported publications matched records in the Web of Science.

The distribution of the quality of publications, as measured by the field normalized citation impact, also illustrates the wide variation across PIRE-produced articles and the highly skewed nature of the data (Exhibit 3.3).

Exhibit 3.3: Distribution of the Field NCI of PIRE-Produced Publications (N=1,399 articles)



Sources: Annual reports submitted by PIs to NSF; Thomson Reuters' Web of Science
Note: There were 60 matched articles with no reported NCI in the Web of Science.

3.2 PIRE and Comparison Projects' Publications

Next, we used comparative descriptive analyses to look for differences between PIRE and comparison projects' research outcomes, with OLS regression models that account for the matched pairs to test for statistically significance of any observed differences. (Note that these analyses do not permit conclusions about the causes of any observed differences between research outcomes for the two groups.)

In addition to comparing citation impacts and the representation of foreign coauthors for these two groups' publications, we also present data illustrating the "global reach" of PIRE and comparison projects' publications, including the extent to which authors at international institutions were citing PIRE research and the extent to which PIRE publications were citing research that involved international researchers.

There were no statistically significant differences between PIRE and the comparison group for the quantity or quality of research produced (Exhibit 3.4). However, PIRE publications had a significantly higher percentage of foreign contributions, measured either as the percentage of foreign institutions represented among the authors per paper (PIRE articles had, on average, 35 percent foreign institutions versus 17 percent for comparison group publications) or measured as the percentage of foreign authors per paper (PIRE articles had an average of 29 percent foreign authors versus an average of 13 percent for comparison group).[15]

An analysis of citations of PIRE and comparison group articles shows that papers citing PIRE projects' research articles have a higher percentage (66 percent), on average, of foreign institutions per paper than do papers that cite comparison projects' articles (54 percent; Exhibit 3.4). Also, PIRE articles cite papers with a higher percentage of foreign institutions than on papers that comparison projects' articles cite. Taken together, these two findings suggest that PIRE research is more widely disseminated among international institutions (and their researchers) than is research produced by the comparison group, and PIRE researchers are more familiar with research that has high international representation.

[15] As discussed in Chapter 2, for publications prior to 2009, Thomson Reuters cannot distinguish individual authors' affiliations but can only count the number of distinct institutions with which authors are affiliated.

Exhibit 3.4: Comparison of Bibliometric Measures (Regression-Adjusted) for PIRE and Comparison Group Articles (N=45 matched project pairs)

	Mean PIRE	Mean Comparison	Difference	p Value	Significance	Standard Error
Indicator						
Number of articles per project	29.3	25.1	4.3	0.325	(ns)	3.03
Field Normalized Citation Impact (NCI)	1.6	1.7	-0.1	0.618	(ns)	0.15
Journal NCI	1.2	1.3	-0.1	0.453	(ns)	0.10
Percentage of non-U.S. institutions on articles produced by matched project pairs	34.5%	16.8%	17.7	< .01	**	2.19
Percentage of non-U.S. authors on articles (published 2009 or later) produced by matched project pairs	28.6%	13.4%	15.2	< .01	**	2.57
Citations of PIRE/comparison articles and citations by PIRE/comparison						
Percentage of non-U.S. institutions on articles citing project articles (PIRE, comparison group)[1]	65.5%	53.7%	11.7	< .01	**	2.12
Percentage of non-U.S. institutions on articles cited by project articles (PIRE, comparison group)[2]	54.2%	47.9%	6.3	< .01	**	1.55

Sources: Annual reports submitted by PIs to NSF; Thomson Reuters' Web of Science

Notes:

[1] Across papers citing one or more PIRE or comparison project-produced publications, the percentage of authors' institutions per citing publication that were located outside the U.S..

[2] Across papers that were cited by one or more PIRE or comparison project-produced publications, the percentage of authors' institutions per cited publication that were located outside the U.S..

3.3 PIRE Participants' Publications

Exhibits 3.5, 3.6, and 3.7 show the quality and quantity of post-onset publications co-authored by PIs, postdocs, and graduate students involved in PIRE, as well as the percentage of co-authors' institutions per paper that are located outside the U.S. On average, PIs produced over 15 journal articles, while postdocs produced over 5 and graduate students produced more than one. These publications were, on average, more frequently cited than the average research article as measured by both field NCI and journal NCI. The percentage of foreign institutions per publication shows that for PIRE PIs' publications, on average, just under one-third of co-authors' institutions are foreign (31.8 percent).

Exhibit 3.5: PIRE Principal Investigators' (N=307) Post-Onset Publications

Bibliometric Indicator	N of articles	Minimum	Q1	Median	Q3	95th percentile	Maximum	Mean	SD
Total number of post-onset articles (per PI)	4,776	0	2	6	14	59	666	15.56	44.73
Field NCI	4,129	0.00	0.34	1.17	2.60	9.08	307.90	2.72	9.76
Journal NCI (ratio observed to expected citations)	4,146	0.00	0.28	0.81	1.76	5.37	90.20	1.54	3.20
Percentage of foreign institutions	4,759	0.0%	0.0%	33.3%	58.7%	75.4%	100.0%	31.8%	31.6%

Exhibit 3.6: PIRE Postdoctoral Researchers' (N=207) Post-Onset Publications

Bibliometric Indicator	N of articles	Minimum	Q1	Median	Q3	95th percentile	Maximum	Mean	SD
Total number of post-onset articles (per postdoc)	1,113	0	0	2	6	22	73	5.38	10.11
Field NCI	938	0.00	0.26	1.23	2.85	9.75	307.90	3.58	13.67
Journal NCI (ratio observed to expected citations)	939	0.00	0.27	1.00	2.15	7.03	63.35	2.00	3.68
Percentage of foreign institutions	1,111	0.0%	0.0%	42.9%	75.0%	100.0%	100.0%	44.1%	35.9%

Exhibit 3.7: PIRE Graduate Students' (n=467) Post-Onset Publications

Bibliometric Indicator	N of articles	Minimum	Q1	Median	Q3	95th percentile	Maximum	Mean	SD
Total number of post-onset articles (per student)	807	0	0	0	1	7	180	1.73	8.73
Field NCI	667	0.00	0.23	1.14	2.86	10.34	280.67	3.08	11.84
Journal NCI (ratio observed to expected citations)	667	0.00	0.18	0.86	1.99	5.82	90.20	1.79	4.38
Percentage of foreign institutions	807	0.0%	0.0%	50.0%	73.7%	80.0%	100.0%	38.6%	33.8%

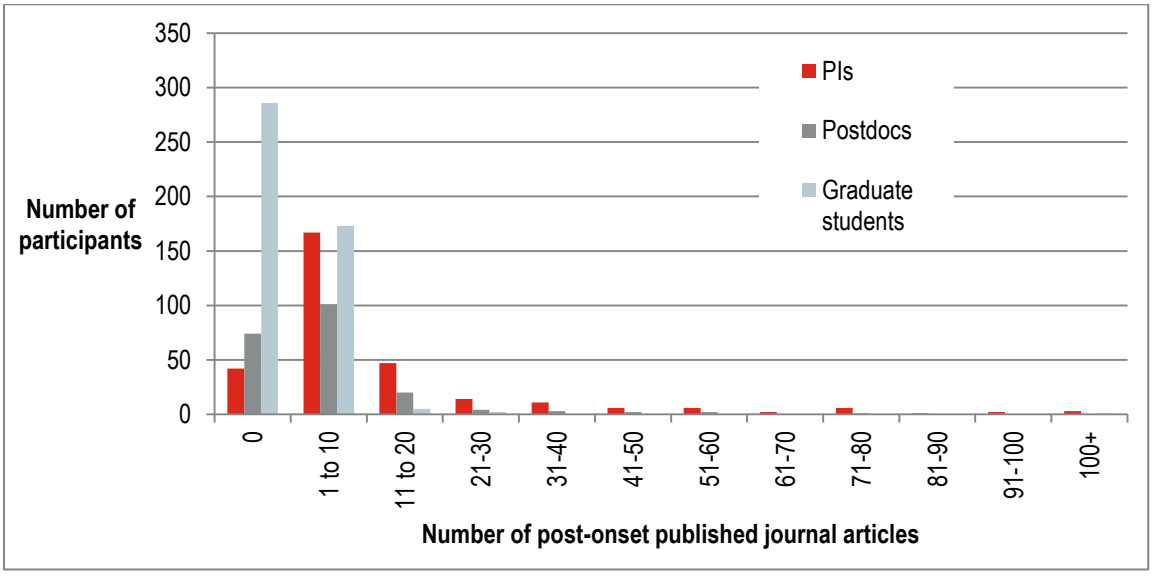
Sources: Web of Science and custom calculations by Thomson Reuters.

Notes:

[1] Articles on which a given participant is an author may include publications that did not result from participation in the PIRE project. For participants without a reported participation start date (i.e., from the study survey), the PIRE award effective date was used as participation start date.

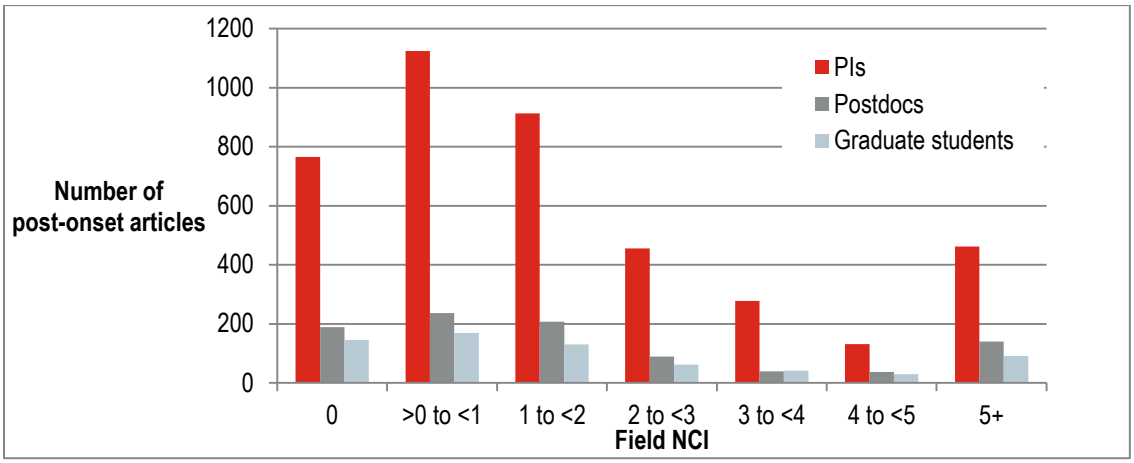
Across PIRE participants, the distribution of the number of journal articles is positively skewed, such that a small minority of participants produced a large number of post-onset publications with most participants producing a smaller total number of post-onset publications (Exhibit 3.8 presents a more fine-grained illustration of the skewed nature of the distribution than Exhibit 3.7).

Exhibit 3.8: Distribution of PIRE Participants' Number of Post-Onset Articles



Similarly, the distribution of the quality of these PIRE participants' publications, as measured by the field normalized citation impact, also illustrates wide variation across articles and the highly skewed nature of the data (Exhibit 3.9). A small percentage of post-onset publications are more highly cited articles than average (e.g., field NCIs of 5 or higher) with a large proportion of publications having about a number of citations approximately equal to the world baseline average (i.e., field NCIs between 0 and 2).

Exhibit 3.9: Distribution of the Field NCI for PIRE Participants' Post-Onset Articles



3.4 PIRE versus Comparison Participants' Publications

Research outcomes were also explored at the participant level for PIRE and comparison project participants. We first present a descriptive comparative analyses of the percentage of foreign contributions to PIRE and comparison participants' post-onset publications, using OLS regression models that control for the percentage of foreign contributions to pre-onset publications. (Note that these analyses do not permit conclusions about the causes of any observed differences between research outcomes for the two groups.)

We then present findings from an impact analysis. Data from articles published before and after the onset of participation from both the PIRE and comparison participants permitted a quasi-experimental "difference-in-differences" analysis to estimate the impact of PIRE on participants' research outcomes. (See Chapter 2: Methodology for further details.) An impact analysis that used random assignment would support the conclusion that any differences in PIRE and the comparison group's outcomes were the result of participation in PIRE. However, because the impact analyses we used were quasi-experimental rather than experimental, attributions of differences in research outcomes to the PIRE program must acknowledge the possibility of alternative explanations.

Percentage of foreign institutions on participants' post-onset publications

First we examined the foreign contributions to research as measured by the percentage of foreign institutions on post-onset publications, controlling for the percentage on pre-onset publications. PIRE PIs' post-onset publications had, on average, a statistically significant higher percentage of non-U.S. institutional affiliations (i.e., a proxy measure of the percentage of foreign co-authors) than comparison PIs' post-onset publications. While postdocs' and graduate students' publications also had higher percentages of non-U.S. institutional affiliations than publications by their comparison project peers, these differences were not statistically significant.

Exhibit 3.10: Regression-Adjusted Mean Percentage of Non-U.S. Institutional Affiliations for Post-Onset Publications

Respondent Group	Adjusted Mean Percentage of Non-U.S. Institutional Affiliations for Post-Onset Publications [a]				
	PIRE	Comparison	Difference (PIRE – Comparison)	Standard Error	p-Value
PIs[b]	15.5	9.7	5.8	1.66	.001**
Postdocs[c]	15.5	12.4	3.1	5.39	0.569
Graduate students[d]	17.4	7.3	10.1	8.44	.236

Sources: Web of Science.

Notes:

[a] The regression model controlled for the pre-onset percentage of foreign institutions per publication per participant and was calculated for the subset of participants who had at least one pre-participation publication and at least one post-participation publication. The comparative analysis was an ordinary least squares regression with a group indicator (PIRE=1, Comparison=0) and dummy variables representing the matched pairs of projects. A pair of projects was included in the analysis sample only if each project within a pair had at least one participant with pre- and post-onset publications.

[b] PIRE N=204; Comparison N=168 in 54 matched project pairs

[c] PIRE N=48; Comparison N=55 in 34 matched project pairs

[d] PIRE N=36; Comparison N=56 in 45 matched project pairs

Impact of PIRE on productivity and field normalized citation impact

Next we examined the impact of PIRE on participants' annual number of publications (i.e., the number of publications produced per year) and average field normalized citations per year (across articles published within a given year). Exhibit 3.11 summarizes the outcomes of PIRE versus comparison project participants for PIs, postdoctoral researchers, and graduate students. We found no significant differences in annual number of publications among PIs. However, among postdocs, PIRE participants had a larger number of average post-award annual publications (.46 more publications per year) and these publications had a larger impact (cited .57 times more often). Among graduate students, PIRE participants also had a higher average number of annual post-award publications than the comparison group (.23 more publications per year).

Exhibit 3.11: Impact of PIRE on PIs', Postdocs' and Graduate Students' Research Outcomes[1]

Outcome	PIRE			Comparison			Impact Estimate	Standard Error	p-value
	Pre Mean	Post Mean	(Post – Pre)	Pre Mean	Post Mean	(Post – Pre)			
PIs[4]									
Annual publications[2]	2.02	2.46	0.44	1.71	2.06	0.35	0.09	0.13	0.486
Field NCI per year[3]	1.28	1.60	0.32	1.66	1.94	0.28	0.04	0.11	0.708
Postdocs[5]									
Annual publications	0.33	1.38	1.04	0.39	0.98	0.59	0.46	0.11	<.0001
Field NCI per year	0.43	2.02	1.58	0.65	1.66	1.01	0.57	0.22	0.010
Graduate Students[6]									
Annual publications	0.15	0.78	0.63	0.11	0.52	0.40	0.23	0.09	0.014
Field NCI per year	0.51	1.15	0.64	0.43	0.99	0.56	0.08	0.13	0.549

Sources: Web of Science and custom calculations by Thomson Reuters for NCI per year.

Notes:

1 We conducted a separate analysis for each respondent group (PIs, postdocs, graduate students). For each analysis, the impact model estimated the PIRE-comparison difference between the pre- and post-onset outcome measure for each group controlling for the matched pairs of projects. For each respondent group, we restricted analysis sample to a subset for which baseline equivalence on first year of participation, pre-onset annual publications and field NCI per year. For further details, see Volume 2.

2 Annual publications refers to the number of publications published by a participant per year. The impact analysis method (CITS) requires yearly data rather than a single total number of publications.

3 The field NCI per year for each respondent group is the average NCI across a participant's articles published in a given year across the participants.

4 PIs: PIRE N=256, Comparison N=199 in 54 matched project pairs

5 Postdocs: PIRE N=102, Comparison N=118 in 34 matched project pairs

6 Graduate students' annual publications: PIRE N=172, Comparison N=296 in 45 matched project pairs; Graduate students' field NCI: PIRE N=170, Comparison N=287 in 45 matched project pairs.

4. Participant Experiences

This chapter provides information about participants' experiences in PIRE. To investigate the progress of the program toward its goals, we paid particular attention to the opportunities for international research collaborations, the experiences that develop research capacity and global perspectives, and the relationships between U.S. and foreign researchers. Specifically, the findings address the following research questions:

- RQ3b. What are the program experiences and educational or career outcomes of PIRE PIs, postdoctoral researchers, and graduate and undergraduate student participants?
- RQ4b. How do the program experiences and educational or career outcomes of these PIRE participants compare to similar participants in this comparison group of NSF-funded projects?
- RQ 6. What are the program experiences of foreign senior investigative partners in PIRE and how do they perceive the effects of PIRE on their research and educational practices and those of their institutions?

Data in this chapter come from the surveys completed by PIRE PIs, postdocs, graduate students, undergraduate students and foreign investigators, and the surveys completed by comparison group project PIs, postdocs, and graduate students.[16] We first present findings for PIRE PIs, postdocs, and graduate students and compare these participants' experiences to that of their peers in comparison projects. We then describe the experiences of undergraduate students who participated in PIRE and traveled abroad and the experiences of foreign senior investigators in PIRE.

- A greater proportion of PIs, postdoctoral researchers, and graduate students in PIRE projects traveled outside the U.S. than participants in comparison projects. For each group, the percent was well over three-fifths among PIRE participants and less than one-quarter among participants in comparison projects. Further, PIRE postdocs and graduate students were more likely than their counterparts in comparison projects to have traveled abroad to conduct research.
- Collaboration with individuals within the U.S. was commonly reported by both PIRE and comparison PIs, postdocs and graduate students; however, PIRE participants were more likely to collaborate with individuals based primarily outside the U.S.
- PIRE PIs and graduate students were more likely to report maintaining these international collaborations than comparison project participants, and commonly these relationships continued to focus on research-related exchanges.
- PIRE postdocs, graduate students, and undergraduates would recommend their peers engage in international research and education because of the benefits associated with working with and learning from international collaborators, cultural and social exchange, enhanced professional networking, and skills and knowledge developed as a researcher. Challenges were not commonly mentioned by respondents.
- Undergraduates who traveled outside the U.S. for PIRE-related research were more likely to have collaborated with foreign faculty, senior- or postdoctoral-level researchers or graduate students rather than with foreign undergraduate students.

[16] Because we did not field surveys of undergraduate students or foreign investigators involved in comparison group projects, we present descriptive analyses only for these groups.

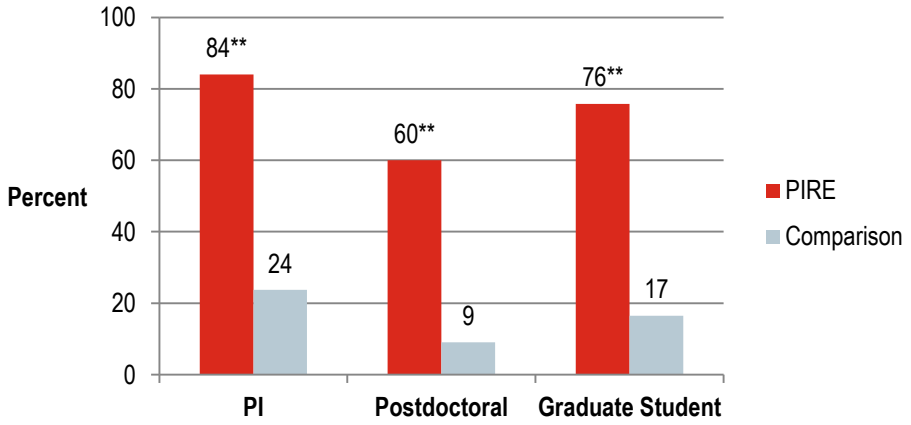
- Among undergraduate respondents who traveled outside the U.S. for PIRE-related research, the majority reported that their participation in the project yielded a range of personal benefits. Most commonly reported among these was an understanding of how scientists work on real problems (81 percent), followed by tolerance for obstacles faced in the research process (71 percent), self-confidence in their field of study (69 percent), and clarification of a career path (67 percent).
- Foreign investigators were less likely than U.S.-based investigators to have traveled internationally during their participation in the PIRE project (48 percent). Among those who traveled abroad, the majority traveled to the U.S. (78 percent).
- Among most foreign investigators, PIRE was not the first international research collaboration with a U.S.-based partner; 82 percent reported working with a U.S.-based individual on research prior to their participation in the PIRE project.

4.1 PIs, Postdocs, and Graduate Students

4.1.1 Travel Outside the U.S. During the Project

A greater proportion of PIs, postdoctoral researchers, and graduate students in PIRE projects traveled outside the U.S. than the proportion of these participants in comparison projects (Exhibit 4.1). Just under one-fourth of PIs (24 percent) in the comparison group reported traveling abroad for their project, compared to more than four-fifths (84 percent) of PIRE PIs. The majority of PIRE postdocs and graduate students traveled abroad (60 percent and 76 percent, respectively) compared to just 9 percent of comparison project postdocs and 17 percent of graduate students participating in a comparison group project. These differences were statistically significant for each group (PIs, postdocs, and graduate students).

Exhibit 4.1: Percent of Participants Who Traveled Outside the U.S. For the Project



Sources: Principal Investigator Survey, Item C2; Postdoc Survey, Item B2; Graduate Student Survey, Item B3.
Notes:
PIs: PIRE N=157, Comparison N=114; Postdocs: PIRE N=114, Comparison N=115; Graduate students: PIRE N=262, Comparison N=331.

On average, PIRE PIs made slightly more frequent but shorter trips abroad (six trips lasting about 2 weeks on average) than PIs in comparison projects (four trips of about 3 weeks in duration; see Exhibit 4.2). Both PIRE and comparison group postdocs reported an average of three trips abroad, but the average duration of a trip for PIRE postdocs was nearly three times as long (14 weeks) than for comparison group postdocs (5 weeks). Similarly, PIRE graduate students made the same number of trips on average as comparison graduate students but the PIRE graduate students' trips lasted more than twice as long (11 weeks), on average, than those of comparison graduate students' (5 weeks).

Exhibit 4.2: Characteristics of Participants' Travel Abroad for the Project

	PI				Postdoc				Graduate Student			
	PIRE		Comparison		PIRE		Comparison		PIRE		Comparison	
Of Those Who Traveled Abroad:	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean
Average number of trips abroad[1]	140	6	24	4	75	3	8	3	213	2	38	2
Average duration of trips abroad, in weeks[2]	140	2.3	24	2.9	71	13.9	5	4.8	213	11.4	38	5.0
Longest trip abroad, in weeks[3]	140	4.5	24	4.1	72	15.3	5	5.8	212	13.4	37	6.4

Sources:
Average number of trips: Principal Investigator Survey, Item C5a; Postdoc Survey, Item B6a; Graduate Student Survey, Item B9a.
Average duration: Principal Investigator Survey, Items C5b and C5d; Postdoc Survey, Items B6b and B6d; Graduate Student Survey, Item B9b and B9d. This captures the average duration of single and multiple trips.
Longest trip: Principal Investigator Survey, Items C5c and C5d; Postdoc Survey, Items B6c and B6d; Graduate Student Survey, Items B9c and B9d. This captures the duration of the longest trip abroad for single and multiple trips.
Notes:
1 Number of trips: PIRE N=140, missing=1, Comparison N=24. Postdocs: PIRE N=75, missing=3, Comparison N=8. Graduate students: PIRE N=213, missing=3, Comparison N=38, missing=3.
2 Average duration: PIs: PIRE N=140, missing=1, Comparison N=24; Postdocs: PIRE N=71, missing=7, Comparison N=5, missing=3; Graduate students: PIRE N=213, missing=3, Comparison N=38, missing=3.
3 Longest trip: PIs: PIRE N=140, missing=1, Comparison N=24; Postdocs: PIRE N=72, missing=6, Comparison N=5, missing=3; Graduate students: PIRE N=212, missing=4; Comparison N=37, missing=4.

Greater proportions of PIRE postdoctoral and graduate students traveled outside the U.S. for research purposes and a greater percentage of PIRE PIs traveled abroad for "research or educational activities" related to the project, compared to their peers in comparison group projects (Exhibit 4.3). These differences in reasons for traveling abroad were statistically significant.

Exhibit 4.3: Regression-Adjusted Mean Percentage of PIRE and Comparison Participants Who Traveled Abroad for Stated Purpose

Respondent Type	Traveled Abroad for	Mean Percent[1]		Difference	Standard Error	p-Value	Statistical Significance
		PIRE	Comparison				
PIs[2]	Research or educational activities	84.0	23.7	60.4		<.01	**
Postdocs[3]	Conduct research	97.8	42.8	55.0	16.5	0.002	***
Graduate students	Conduct research	94.2	79.7	14.4	5.8	0.014	*

Sources: Principal Investigator Survey, Item C2; Postdoc Survey, Item B4; Graduate Student Survey, Item B5.

Notes:

1 The regression model controlled for the fact that participants were within matched pairs of projects (N=55 pairs).

2 PIs, PIRE N=157, Comparison N=114. Because PIs were asked if they traveled abroad "to conduct research or educational activities (other than travel solely to attend a professional conference)" it is not possible to disambiguate "research" from "educational" purposes for this participant group.

3 Postdocs, PIRE N=72, Comparison N=8; Graduate Students: PIRE N=195, Comparison N=42. Postdocs and graduate students were asked to identify the purposes for which they traveled abroad as part of the project. Those who indicated "conduct research" are shown.

Exhibit 4.4 shows a broader range of activities for which postdoctoral and graduate student participants traveled abroad. In addition to traveling outside the U.S. to conduct research, the next most frequently reported activity abroad for PIRE postdocs was attending planning meetings or workshops; in contrast, the next most frequently reported activity abroad for comparison postdocs was attending a professional conference. No comparison postdocs taught a course while abroad, compared to 17 percent of PIRE postdocs. Five percent of comparison graduate students took classes while abroad, compared to nearly one-fifth of PIRE graduate students who traveled abroad.

Exhibit 4.4: Reasons Postdoctoral and Graduate Student Participants Reported for Travel Abroad for the Project

	Postdocs				Graduate Students			
	PIRE		Comparison		PIRE		Comparison	
	N	Percent	N	Percent	N	Percent	N	Percent
Conduct research[1]	72	94%	4	50%	201	93%	33	79%
Attend planning meetings or workshops for upcoming research[2]	28	45%	2	25%	80	37%	13	31%
Attend a professional conference[3]	28	36%	4	50%	62	29%	7	17%
Other—specify[4]	14	18%	2	25%	19	9%	5	12%
Teach and/or prepare curriculum for a course[5]	35	17%	0	0%	na	na	na	na
Take classes at a university or other educational institution[6]	3	4%	0	0%	41	19%	2	5%
Participate in an internship[7]	na	na	na	na	11	5%	2	5%
None of the above	0	0%	0	0%	0	0%	0	0%

Sources: Postdoctoral Survey, Item B4; Graduate Student survey, Item B5.

Notes:

1 Conduct research: Postdocs: PIRE N=77, missing=1, Comparison N=8; Graduate students: PIRE N=216, Comparison N=42.

2 Attend planning meetings/workshops: Postdocs: PIRE N=77, missing=1, Comparison N=8; Graduate students: PIRE N=216, Comparison N=42.

3 Attend professional conference: Postdocs: PIRE N=77, missing=1, Comparison N=8; Graduate students: PIRE N=216, Comparison N=42.

4 Other: Postdocs: PIRE N=77, missing=1, Comparison N=8; Graduate students: PIRE N=216, Comparison N=42.

5 Teach/prepare for course: Postdocs: PIRE N=77, missing=1, Comparison N=8. Graduate students were not asked if they traveled abroad to teach or prepare curriculum for a course.

6 Take classes at university/educational institution: Postdocs: PIRE N=77, missing=1, Comparison N=8; Graduate students: PIRE N=216, Comparison N=42.

7 Participate in internship: Graduate students: PIRE N=216, Comparison N=42. Postdoctoral participants were not asked if they traveled abroad to participate in an internship

8 None of the above: Postdocs: PIRE N=77, missing=1, Comparison N=8; Graduate students: PIRE N=216, Comparison N=41, missing=1.

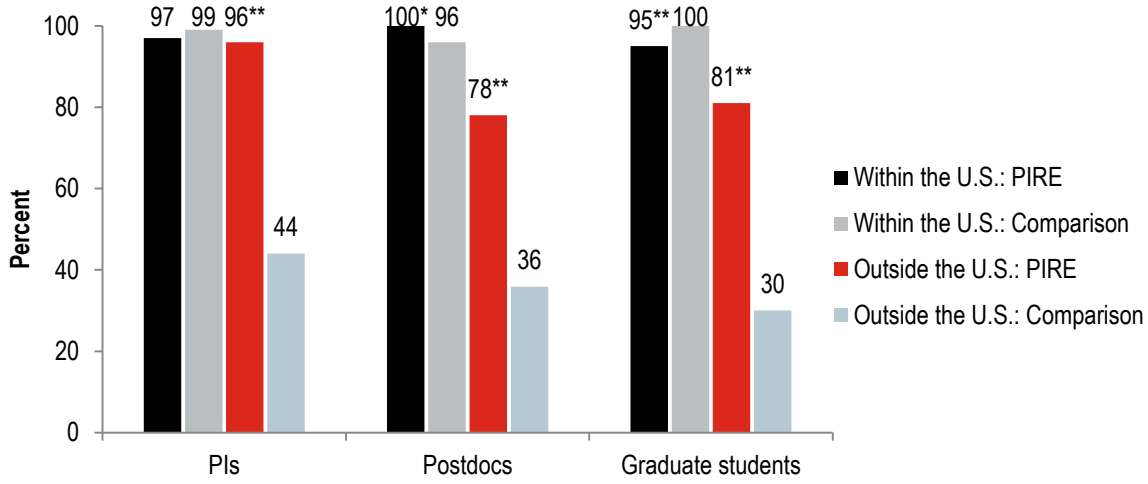
4.1.2 Collaborations

Participants reported on collaborations during and subsequent to their participation in the project with individuals who were primarily based in and outside of the U.S.

Collaborations during participation in the project

The overwhelming majority of both PIRE and comparison participants had collaborated during the project with individuals within the U.S. (Exhibit 4.5). Across the PI, postdoctoral and graduate student respondents, a larger proportion of PIRE participants versus comparison project participants had collaborated with individuals based primarily outside the U.S.

Exhibit 4.5: Percent of Participants Who Collaborated During the Project with Individuals Based Within[1] and Outside the U.S.[2]



Sources: Principal Investigator Survey, Item B1a; Postdoc Survey, Item B1a; Graduate Student Survey, Item B2.
Notes:

1 Within U.S.: PIRE N=157, Comparison N=114; Postdocs: PIRE N=117, Comparison N=116, missing=1; Graduate students: PIRE N=235, Comparison N=316.

2 Outside the U.S.: PIs: PIRE N=157, Comparison N=112; Postdocs: PIRE N=117, Comparison N=116, missing=1; Graduate students: PIRE N=234, Comparison N=316.

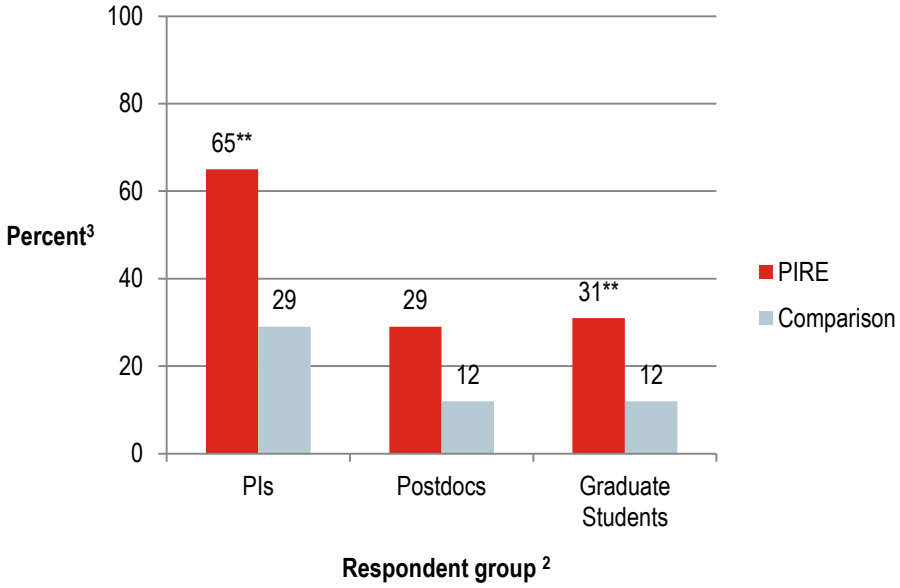
Collaborations subsequent to participation in the project

A key outcome for the study is the extent to which collaborations with foreign colleagues continued after U.S. participants' role in the project had concluded. The study collected information on these collaborations for PIRE and comparison PIs, postdocs, and graduate students, as well as descriptive data on the nature of these continued collaborations and any subsequent collaboration with foreign colleagues who were not part of the PIRE or comparison project teams. Only participants in expired projects (i.e., PIRE or comparison projects in which the official NSF award period had ended) and participants who reported that their contributions to the project had ended prior to the survey reference date were asked to report on these post-participation outcomes.

Post-award (or post-participation), PIRE PIs and graduate students were significantly more likely to collaborate with non-U.S.-based colleagues who had been part of the reference award (Exhibit 4.6); there were no statistically significant differences among postdocs. These collaborations commonly involved discussing developments in their research field(s), planning research projects, conducting research, and sharing data or other resources (Exhibits 4.7). These types of research-related collaborative activities were reported by larger proportions of PIRE than comparison group

participants. This suggests that the continued collaborations went beyond simply encountering foreign colleagues at conferences.

Exhibit 4.6: Percent of Participants (Regression Adjusted) Who Continued, After Participation in the Project, to Collaborate with a Non-U.S.-Based Colleague Who Was a Member of the PIRE or Comparison Project[1]



Sources: Principal Investigator Survey, Item B1b; Postdoc Survey, Item B1b; Graduate Student Survey, Item B2a.
Notes:

1 Stepwise regression models controlled for the fact that participants were within matched pairs of projects (N=55 pairs); other covariates were excluded in the PI and postdoc models; for graduate students only, the regression model also included a covariate for graduate field of study. Non-U.S.-based colleagues was restricted to include only project members who "were based outside the U.S." and who "still are" based outside the U.S., to the best of the respondent's knowledge at the time of the survey. When the definition of non-U.S.-based colleague is expanded to include both (a) project members who were and still are based outside the U.S. and (b) project members who were based outside the U.S. but who "are now" based primarily *within* the U.S., the results change by less than two percentage points for PIRE or comparison participants.

2 PIs, PIRE N=62, Comparison N=48; Postdocs, PIRE N=60, Comparison N=83; Graduate Students: PIRE N=149, Comparison N=219.

3 Asterisks indicate that the difference between PIRE and comparison groups is statistically significant: *p<.05, **p<.01

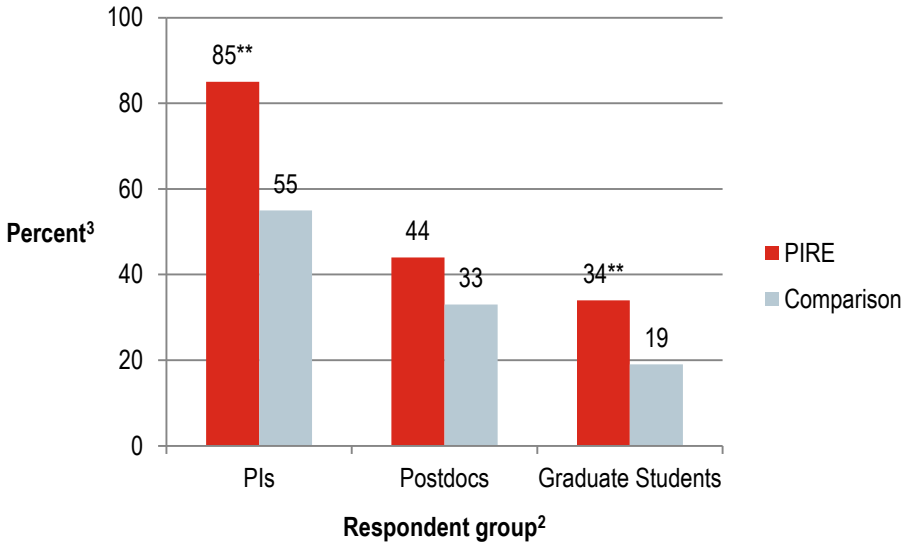
PIRE PIs and graduate student participants also were significantly more likely to collaborate post-award (or post-participation) with non-U.S.-based colleagues who had not been part of the reference award (Exhibit 4.8); again, there were no statistically significant differences among postdocs who had participated in a PIRE or comparison project.

Exhibit 4.7: Percent Reporting Selected Types of Collaborative Activities with Non-U.S.-Based Colleague from the Project Team, After Participation in the Project Had Concluded

Type of Activity	PIs		Postdocs		Graduate Students	
	PIRE	Comparison	PIRE	Comparison	PIRE	Comparison
Discussed developments in research field(s) with a foreign partner	91%	62%	84%	75%	76%	64%
Planned one or more research projects with a foreign partner	85%	52%	74%	30%	58%	24%
Conducted one or more research projects with a foreign partner	82%	52%	48%	25%	64%	45%
Shared data or other resources with a foreign partner	82%	57%	71%	40%	71%	55%
Traveled outside the U.S. to work with one or more foreign partners	76%	43%	58%	20%	69%	21%
Met with one or more foreign partners at conferences outside the U.S.	67%	52%	52%	35%	51%	15%
A foreign partner has traveled to the U.S. to work with me	55%	52%	35%	15%	36%	27%
A former U.S.-based partner has (or has had) a position at an institution outside the U.S.	29%	29%	29%	30%	13%	36%
A former foreign partner has (or has had) a position at an institution in the U.S.	25%	14%	32%	25%	18%	15%
Have (or have had) a position at an institution outside the U.S.	16%	5%	39%	25%	16%	9%
None of the Above	0%	0%	0%	15%	4%	9%

Sources: Principal Investigator Survey, Item B1d; Postdoctoral Survey, Item B1d; Graduate Student Survey, Item B2c.
Notes: PIs: PIRE N=55, Comparison N=21; Postdocs: PIRE N=31 ; Comparison N=20, missing=1; Graduate students: PIRE N=55, Comparison N=33.

Exhibit 4.8: Percent of Participants (Regression-Adjusted) Who Collaborated, After Participation in the Project, with a Non-U.S.-Based Colleague Who Was *Not* a Member of the PIRE or Comparison Project



Sources: Principal Investigator Survey, Item B1e; Postdoc Survey, Item B1e; Graduate Student Survey, Item B2d.
Notes:

1 Stepwise regression models controlled for the fact that participants were within matched pairs of projects (N=55 pairs); other covariates were excluded in the PI and postdoc models; for graduate students only, the regression model also included a covariate for graduate field of study.

2 PIs, PIRE N=62, Comparison N=49; Postdocs, PIRE N=69, Comparison N=90; Graduate Students: PIRE N=150, Comparison N=219.

3 Asterisks indicate that the difference between PIRE and comparison groups is statistically significant: *p<.05, **p<.01

4.1.3 Educational and Career Outcomes[17]

We asked PIs, postdocs and graduate students to report on a handful of other post-participation career or educational outcomes. Because these groups were at different points in their careers (or educational trajectories), these items differed somewhat between groups.

A majority of PIs from both PIRE (68 percent) and comparison projects (67 percent) reported that their NSF award had helped them leverage other funds to support their research (Exhibit 4.9). A larger proportion of comparison postdocs (46 percent) than PIRE postdocs (26 percent) indicated that the project experience helped them win grant funding for their research, whereas a higher percentage of PIRE graduate students than comparison project graduate participants reported this effect. None of these differences were statistically significant.

17 Volume 2 includes findings from a secondary set of analyses comparing PIRE postdoctoral, graduate and undergraduate participants' employment outcomes to national trends using data from the Survey of Doctorate Recipients and the National Survey of Recent College Graduates.

Exhibit 4.9: Percent (Regression-Adjusted) of PIRE and Comparison Participants Reporting that the Project Helped Secure a Benefit[1]

	PIRE	Comparison	Difference	p-value
The project helped secure funds to support research				
Principal Investigators[2]	68%	67%	1.4	0.830
Postdoctoral researchers[3]	26%	46%	-20.5	0.125
Graduate students[3]	40%	31%	9	0.173
The project helped secure a promotion or first choice of full-time position[1]				
Principal Investigators[2]	34%	32%	2.1	0.743
Postdoctoral researchers[3]	65%	68%%	-2.6	0.815
Graduate students[3]	59%	53	6.3	0.402

Sources: Principal Investigator Survey, Item D7b; Postdoc Survey, Item E5 ; Graduate Student Survey, Item E6.

Notes:

1 Stepwise regression models controlled for the fact that participants were within matched pairs of projects (N=55 pairs); other covariates were excluded in the PI and postdoc models; for graduate students only, the regression model also included a covariate for graduate field of study.

2 PIs were asked whether the project (a) provided an opportunity to leverage other funds to support their research and (b) helped them secure a promotion. PIRE N=157, Comparison N=114.

3 Postdocs and graduate students were asked whether the project (a) helped them win grant funding to support their research and (b) helped them receive a full-time position that was their top choice. Postdocs, PIRE N=49, Comparison N=58. Graduate students, PIRE N=111, Comparison N=147.

A greater percentage of comparison project (former) graduate students than PIRE (former) graduate students who completed a doctorate reported that they subsequently held a postdoctoral appointment, but among those who did, a greater percentage of PIRE's former graduate participants than the comparison group had a postdoctoral appointment outside the U.S. Neither difference was statistically significant.

Exhibit 4.10: Percent (Regression-Adjusted) of PIRE and Comparison Graduate Students Who Held a Postdoctoral Position After Completing Their Doctorate[1]

Former Graduate Student Participants	PIRE	Comparison	Difference	p-Value
Ever had a postdoctoral appointment[2]	60%	70%	-9.4	0.206
Had a postdoctoral appointment outside the U.S.[3]	31%	17%	13.9	0.089

Sources: Graduate Student Survey, Items E1c, E1d.

Notes:

1 Stepwise regression models controlled for the fact that participants were within matched pairs of projects (N=55 pairs) and included a covariate for graduate field of study.

2 PIRE N=100, Comparison N=137.

3 PIRE N=59, Comparison N=88.

One potential effect of winning an NSF grant is that it could raise a PI's academic or public profile and lead either to unsolicited job offers or opportunities to move from one institution to one perceived as more prestigious. Few PIRE or comparison PIs reported that the project had provided a means to move to a more prestigious institution, although more than 40 percent of PIRE and comparison PIs had received unsolicited job offers since the start of their award. There were no significant differences for either outcome.

Exhibit 4.11: Percent (Regression-Adjusted) of PIRE and Comparison PIs Who Reported that the Project Led to Job Opportunities or Offers[1]

Principal Investigators	PIRE	Comparison	Difference	p-Value
Provided an opportunity to move to a more prestigious institution[2]	12%	7%	5	0.203
Since the start of the project have received unsolicited offers of employment[2]	42%	42%	-0.1	0.983

Sources: Principal Investigator Survey, Items D7b and D8.
Notes:
[1] Stepwise regression models controlled for the fact that participants were within matched pairs of projects (N=55 pairs).
[2] PIRE N=157, Comparison N=114. The survey displayed the following mouse-over definition: "An unsolicited offer of employment is one that occurs independently of any action you initiated to seek different employment."

4.1.4 Perceived Benefits and Challenges

Overwhelmingly, both postdocs and graduates students would recommend that their peers participate in international research and evaluation activities (Exhibit 4.12). In describing why they would recommend that others participate in international research or educational activities, postdocs' and graduate students' top benefits cited included working with and learning from international collaborators, cultural and social exchange, enhanced professional networking, and skills and knowledge developed as a researcher. The experience working with and learning from international collaborators was also most commonly selected **most** beneficial aspect of their participation.

Exhibit 4.12: Respondent Level of Recommendation to Academic Peers on Participating in International Research or Educational Activities

Level of Recommendation	Postdocs		Graduate Students	
	N	%	N	%
Strongly recommend	34	81%	126	82%
Recommend	7	17%	18	12%
Recommend with reservations	1	2%	8	5%
Not recommend	0	0%	2	1%

Sources: Postdoc Survey, Item E6; Graduate Student Survey, Item E7.
Notes: Postdocs, N=42, missing=4. Graduate students, N=154, missing=5.

Participants agreed that their research had benefited in a variety of ways from access to resources available through the non-U.S. locations and partnerships (Exhibit 4.13). Challenges were not commonly reported by respondents. We asked each group whether bureaucratic challenges or language differences in a foreign country hindered the research: less than one-third of the PIs, postdocs or graduate students agreed or strongly agreed that bureaucratic challenges hindered the progress of the research, and less than 20 percent of each group agreed or strongly agreed that language differences had hindered the research. When asked about other possible challenges, more than half of PIs cited no other challenges and more than 60 percent of postdoctoral and graduate student participants cited no other challenges (Exhibit 4.14).

Exhibit 4.13: Benefits and Challenges to Research

Benefit/Challenge	Principal Investigators			Postdocs			Graduate Students		
	Strongly Agree or Agree	Strongly Disagree or Disagree	Not Appl.	Strongly Agree or Agree	Strongly Disagree or Disagree	Not Appl.	Strongly Agree or Agree	Strongly Disagree or Disagree	Not Appl.
Research benefited from access to expertise of foreign partners in field	94%	4%	2%	96%	3%	1%	86%	5%	9%
Research benefited from access to data acquired in foreign locations	85%	6%	9%	84%	6%	9%	76%	7%	17%
Different cultural perspectives improved the quality of the research	78%	16%	6%	78%	14%	8%	73%	11%	16%
Research benefited from access to place-based phenomena that occur outside the U.S. (e.g., biological, geological, cultural phenomena)	68%	7%	25%	60%	16%	24%	63%	9%	27%
Research benefited from access to equipment or facilities in foreign locations	66%	12%	21%	63%	20%	17%	65%	13%	22%
Regulatory, bureaucratic or administrative procedures in a foreign country hindered the progress of the research	31%	60%	9%	22%	62%	16%	29%	49%	23%
Language differences hindered the progress of the research	19%	75%	6%	9%	77%	14%	16%	69%	16%

Sources: Principal Investigator Survey, Item D5; Postdoc Survey, Item C4; Graduate Student Survey, Item C4.
Notes: PIs, N=170. Postdocs, N=95, missing=7. Graduate students, N=282-283, missing=2-3.

Exhibit 4.14: Other Challenges Experienced While Participating in PIRE Project

Challenges	Principal Investigators		Postdocs		Graduate Students	
	N	%	N	%	N	%
None	89	52%	60	63%	182	64%
Key foreign partners were not as available as I expected or did not contribute enough to the project[1]	33	19%	NA	NA	NA	NA
Inadequate access to data, specimens, facilities, equipment, other resources	31	18%	12	13%	NA	NA
Funding expected from foreign (non-U.S.) sources did not materialize[2]	23	14%	NA	NA	NA	NA
Unexpected financial burdens[2]	NA	NA	8	8%	29	10%
Delays in getting publications written due to the cross-cultural nature of the team	22	13%	7	7%	15	5%
Conflicts over authorship or credit for contributions to the research	14	8%	9	9%	22	8%
Other	12	7%	4	4%	13	5%
Bias from foreign partners based on my nationality, gender, race, ethnicity, religion, disability or sexual orientation	5	3%	1	1%	12	4%
Not have enough information or guidance to prepare for the foreign component of the research[3]	NA	NA	6	6%	28	10%
Delays pursuing/completing goals of postdoctoral appointment or graduate degree[4]	NA	NA	11	12%	39	14%

Sources: Principal Investigator Survey, Item D6; Postdoc Survey, Item C5; Graduate Student Survey, Item C5.
Notes: PIs, N=170. Postdocs, N=94-95, missing=7-8. Graduate students, N=284, missing=1.

1 Postdocs and graduate students were not asked whether key foreign partners were not as available as expected or did not contribute enough to the project.

2 Principal investigators were asked whether funding expected from foreign (non-U.S.) sources did not materialize. Postdoctoral researchers and graduate students were asked if they experienced unexpected financial burdens.

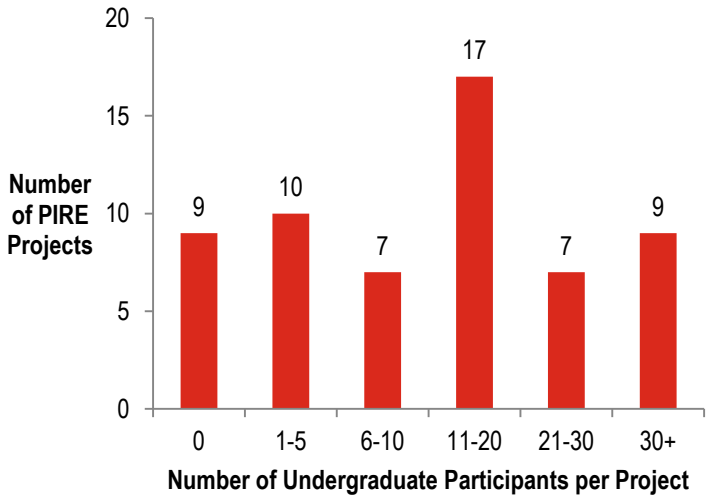
3 Principal investigators were not asked whether they had enough information or guidance to prepare for the foreign component of the research.

4 Principal investigators were not asked whether they experienced delays in pursuing/completing goals of their academic appointment.

4.2 Undergraduate Students in PIRE

Of the 59 PIRE awards, 50 included one or more undergraduate participants, from which we selected a sample to complete a study survey (Exhibit 4.15 shows a distribution of PIRE projects by the number of undergraduate participants). Their responses provide some insight into experiences of undergraduate students who participated in a PIRE project.

Exhibit 4.15: Distribution of PIRE Projects (N=59) by the Number of Undergraduate Participants



Sources: Annual reports submitted by PIs to NSF.

4.2.1 Travel Outside the U.S. During the Project

Eighty-seven percent of undergraduate respondents reported that they had traveled abroad for the PIRE project to help conduct a research project, participate in an internship, attend a professional conference, and/or take classes or participate in educational activities abroad (Exhibit 4.16). The most commonly reported activity for which these undergraduate PIRE participants traveled abroad was research (90 percent), followed by participation in an internship (74 percent), attendance at a professional conference (65 percent), and participation in classes or education abroad (53 percent). On average, during their participation in PIRE, undergraduates whose travel was related to PIRE took one trip abroad and these trips lasted an average of eight weeks. The majority of undergraduates (83 percent) reported that they had traveled with other U.S.-based peers, faculty, postdoctoral researchers or graduate students.

Exhibit 4.16: Characteristics of Undergraduates' Travel Abroad for PIRE

Travel Abroad	Percent
Traveled abroad for PIRE for one of four purposes	
Traveled abroad for the PIRE project to participate in: research project, internship, professional conference and/or classes or educational program abroad[1]	87%
Participated in activity/activities while abroad for the PIRE project:	
Help conduct an original research project[2]	90%
Participate in an internship[3]	74%
Attend a professional conference[4]	65%
Take classes at an educational institution or participate in educational program abroad [5]	53%
Traveled abroad with other U.S.-based individuals[6]	
Other U.S.-based undergraduates	83%
U.S.-based faculty or postdoctoral researchers	69%
U.S.-based graduate students	60%
Of those who traveled abroad for the PIRE project:	**Mean**
Average number of trips abroad[7]	1.2
Average duration of trips abroad, in weeks[8]	8.0
Longest trip abroad, in weeks[9]	8.6

Sources: Undergraduate Student Survey.
Traveled abroad: Item B1.
Participated in activity: Item B2.
With other U.S.-based individuals: Item B14.
Average number of trips: Item B13a.
Average duration: Items B13b and B13d. This captures the average duration of single and multiple trips.
Longest trip: Items B13c and B13d. This captures the duration of the longest trip abroad for single and multiple trips.
Notes:

1 Traveled abroad for the PIRE project: N=241. Results show undergraduates who indicated that they had traveled outside the U.S. to (a) help with a research project, or take classes/participate in educational activities abroad, or participate in an internship or attend a professional conference and who indicated (Item B2) that the PIRE project was the reason for this activity/these activities abroad. Note that respondents who indicated "yes" or "not sure" that the activity was related to the PIRE project were included; although survey respondents had been identified as project participants in a PI's annual report, undergraduate participants may not have been familiar with the official NSF project title used in the survey item. For this reason, Item B2 included a "not sure" option: "Was this travel abroad while an undergraduate for the purpose of the [PROJECT TITLE] project?" The percent who answered "not sure" were as follows:

- Research project: 1%
- Internship: 8%
- Attend a professional conference: 6%
- Classes or educational activities abroad: 2%.

2 N=191 had traveled abroad to help conduct an original research project.
3 N=103 had traveled abroad to participate in an internship.
4 N=83 had traveled abroad to attend a professional conference.
5 N=113 had traveled abroad to take classes at an educational institution or participate in educational activities abroad.
6 N=209, Other U.S.-based undergraduates, missing=1; U.S.-based faculty or postdocs, missing=1.
7 Average number of trips: N=208, missing=1.
8 Average duration of trips abroad: N=208, missing=1.
9 Longest trip abroad: N=208, missing=1.

Among respondents who enrolled in courses or participated in educational activities abroad related to their PIRE project while traveling abroad, the majority took courses, seminars, or lectures in their primary major (78 percent) and studied a foreign language (57 percent; see Exhibit 4.17). Less than half of these respondents reported taking courses, seminars, or lectures outside their primary major, or studying the history, geography, and culture of the local country or region (43 percent each).

Exhibit 4.17: Types of Coursework Taken Outside the U.S. by Undergraduate PIRE Participants Who Participated in Coursework Abroad (N=60)

Type of Coursework	Percent
Courses, seminars, lectures, or other education in my primary major or field of study	78%
Foreign language classes or education	57%
Courses, seminars, lectures, or other education in fields other than my primary major field of study	43%
Classes or other education about the history, geography, and culture of the country/region	43%
Other	2%

Source: Undergraduate Student Survey, Item B10.
Notes: N=60.

Respondents with internships abroad related to PIRE typically worked in a college, university, or other institution of higher education (88 percent) and conducted research or research and development (99 percent). Exhibit 4.18 summarizes all settings and types of work these undergraduates reported.

Exhibit 4.18: Internship Setting and Type of Work Involved Among Undergraduate PIRE Participants with an Internship Abroad (N=76)

Internship Setting and Type of Work	Percent
College, university, or other institution of higher education	88%
Government agency or non-governmental organization	12%
Another setting	7%
Industry or business	5%
Medical or health care institution	3%
Elementary or secondary school	0%
Type of Work	
Research or research & development (R&D)	99%
Teaching, training, or mentoring others	8%
Providing help or services to others	7%
Policy-related work	1%
Another type of work	1%

Source: Undergraduate Student Survey, Item B11.
Notes: N=76.

4.2.2 Collaborations

Undergraduate participants reported on collaborations during and subsequent to their participation in the project with individuals who were primarily based within and outside the U.S. Only undergraduates who traveled outside the U.S. for PIRE-related research were asked about their collaborations.

Collaborations during the project with U.S. and non-U.S. project colleagues

Among undergraduate respondents who traveled outside the U.S. for PIRE-related research, a greater proportion collaborated with foreign faculty, senior- or postdoctoral-level researchers, or graduate students than with foreign undergraduate students (85 percent compared to 39 percent; Exhibit 4.19).

Exhibit 4.19: Undergraduate Collaboration During PIRE Project with Individuals Based Outside the U.S. (N=172)

Type of Individual Based Outside the U.S.	Percent
Faculty, senior- or postdoctoral-level researchers or graduate students based primarily at an institution outside the U.S.	85%
Undergraduate students based primarily at an institution outside the U.S.	39%

Source: Undergraduate Student Survey, Item C1.
Notes: N=172. Only undergraduates who traveled outside the U.S. for PIRE-related research were asked about their collaborations.

Collaborations subsequent to participation in the project

A key outcome for the study is the extent to which PIRE undergraduate students continued collaborations with non-U.S.-based colleagues after their participation in the project had ended. In addition, the study collected descriptive data on the nature of these continued collaborations and any subsequent collaborations with foreign colleagues who were not part of the PIRE or comparison project teams. Only participants in expired projects (and participants who reported that their contributions to the project had ended prior to the survey) were asked to report on these outcomes.

Less than half of undergraduate respondents who traveled outside the U.S. for PIRE-related research and collaborated with a foreign partner on research during their participation in the PIRE project went on to collaborate with a foreign partner after their participation in the project ended. A higher proportion of these respondents collaborated with a non-PIRE affiliated foreign partner (33 percent) than with a member of the project team (20 percent).

Exhibit 4.20: Collaboration, After Participation in the Project, with a Non-U.S.-Based Partner (N=142)

Type of Non-U.S.-Based Partner	Percent
Foreign project member affiliated with the PIRE project[1]	20%
Foreign partner not affiliated with the PIRE project	33%

Source: Undergraduate Student Survey, Items C2a & C2d.

Notes:

[1] N=142. Non-U.S.-based project members were restricted to include only project members who "were based outside the U.S." and who "still are" based outside the U.S., to the best of the respondent's knowledge at the time of the survey. When the definition of non-U.S.-based colleague is expanded to include both (a) project members who were and still are based outside the U.S. and (b) project members who were based outside the U.S. but who "are now" based primarily within the U.S., the results change by less than three percentage points.

[2] N=142. Only undergraduates who traveled outside the U.S. for PIRE-related research were asked about their collaborations, and of those, only those who had participated in an expired PIRE award or those who reported that their participation in an active award had ended prior to the survey were asked about collaborations subsequent to their project participation.

Among undergraduate respondents who traveled outside the U.S. for PIRE-related research and collaborated with a foreign member of the project team after their participation in the PIRE project ended, more than half reported that they discussed developments in their research field with a foreign partner (55 percent) and shared data or other resources with a foreign partner (52 percent). Just under half of respondents traveled abroad to collaborate with a foreign partner (48 percent) and conduct research with a foreign partner (42 percent). Approximately one-quarter of participants planned a research project with a foreign partner (27 percent) and about one-fifth met with a foreign partner at a conference outside the U.S. (18 percent).

Exhibit 4.21: Percent of Undergraduates Reporting Selected Types of Collaborative Activities with Non-U.S.-Based Colleague from the Project Team, After Participation in the Project Had Concluded (N=33)

Type of Activity	Percent
Discussed developments in our research field(s) with a foreign partner	55%
Shared data or other resources with a foreign partner	52%
Traveled outside the U.S. to work with one or more foreign partners	48%
Conducted one or more research projects with a foreign partner	42%
Planned one or more research projects with a foreign partner	27%
Met with one or more foreign partners at conferences outside the U.S.	18%
A foreign partner has (or had) enrolled as a student at an institution in the U.S.	9%
Have (or have had) a job or position at an institution outside the U.S.	6%
A foreign partner has (or has had) a job at an institution in the U.S.	6%
Have enrolled as a student at an institution outside the U.S.	3%
A former U.S.-based partner has (or has had) a position at an institution outside the U.S.	3%
None of the above	21%

Sources: Undergraduate Student Survey, Item C2c.
Note: N=33. Only undergraduates who traveled outside the U.S. for PIRE-related research were asked about their collaborations, and of those, only those who had participated in an expired PIRE award or those who reported that their participation in an active award had ended prior to the survey were asked about collaborations subsequent to their project participation. Those who reported a collaboration with a foreign member of the PIRE project after their participation in the project had ended were asked about the type of collaborative activity.

4.2.3 Undergraduates' Role in the Project

Among undergraduate respondents who traveled outside the U.S. for PIRE-related research, most reported that during their participation in the PIRE project, they collected data (80 percent) and analyzed data (68 percent). Almost half of respondents reported that they prepared samples or specimens (48 percent), and approximately one-third reported that they wrote part of a manuscript or report on research (34 percent), conducted computer or mathematical simulations (32 percent), or designed research (30 percent).

Exhibit 4.22: Percent of Undergraduates Reporting Various Roles in the PIRE Project (N=172)

Role	Percent
Collecting data	80%
Analyzing data	68%
Preparing samples or specimens	48%
Writing part of a manuscript or report on the research	34%
Conducting computer or mathematical simulations	32%
Designing the research	30%
Synthesizing or fabricating materials	20%
Editing drafts of manuscript written by others	20%
Manufacturing or building a prototype or model	12%
Testing a prototype	11%
Other	2%
None of the above	7%

Source: Undergraduate Student Survey, Item D3.
Notes: N=172.

4.2.4 Undergraduates' Contributions to PIRE Publications

Among undergraduate participants in the PIRE project who traveled outside the U.S. for PIRE-related research, few reported that they had been, or would be, listed as a co-author on a PIRE-related publication (14 and 12 percent, respectively). Among undergraduate co-authors on a PIRE publications, 75 percent reported one such publication, with one-quarter reporting six or more; the

average number of publications was one. For the undergraduates anticipating co-authorship, 80 percent reported one publication in preparation, under review or in press and 20 percent reported two such publications. On average, 90 percent of these publications and 60 percent of the publications not yet published included a foreign co-author.

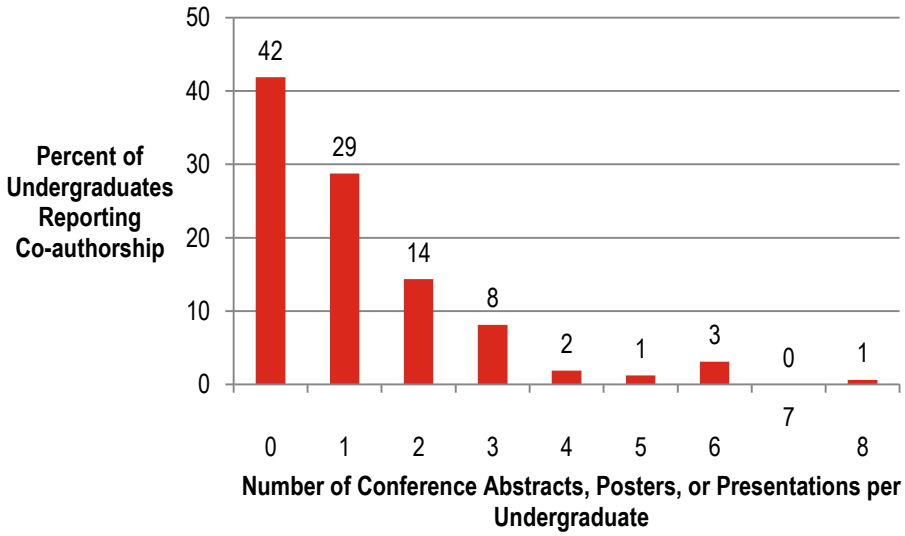
Exhibit 4.23: Percent of Undergraduate Students Reporting that They Have Been Or Will Be Listed as a Co-Author on a Paper Resulting from the Project (N=172)

Actual or Anticipated Co-authorship	Percent
I have been listed as a co-author on a publication	14%
I will be listed as a co-author on a paper that is in preparation, under review for possible publication or in press (accepted for publication but has not yet appeared)	12%

Source: Undergraduate Student Survey, Items D1 and D2a.
Notes: N=172.

Among undergraduate participants in the PIRE project who traveled outside the U.S. for PIRE-related research, more than half (58 percent) reported contributing to at least one conference abstract, poster or presentation. Exhibit 4.24 shows the distribution of the number of undergraduates contributing as a co-author on a conference abstract, poster or presentation (the average undergraduate contributed to one such product). On average, 60 percent of these conference-related materials included a foreign author. Less than 2 percent of PIRE undergraduates who traveled abroad for PIRE-related research reported contributing to a patent, but 15 percent of these undergraduates reported contributing to some other product that had been disseminated to a scholarly community or the public (e.g., educational materials, software, dataset or database).

Exhibit 4.24: Distribution of Number of Co-Authored Conference Abstracts Reported by PIRE Undergraduates Who Traveled Abroad to Conduct Research (N=172)



Source: Undergraduate Student Survey, Item D2b.
Notes: N=172, missing=12. Only under undergraduates who had traveled abroad for the PIRE project were asked about any co-authored publications, conference papers, patents or other products.

4.2.5 Mentoring

Among undergraduate respondents who traveled outside the U.S. for PIRE-related research, the majority of students reported that a U.S.-based faculty member acted as their primary mentor (70

percent). Another 19 percent reported that a non-U.S.-based faculty member or senior-level researcher served in this role, and 10 percent reported having a graduate student mentor.

Exhibit 4.25: Undergraduate Students' Primary Mentor for Research Related to PIRE Project (N=172)

Primary Mentor	N	%
A U.S.-based faculty member (or other senior-level researcher, such as a postdoc)	121	70%
A faculty member or senior-level researcher based primarily outside the U.S.	32	19%
A graduate student based primarily outside the U.S.	9	5%
A U.S.-based graduate student	8	5%
Other	1	1%
I did not have a mentor for this research	1	1%

Source: Undergraduate Student Survey, Item B15.
Notes: N=172.

Respondents reported high levels of satisfaction with their PIRE mentors. The majority reported that their mentor helped them acquire research methods and techniques, and demonstrated a sincere interest in their learning (92 percent each).

Exhibit 4.26: Undergraduate Students' Opinions on Primary Mentor While Working on PIRE Project (N=171)

	Strongly Disagree or Disagree		Strongly Agree or Agree	
Mentor's Contribution to Student	N	%	N	%
Mentor helped me acquire the methods or techniques needed for the research	14	8%	157	92%
Mentor showed sincere interest in my learning	14	8%	157	92%

Source: Undergraduate Student Survey, Item B16.
Notes: N=171.

4.2.6 Undergraduates Who Enrolled in, or Planned to Enroll in, Graduate School

Among undergraduate respondents who earned their bachelor's degrees prior to the survey date, approximately half reported that they were currently enrolled in a graduate degree program (54 percent).[18] The majority of these students reported that they expect to earn a doctoral degree (61 percent), while approximately one-third expect to earn a master's degree (30 percent). Ten percent of respondents expect to earn a professional degree (8 percent) or a post-baccalaureate certificate (2 percent).

[18] Less than 5 percent were in graduate school outside the U.S.

Exhibit 4.27: Percent Enrolled in and Degree Expected to Earn in Graduate Degree Program

Graduate Degree Expectations	N	%
Currently enrolled in graduate degree program[1]	132	54%
Degree expected[2]:		
Post-baccalaureate certificate (e.g., teaching certificate)	2	2%
Master's degree (includes MBA, MEd, etc.)	39	30%
Doctoral degree (PhD, EdD, etc.)	81	61%
Professional degree (only includes: chiropractic, dentistry, law, medicine, optometry, osteopathic medicine, pharmacy, podiatry, ministry or divinity, or veterinary medicine)	10	8%

Source: Undergraduate Student Survey, Items E3 & E4a.

Notes:

[1] Only participants who had completed their bachelor's degree (N=246) were asked about graduate school enrollment. Currently enrolled: N=244, missing=2.

[2] Degree expected: N=132.

The majority of respondents enrolled in a graduate program reported that their field of study is in the sciences, mathematics, or engineering fields (77 percent). Within this group, engineering was the most commonly reported subfield (25 percent), followed by biological sciences (13 percent), physics (12 percent), and earth, atmospheric, and ocean sciences (11 percent).

Exhibit 4.28: Field of Degree for Graduate Program Among Former PIRE Undergraduates Currently Enrolled in Graduate School (N=132)

Field of Expected Graduate Degree	N	%
Sciences, mathematics, or engineering	102	77%
Medical or health sciences	12	9%
Social sciences	10	8%
Other fields	6	5%
Humanities/arts	1	1%
Business, management	1	1%

Source: Undergraduate Student Survey, Item E4c.

Notes: N=132. See the Undergraduate Student Survey for the list of subfields associated with the major disciplines above.

Among respondents who had earned their bachelor's degree but were not enrolled in a graduate program as of the survey date, the majority reported that they intend to pursue a master's or doctoral degree in a STEM field (43 percent). Fourteen percent of respondents reported that they do not intend to pursue any additional education and 12 percent intend to pursue a medical degree.

Exhibit 4.29: Educational Plans Beyond Bachelor's Degree (N=76)

Educational Plans	N	%
A master's or doctoral degree in engineering, computer science, mathematics or the natural (biological or physical) sciences	33	43%
A medical degree (MD)	9	12%
A master's or doctoral degree in the social sciences	6	8%
A business degree (MBA)	6	8%
A master's or doctoral degree in a field other than engineering, computer science, math, the natural or social sciences	4	5%
A joint medical and doctoral degree (MD/PhD)	1	1%
Another health-related or professional counseling degree (e.g., nursing, Psy.D., social work)	1	1%
A teaching certificate or master's degree related to a field in which I teach/will teach	1	1%
None of the above: a different graduate degree or certificate	4	5%
I do not intend to pursue a graduate degree or certificate	11	14%

Source: Undergraduate Student Survey, Item E5.

Notes: N=76.

4.2.7 Reported Benefits and Challenges of PIRE

Among undergraduate students who traveled outside the U.S. for PIRE-related research, 82 percent of respondents agreed or strongly agreed that different cultural perspectives improved the quality of the research. The majority of students reported that neither administrative procedures nor language differences hindered the progress of their project's research (80 percent and 82 percent, respectively).

Exhibit 4.30: Reported Benefits/Challenges While Participating in PIRE Project (N=172)

	Strongly Agree or Agree		Strongly Disagree or Disagree		Not Applicable	
Benefit/Challenge	N	%	N	%	N	%
Different cultural perspectives improved the quality of the research	140	82%	13	8%	18	11%
Regulatory, bureaucratic or administrative procedures in a foreign country hindered the progress of the research	30	18%	136	80%	5	3%
Language differences hindered the progress of the research	27	16%	140	82%	4	2%

Source: Undergraduate Student Survey, Item B17.
Notes: N=172.

Among those who traveled abroad, 70 percent reported facing no challenges (Exhibit 4.31). The challenges most commonly reported by undergraduates were not enough opportunity to contribute to research and not enough supervision or mentoring (10 percent each).

Exhibit 4.31: Reported Challenges Encountered While Participating in PIRE Project (N=172)

Challenges	N	%
None	121	70%
Not enough opportunity to contribute to the research	17	10%
Not enough supervision or mentoring	17	10%
Not enough information or guidance to prepare for the foreign component of the research	11	6%
Other—specify	10	6%
Unexpected financial burdens	9	5%
Delays pursuing/completing my bachelor's degree	8	5%
Bias from foreign members of the research team based on my nationality, gender, race, ethnicity, religion, disability	6	3%
My contributions to the research were not always appreciated or respected	3	2%
Too much supervision	1	1%

Source: Undergraduate Student Survey, Item B18.
Notes: N=172.

Among undergraduate respondents who traveled outside the U.S. for PIRE-related research, the majority reported that their participation in the project yielded a range personal benefits (Exhibit 4.32). Most commonly reported among these was an understanding of how scientists work on real problems (81 percent), followed by tolerance for obstacles faced in the research process (71 percent), self-confidence in their field of study (69 percent), and clarification of a career path (67 percent).

Exhibit 4.32: Reported Benefits of PIRE Participation (N=172)

Benefit of Participation	Very Large to Large Benefit		Moderate to Small Benefit		No Benefit		Not Applicable	
	N	%	N	%	N	%	N	%
Understanding of how scientists work on real problems	140	81%	31	18%	0	0%	1	1%
Tolerance for obstacles faced in the research process	122	71%	45	26%	2	1%	3	2%
Self-confidence in my field of study	118	69%	43	25%	9	5%	2	1%
Clarification of a career path	115	67%	53	31%	2	1%	2	1%

Source: Undergraduate Student Survey, Item D4.
Notes: N=172.

Ninety-two percent of PIRE undergraduate participants indicated that they would strongly recommend international research or education to their peers, with an additional 6 percent indicating they would recommend it. Only 3 percent indicated they would recommend it with reservations, and no undergraduates indicated they would not recommend it.

In explaining why they would recommend participation in PIRE to others, undergraduates cited PIRE as an opportunity for: broadening of research/academic perspectives (62 responses); cultural and social exchange (45 responses); enhancing knowledge and skills (31 responses); professional growth and improves post-graduate opportunities (28 responses); expanding ability to conduct relevant/hands on research (23 responses); personal growth (20 responses); gaining a better understanding of research opportunities/field (18 responses); developing important connections or networks (14 responses); learning from scientific experts (6 responses); and international travel (5 responses).

When asked about the specific aspects of their participation in PIRE that had been most beneficial to them, undergraduate students who traveled abroad for the project described: experiences collaborating with international researchers (34 responses); development of new tools/skills (26 responses); enhanced network (26 responses); role in clarifying/aiding career goals (27 responses); opportunity to live/travel abroad (23 responses); cultural and social exchange (22 responses); improved understanding of research experience/process (21 responses); exposure to new research/academic perspectives (19 responses); language acquisition (13 responses); personal growth (10 responses); experience presenting findings (8 responses); and relationship with mentor (5 responses).

Specific aspects of their PIRE participation that they cited as most challenging included: specific research issues (28 responses); limited knowledge or experience needed for project (22 responses); communication or cultural barriers (34 responses); issues with collaborative partnerships (16 responses); issues related to travel (9 responses); lack of guidance or support (9 responses) lack of time (8 responses); and issues related to resources or equipment (5 responses).

4.3 Foreign Senior Investigators in PIRE

Surveys of PIRE senior investigators based in foreign institutions provided data on the perspectives of the experiences of participants in partner countries.

4.3.1 Travel for the PIRE Project

Less than half of foreign investigators traveled internationally during their participation in the PIRE project (48 percent; Exhibit 4.33). Among those who traveled abroad, the majority traveled to the U.S. (78 percent). On average, foreign investigators took 3 to 4 international trips during their participation in the project.

Exhibit 4.33: Percentage of Foreign Investigators Who Traveled Abroad During the PIRE Project

Traveled Abroad	N	Percent
Traveled internationally during project[1]	58	48%
Among those who traveled, traveled to U.S.[2]	45	78%
Number of International Trips	**Mean**	**SD**
Among those who traveled, average number of international trips[3]	3.4	3.0

Source: Foreign Senior Investigator Survey, Items C8, C9 and C10a.
Notes:
[1] N=120, missing=2.
[2] N=58.
[3] N=57, missing=3.

In addition to their own travel, foreign investigators were also asked to report whether other project staff at their institution traveled internationally and whether any of that travel was to the U.S. Forty-eight percent of respondents reported that one or more members of their institution traveled abroad for PIRE, and 84 percent reported that team members who traveled abroad visited the United States. The most commonly reported group of individuals to travel abroad was senior researchers (72 percent), followed by graduate students (63 percent), postdoctoral researchers (37 percent), and undergraduate students (10 percent). Similar proportions of foreign investigators reported that senior researchers and graduate students traveled to the U.S. (69 percent and 61 percent, respectively). In comparison, fewer respondents reported that postdoctoral researchers and undergraduate students visited the U.S. (42 percent and 14 percent, respectively).

Exhibit 4.34: Types of Individuals from FI's Institution Who Traveled Internationally and Visited the U.S. for the PIRE Project

Type of Individual Who Traveled Abroad	Internationally for PIRE Project		To the U.S. for PIRE Project	
	N of Foreign Investigators	%	N of Foreign Investigators	%
Any member of FI's institution traveled outside home country[1]	49	91%	46	84%
FI reported that one or more undergraduate students traveled…[2]	5	10%	7	14%
FI reported one or more graduate students traveled…[3]	31	63%	31	61%
FI reported one or more postdoctoral researchers traveled…[4]	19	37%	21	42%
FI reported one or more senior researchers traveled…[5]	39	72%	38	69%

Source: Foreign Senior Investigator Survey Item C12.
Notes: N indicates the number of foreign senior investigators who reported that a certain member from their institution traveled internationally and/or to the U.S. for the project.
[1] Traveled internationally: N=54, missing=5; visited the U.S.: N=55, missing=4.
[2] Traveled internationally: N=50, missing=9; visited the U.S.: N=49, missing=10.
[2] Traveled internationally: N=49, missing=10; visited the U.S.: N=51, missing=8.
[3] Traveled internationally: N=51, missing=8; visited the U.S.: N=50, missing=9.
[4] Traveled internationally: N=54, missing=5; visited the U.S.: N=55, missing=4.

4.3.2 Collaborations

Foreign investigators reported on collaborations before, during, and after to their participation in the project with individuals who were primarily based inside the U.S.

Collaborations during the project with U.S. project colleagues

The majority of respondents reported that they collaborated with PIRE team members based within the U.S. The highest proportion of foreign investigators reported working with senior-level

researchers (94 percent), followed by graduate or undergraduate students (81 percent) and postdoctoral researchers (69 percent).

Exhibit 4.35: Percent of FIs Who Collaborated During the Project with Individuals Based within the U.S.

Type of U.S.-Based Partner	N	%
Senior-level researchers based primarily in the U.S.[1]	114	94%
Postdoctoral researchers based primarily in the U.S.[2]	82	69%
Graduate or undergraduate students based primarily in the U.S.[3]	96	81%

Source: Foreign Senior Investigator Survey, Item B1a.

Notes:

[1] Senior-level researchers: N=121, missing=1.

[2] Postdoctoral researchers: N=119, missing=3.

[2] Graduate or undergraduate students: N=119, missing=3.

Percent of FIs who had a collaboration before the start of the PIRE project

For most foreign investigators, PIRE was not their first research collaboration with a U.S.-based partner. Eighty-two percent of respondents reported working with a U.S.-based individual on research prior to their participation in the PIRE project. Among these respondents, 69 percent reported that they collaborated with a U.S.-based partner with whom they would eventually work on the PIRE project. Ninety-four percent reported that their pre-PIRE collaboration had existed for one year or longer.

Exhibit 4.36: International Research Collaborations Prior to Participation in PIRE

Collaborated Prior to PIRE Project with:	N	%
U.S.-based partner(s)[1]	94	82%
U.S.-based partner(s) who also participated in PIRE project[2]	65	69%
Of those collaborated prior to PIRE with U.S-based PIRE colleague:[3]		
Duration of prior collaboration was 1 year or more	61	94%
Duration of prior collaboration was 1 to 12 months	4	6%

Source: Foreign Senior Investigator Survey, Items D1, D2, D3.

Notes:

[1] N=114, missing=8.

[2] N=94.

[3] N=65.

Collaborations subsequent to participation in the project

A key outcome for the study is the extent to which PIRE foreign investigators continued collaborations with U.S.-based colleagues after their participation in the project had ended. In addition, the study collected descriptive data on the nature of these continued collaborations and any subsequent collaborations with U.S-based colleagues who were not part of the PIRE or project teams. Only participants in expired projects (and participants who reported that their contributions to the project had ended prior to the survey reference date) were asked to report on these outcomes.

Foreign investigators continued to collaborate with U.S.-based researchers after their participation in the PIRE project. Eighty-four percent of respondents reported collaborating with a U.S.-based member of the PIRE team who was and still is based in the U.S., and 32 percent reported working with a U.S.-based member of the PIRE team who was based in the U.S. but is currently based outside the U.S. (Exhibit 4.37). Additionally, 77 percent of foreign investigators reported collaborating with a non-PIRE U.S.-based partner after the end of their project participation.

Exhibit 4.37: Collaboration, After Participation in the Project, with a U.S.-Based Partner

Type of U.S.-Based Partner	N	%
One or more project members who were—and are still—based primarily in the U.S.[1]	51	84%
One or more project members who were based primarily in the U.S. but who are now based primarily outside the U.S. [2]	18	32%
With a U.S. partner not affiliated with PIRE project[1]	47	77%

Source: Foreign Investigator Survey, Item B1b & B1e.
Notes:
[1] N=61.
[2] N=57, missing=4.

Types of Collaborative Activity After Participation in PIRE

Foreign investigators reported engaging in a range of different activities with their U.S.-based partners after their participation in the PIRE project (Exhibit 4.38). Most common among them was discussing developments in the research field (83 percent), followed by sharing data or other resources (76 percent), meeting with one or more partners at a U.S. conference (67 percent), working with a U.S.-based partner outside the U.S. (63 percent), and planning and conducting research project(s) (57 percent each). Less than half of respondents reported traveling to the U.S. (46 percent), and less than one-tenth reported having a position in the U.S. (9 percent) or working with a U.S.-based partner with a position outside the U.S. (7 percent).

Exhibit 4.38: Percent Reporting Selected Types of Collaborative Activities with U.S.-Based Colleague from the Project Team, After Participation in the Project Had Concluded (N=54)

Type of Activity	N	%
Discussed developments in our research field(s) with a U.S.-based partner	45	83%
Shared data or other resources with a U.S.-based partner	41	76%
Met with one or more U.S.-based partners at conferences in the U.S.	36	67%
A U.S.-based partner has worked with me at location(s) outside the U.S.	34	63%
Planned one or more research projects with a U.S.-based partner	31	57%
Conducted one or more research projects with a U.S.-based partner	31	57%
Traveled to the U.S. to work with one or more U.S.-based partners	25	46%
Have (or have had) a position at an institution within the U.S.	5	9%
A U.S.-based partner has (or has had) a position at an institution outside the U.S.	4	7%

Source: Foreign Investigator Survey Item B1d.
Notes: N=54.

4.3.3 Foreign Investigators' Funding for Participation in the PIRE project

PIRE award funds are restricted to U.S. personnel; as a result, foreign investigators needed their own resources to participate in the PIRE project. Beginning with the competition for the 2012 cohort of PIRE awards, NSF began working with counterpart funding agencies in a number of countries to enhance opportunities for FIs to obtain funding (the U.S. Agency for International Development and the U.S. Environmental Protection Agency were among these counterpart agencies). Although NSF's outreach to these agencies to support PIRE awards began in 2012, investigators were likely aware of these counterpart agencies as a potential funding source before then. Thus, we asked all FIs (regardless of PIRE cohort) whether they obtained funding from any of these counterpart agencies or from another source.

Nearly one-quarter of FIs reported that they received funding from none of the sources listed (including any other source not listed which they could specify). Among the most commonly reported source of funding to support PIRE activities was foreign investigators' institution or employer (44 percent), followed by a government or institution in another country (38 percent). Less than 20

percent of foreign investigators reported that they received funding from each of several other potential sources listed in Exhibit 4.39, below.

Exhibit 4.39: Sources and Uses of Funding Received for Project Participation

Funding Sources and Uses of Funding	N	%
Funding Sources[1]		
My institution or employer	53	44%
Another government or national institution not among those listed in the survey[2]	46	38%
An international institution (not among those listed)	13	11%
U.S. Agency for International Development (USAID)	4	3%
Private industry (domestic, foreign, or multinational company)	3	2%
A foundation or philanthropic organization (e.g., Gates Foundation)	2	2%
U.K. Engineering and Physical Sciences Research Council (EPSRC)	1	1%
Ministry of Education and Science (MES) of the Russian Federation (RF)	1	1%
U.S. Environmental Protection Agency (US EPA)	1	1%
Other	19	16%
U.K. Economic and Social Research Council (ESRC)	0	0%
Japan Science and Technology Agency (JST)	0	0%
Inter-American Institute for Global Change Research (IAI)	0	0%
None of the above	29	24%
Funding Uses[3]		
To support my work on the project	67	55%
To pay for equipment, supplies, resources or facilities, or for access to such resources	51	42%
To support one or more graduate students working on the project	46	38%
For travel outside my country that was necessary to conduct the research	44	36%
For travel to professional conferences (either outside my country or within my country)	41	34%
For expenses related to hosting international guests (e.g., housing, meals, etc.)	39	32%
For travel within my country that was necessary to conduct the research	38	31%
None	28	23%
To support one or more postdoctoral researchers working on the project	26	21%
To support educational activities such as courses, lecture series, seminars	23	19%

Sources: Foreign Senior Investigator Survey, Items C1 and C2.

Notes:

1 Funding sources: N=121, missing=1.

2 The survey listed counterpart agencies in other countries with whom NSF works to coordinate joint international research and educational efforts. The survey included an option for FIs to indicate "another government or national institution" that was not among the counterpart agencies listed in the survey but from which they had received funding.

3 Funding uses: N=121, missing=1.

The most commonly reported use of funding that FIs did obtain was to support foreign investigators' own work on the project (55 percent), followed by purchasing equipment, supplies, resources or facilities (42 percent). Approximately one-third of respondents reported that they used these funds to support graduate students (38 percent), to travel abroad for research (36 percent) or to a conference (34 percent), to house international guests (32 percent), and to travel within their country to conduct research (31 percent). Roughly one-fifth of foreign investigators used these funds to support postdoctoral researchers (21 percent) or educational activities (19 percent).

Almost half of foreign investigators reported receiving less than $50,000 to support PIRE activities (Exhibit 4.40), while another 20 percent reported receiving more than $100,000 and 7 percent reported receiving a figure between those two amounts.

Exhibit 4.40: Total Estimated Amount of Funding Received to Support Research or Educational Activities for the PIRE Project (in USD) (N=59)

Amount in USD	N	%
Less than 50,000 USD	29	49%
50,001 to 100,000 USD	4	7%
More than 100,000 USD	12	20%

Source: Foreign Senior Investigator Survey, Items C3a & C3b.
Notes: N=59, missing=1. Fourteen (24 percent) FIs who answered in USD did not know the total amount of funding received. Respondents were asked if they could report the total amount of funding received in terms of U.S. dollars. Of 122 FIs respondents who reported that they had obtained funding (Item C1) to support their PIRE participation, 60 provided an amount in U.S. dollars.

4.3.4 Foreign Senior Investigators' Role in the Project

The majority of foreign investigators report that they were involved in the planning, designing or conceptualizing of the PIRE project activities (78 percent). Among these respondents, 88 percent met in person with project team members based outside their own country. Among the 22 percent of foreign investigators not involved in the initial planning stages, the majority reported that their exclusion resulted in either no or only minor difficulties with the project (92 percent).

Exhibit 4.41: Foreign Investigators' Participation in Project Planning

Role in Project Planning	N	%
Involved in planning, designing or conceptualizing the research or educational activities for the project[1]	93	78%
During planning of the project, met in person with project colleagues based outside your own country (for those who were involved in planning)[2]	83	88%

Source: Foreign Senior Investigator Survey, Items C4-C6.
Notes:
1 N=119, missing=3. Respondents who answered "yes" [involved in planning, designing or conceptualizing the research or educational activities for the project] (93) or who did not answer the question (3) were directed to Item C6 [During planning of the project, met in person with project colleagues based outside their own country].
2 N=94, missing=2.
3 N=26. 26 (22%) respondents were not involved in planning, designing or conceptualizing the research or educational activities for the project.

Foreign investigators were asked to report which PIRE project team member(s) had primary responsibility for key aspects of project research—both U.S.-based and non-U.S.-based partners, only U.S.-based partners, or only non-U.S.-based partners. For all but two research activities listed in Exhibit 4.42 below, the greatest proportion of respondents reported that responsibility was shared equally by U.S.- and non-U.S.-based team members. Foreign investigators reported that U.S.-based partners had primary responsibility for developing ideas, hypotheses, or vision for the project (53 percent) and coordinating the multi-national team of researchers (56 percent).

Exhibit 4.42: Percent of FIs Reporting Who Had Primary Responsibility for Key Project-Related Research Activities (N=113)

Project-Related Research Activity	U.S.-Based and Non-U.S.-Based Partners Shared Responsibility About Equally	U.S.-Based Partners Had Primary Responsibility	Non-U.S.-based Partners Had Primary Responsibility	Not Applicable (this activity was not part of the research)	Don't Know
Interpreting results	73%	13%	5%	5%	4%
Disseminating results through publications and presentations	71%	19%	5%	1%	4%
Analyzing data	65%	15%	9%	7%	4%
Collecting data	56%	17%	12%	9%	6%
Developing instrumentation, software, equipment, or data collection approaches	43%	26%	12%	8%	11%
Developing the ideas, hypotheses, or vision for the research project	42%	53%	3%	0%	3%
Preparing samples or specimens	38%	18%	16%	22%	7%
Coordinating the multi-national team of researchers	36%	56%	4%	2%	3%
Synthesizing or fabricating materials	23%	15%	11%	34%	18%

Source: Foreign Senior Investigator Survey, Item C13.
Note: N=113, missing=8.

4.3.5 Reported Benefits and Challenges of PIRE

Foreign investigators were asked to report on the benefits and challenges experienced during their participation in the PIRE project. Almost all respondents agreed or strongly agreed that their research benefitted from access to the expertise of U.S.-based researchers (96 percent), and large proportions agreed or strongly agreed that their research benefitted from access to data acquired in foreign locations (81 percent), different cultural perspectives (76 percent), and access to equipment or facilities in foreign locations (71 percent). The majority of foreign investigators reported that neither administrative procedures nor language differences, hindered the progress of their project's research (75 percent and 86 percent, respectively).

Exhibit 4.43: Benefits and Challenges of PIRE Project on Foreign Senior Investigator's Research

Benefit/Challenge	Strongly Agree or Agree		Strongly Disagree or Disagree	
	N	%	N	%
My research benefited from access to expertise of U.S. researchers in my field	109	96%	4	4%
My research benefited from access to data acquired in foreign locations	92	81%	21	19%
Different cultural perspectives improved the quality of the research	85	76%	27	24%
My research benefited from access to equipment or facilities in foreign locations	79	71%	32	29%
My research benefited from access to place-based phenomena that occur outside my country (e.g., biological, geological, cultural phenomena)	53	47%	59	53%
Regulatory, bureaucratic or administrative procedures for U.S. personnel [have hindered/hindered] the progress of the research	28	25%	84	75%
Language differences hindered the progress of the research	16	14%	96	86%

Source: Foreign Senior Investigator Survey, Item E1.
Note: Ns range from 111-113, missing range from 9-11.

Similarly, when asked about a range of other potential challenges to participation in the PIRE project, 77 percent reported that they did not experience any challenges (Exhibit 4.44). The most commonly reported specific challenge faced by foreign investigators was that expected funding was not obtained, was reduced, or was withdrawn (10 percent).

Exhibit 4.44: Challenges Foreign Senior Investigators' Experienced During Project (N=114)

Challenges	N	%
None	88	77
Funding expected was not obtained, was reduced or withdrawn	11	10
Inadequate access to data, specimens, facilities, equipment, or other resources	7	6
Delays in getting publications written due to the cross-cultural nature of the team	4	4
Conflicts over authorship or credit for contributions to the research	2	2
Bias from U.S.-based researchers based on my nationality, gender, race, ethnicity, religion, disability, nationality, or sexual orientation	1	1
Key U.S.-based researchers were not as available as I expected or did not contribute enough to the project	1	1
Other	12	11

Source: Foreign Senior Investigator Survey, Item E3.
Note: N=114, missing=8.

Foreign investigators were overwhelmingly positive when asked about their U.S.-based partners (Exhibit 4.45). All respondents reported that they either agreed or strongly agreed that senior partners were sufficiently knowledgeable and expert to fully participate in the research collaboration. Foreign investigators agreed or strongly agreed that their U.S.-based partners integrated well with members of their group (94 percent) and demonstrated interest in the scientific culture and organization and the history, culture, and customs of their country (87 percent and 82 percent, respectively).

Exhibit 4.45: Perception of U.S. Colleagues By Foreign Senior Investigators (N=113)

Perception of U.S. Colleagues	Strongly Agree or Agree		Strongly Disagree or Disagree		Not Applicable	
	N	%	N	%	N	%
Senior U.S.-based partners had sufficient knowledge and expertise to be a full participant in a research collaboration	113	100%	0	0%	0	0%
U.S.-based partners integrated well with members of my group	106	94%	4	4%	3	3%
U.S.-based partners showed interest in scientific culture and organization, and how it is organized and funded in my country	98	87%	10	9%	5	4%
U.S.-based partners showed interest in learning about the history, culture, and customs of my country	93	82%	12	11%	8	7%

Source: Foreign Senior Investigator Survey, Item E2.
Note: Note: N=113, missing=9.

5. Institutional Policies and Practices for International Research and Education

From each of the 59 PIRE sponsoring institutions (i.e., the institution of the lead PI), we sought an administrator who could speak to the institutional policies and practices that may have influenced the operation of research and educational activities associated with their institution's PIRE award. This chapter examines these institutional policies and practices and the influence that these policies and practices might have had on the PIRE project—and how PIRE might have affected any institutional changes. Specifically, the findings address the following research question:

- RQ 5. How do international affairs representatives at PIRE lead PIs' institutions perceive the effects of PIRE on their institutions' policies and practices for supporting international research and educational collaborations?

Surveys of institutional administrators provide insight into how PIRE projects operate within U.S. institutions of higher education (IHEs) and the role these projects played within IHEs. Key findings include:

- Institutional representatives reported that their institutions support international research and education initiatives through a variety of mechanisms, and the majority indicated that policies and practices mostly facilitated graduate and undergraduate participation in international opportunities.
- Institutional representatives found that PIRE aligned well with existing institutional goals for internationalization.
- A greater number of representatives described institutional factors that support undergraduate and graduate student involvement in education and research activities abroad than the number that described barriers to such involvement. However, more representatives mentioned barriers to undergraduate than graduate student participation in international opportunities.
- The majority of administrators responded that PIRE had not resulted in any changes in policies or practices related to undergraduate or graduate education in STEM fields (32 respondents). Among the 14 responses that credited PIRE with effecting change, many indicated that faculty, students and administrators had increased awareness of the value of international research experiences for students.

5.1 PIRE Institutions' Mechanisms of Support for International Research and Education

Administrators were asked whether their institution had supported international research and education initiatives through the specific mechanisms presented in Exhibit 5.1. The large majority of administrators responded that their institutions: assisted students with arrangements for research/education abroad (42 respondents); coordinated with partner institutions outside the U.S. (41); assisted faculty with international arrangements (40); had an existing international exchange program (40); provided assistance developing international components of proposals (37); and provided seed money to faculty planning international collaboration (33).

Exhibit 5.1: Ways in which the PIRE Sponsoring Institution Facilitated International Research or Education Initiatives

	Institutional Administrator Survey	
	N	%
Assisted students with arrangements for research/education abroad	42	93%
Helped participants in international activities coordinate with a partner institution in one or more countries outside the U.S.	41	91%
Assisted faculty with arrangements for international research/education abroad	40	89%
Have existing exchange program with one or more countries outside the U.S.	40	89%
Provided faculty writing grant proposals with assistance developing the international components of a proposal	37	82%
Provided faculty planning international research/education collaborations with seed money	33	73%
Have a campus in a country outside the U.S.	11	24%
Other	5	11%

Source: Institutional Administrator Survey, Item Q6.
Note: N=46.

Administrators also described how PIRE fit within a larger institutional context. For example, administrators frequently cited the PIRE award as being aligned with the institution's goal of expanding its global reach (15 responses) and/or with efforts to build international partnerships (13). Other respondents reported that the PIRE project fit the institution's goal of providing students with new experiences and opportunities (9) and others that PIRE supported their institution's goal of producing a strong record of research and publications (6).

> *The PIRE program has complete synergy with our institution's strategy of expanding our global reach through sending more students abroad, hosting more international students and scholars and building long-lasting strategic partnerships with select institutions around the world. It convinces us that our philosophy of not developing offshore campuses is the right one for us. (Administrator at a 2005 PIRE awardee)*

> *One mandate for our institution is to expand its global reach, and in addition, international experiences are considered an asset in students' educations. The PIRE stands as an example of how interdisciplinary research and education at both the undergraduate and graduate levels can all come together. (Administrator at a 2010 PIRE awardee)*

> *Our institution strives for excellence and its goal is to become a "world's ahead" university. Being aware of other top international universities is a key to achieve this goal. PIRE has helped our institution to partner with some of the best academic research institutions in the world. We have learned a great deal from their success and we believe that we have made a great impression on them by sending some of our top student and faculty researchers to their institutions. (Administrator at a 2007 PIRE awardee)*

> *The PIRE award advanced the university's goals of advancing undergraduate research and research abroad. It provided a concrete model of an undergraduate research abroad program. (Administrator at a 2007 PIRE awardee)*

> *PIRE broadened the scope of joint international research and academic collaboration for our faculty and provided excellent opportunities for our students to conduct cutting-edge research in some of the best laboratories/institutions abroad. (Administrator at a 2012 PIRE awardee)*

5.2 Institutional Factors Influencing Student Participation in International Research and Education

Responses provided insight into institutional factors that facilitated participation of students in research or education outside the U.S. (Exhibit 5.2). The majority of institutional administrators perceived institutional policies and practices as "mostly facilitating" participation of STEM undergraduate and graduate students in international research or education activities (26 and 28 respondents, respectively). More than one-quarter thought that policies and practices had mixed effects for undergraduates, with some policies facilitating and others hindering participation (12 and 7 respondents, respectively), whereas just 15 percent (7 respondents) thought that there were mixed effects for graduate students. Small proportions of respondents reported that their institutional policies and practices mostly hindered or had no effect on participation by undergraduate or graduate students.

Exhibit 5.2: Institutional Policies or Practices that Facilitate or Hinder Undergraduate or Graduate Student Participation in Research or Education Activities Outside the U.S.

	Undergraduate Students		Graduate Students	
	N	%	N	%
Policies or practices mostly facilitate participation	26	57%	28	61%
Both: Some policies or practices facilitate participation and other policies or practices hinder participation	12	26%	7	15%
Policies or practices mostly hinder participation	4	9%	4	9%
Neither: Institutional policies or practices neither facilitate nor hinder participation	3	7%	6	13%
Not applicable	1	2%	1	2%

Source: Institutional Administrator Survey, Items Q2 & Q3.
Note: N=46.

5.2.1 Factors Facilitating Undergraduate International Engagement

Forty-three respondents cited one or more factors that served to facilitate undergraduate engagement in international opportunities. These factors varied, but multiple respondents mentioned general institutional support for international experiences for undergraduate students (13 responses).

> *The University wholeheartedly embarked on a strategic path of expanding our global reach. This University-wide effort was largely faculty-driven and administratively-enabled. This encouraged faculty to look beyond the traditional study-abroad programs and creatively integrate international experiential learning into courses and research programs. This greatly facilitated global research opportunities for undergraduate students. (Administrator at a 2005 PIRE awardee)*

> *We are implementing a comprehensive internationalization program, which considers undergraduate overseas research participation highly valuable. (Administrator at a 2007 PIRE awardee)*

Administrators also cited their study abroad/international programs office as a more specific example of the institution facilitating undergraduates' participation in international research and education (13 responses).

> *Our Office of International Programs has several programs to facilitate UG visits to international universities. Some of these offer opportunities for research participation. Our Chancellor encourages international travel and engagement during every convocation. (Administrator at a 2005 PIRE awardee)*

[Our institution] has an active Office of International Affairs with a strong Study Abroad component. Personnel and associated policies are designed to help students in multiple ways, including academically, financially, and procedurally. (Administrator at a 2007 PIRE awardee)

The study abroad office works closely with the colleges / academic disciplines to facilitate undergraduate study/research abroad. The study abroad office helps students with the application process, visas, finances, etc. (Administrator at a 2010 PIRE awardee)

Some administrators mentioned that their institution helped undergraduates find sources of funding to support international experiences (6 responses) including scholarships, travel support, or financial subsidies for study abroad programs.

Five administrators reported that their institution specifically promotes opportunities for international engagement to STEM students.

My office designs and administers international exchanges and partnerships, and we actively promote participation of STEM students in our exchanges and specialized programs. We conduct orientations, produce manuals, have an advising infrastructure, and have committees dealing with health and safety abroad. (Administrator at a 2007 PIRE awardee)

5.2.2 Factors Hindering Undergraduate International Engagement

Twenty administrators listed policies or practices that restricted the opportunities for undergraduates to pursue international research or education. The factors cited varied across institutions, but some trends did emerge.

Multiple respondents cited institutional or departmental policies that restricted the ability of undergraduates to pursue international opportunities. At the departmental level, these policies included such things as the structure and scheduling of the curriculum for undergraduate STEM major and/or limited flexibility for meeting course or credit requirements (6 responses):

We actively promote these opportunities, but the structured curricula of many students in these disciplines make it difficult for them to take advantage of international opportunities. (Administrator at a 2007 PIRE awardee)

…by instituting policies limiting the number of credit hours for a degree, STEM faculty have clamped down on both the number of elective credits and the number of required credits outside the faculty's immediate control. (Administrator at a 2007 PIRE awardee)

One of these respondents also cited increasing pressure on undergraduates to graduate early, which, combined with departmental restrictions on course requirements and the schedule of course offerings, was seen as a barrier to international engagement:

There [is] a push for decreasing graduation time and time spent abroad can add to the time taken to graduate. (Administrator at a 2012 PIRE awardee)

Multiple respondents also cited the high cost of international experience and limited funding sources such as fellowships that might help offset these higher costs (5 responses). Even indirectly, the cost of an international experience can be high, if, for example, time abroad lengthens a student's time to degree completion (thus requiring additional semesters of tuition and other costs of obtaining an undergraduate degree). Three respondents mentioned the challenges of international travel as a barrier, including such factors as export control regulations, or "excessive" university protocols for ensuring students' safety while abroad.

5.2.3 Factors Supporting Graduate Students International Engagement

Thirty-four respondents described institutional policies or practices that facilitated graduate student engagement in international research and education. Eight respondents provided general assurances that their institutions supported international experiences for graduate students. For example:

> *We encourage graduate students to participate in international activities and do what we can to make this as easy as possible for the students and their advisors. (Administrator at a 2012 PIRE awardee)*

Other administrators reported more specific mechanisms to support graduate students' international engagement. Some cited existing partnerships with international institutions (7 responses) or the role of the institution's study abroad or international programs office in assisting graduate students (5 responses). Notably, when describing mechanisms of support for graduate students, fewer administrators mentioned their study abroad office than the number who mentioned this office when describing such support for undergraduate students.

> *The institution has Memoranda of Understanding with institutions across the globe. These MOUs generally provide a mechanism for exchange of graduate students, post-docs, and faculty. Mechanisms will vary depending upon funding source. We currently have graduate students working in Europe, Africa, South America and Southeast Asia and probably other places of which I might not be aware. (Administrator at a 2010 PIRE awardee)*

> *The office that supports undergraduate study abroad can also support graduate study abroad. Fewer graduate students avail themselves of these activities largely because of cost or restrictions on their funding by the funding agencies, or because they simply prefer to stay in the area throughout their training. The award to us of the PIRE was really good in addressing some of these limitations. (Administrator at a 2007 PIRE awardee)*

Other administrators indicated that funding was available for graduate students wishing to pursue international research or education (5 responses), or that the institution and/or departments were flexible enough to accommodate international engagement by graduate students (5 responses), for example, by assisting with credit transfers. In addition, three administrators mentioned that there was strong support from individual faculty for graduate student engagement in international research and education; none of the respondents mentioned this factor when describing support mechanisms for undergraduate international engagement.

5.2.4 Factors Hindering Graduate Students International Engagement

Twelve administrators described institutional policies or practices that hindered graduate student engagement in international opportunities. Multiple respondents cited the high cost of international research or educational opportunities and inadequate availability of funding mechanisms (4 responses). For example, one respondent reported that graduate students who traveled abroad risked losing the tuition waivers they received as part of the university's financial support to graduate students:

> *Since most graduate students are on assistantships and do not pay tuition, study abroad programs do not receive a "tuition return" for graduate students participating in international programs as they do for undergraduates. (Administrator at a 2007 PIRE awardee)*

Others mentioned barriers related to international travel (4 responses) including a risk-averse culture in which administrators were concerned with graduate students' safety abroad, and export control regulations (e.g., on what equipment or data students could bring with them to support the research). International graduate students attending the institution on a single-entry visa had concerns about

their ability to re-enter the U.S. after taking advantage of an international research opportunity. Other respondents cited a lack of structures to facilitate graduate student travel abroad (2 responses).

> *Many units encourage graduate students to engage abroad, and there are some good funding systems in place. But there are few resources to help them prepare to do so, or to provide pre-departure education around health, safety, and cultural adjustment. (Administrator at a 2007 PIRE awardee)*

5.3 Changes Resulting from PIRE

The majority of administrators indicated that their institution's PIRE award had not resulted in any changes in policies or practices related to undergraduate or graduate education in STEM fields (32 respondents). Among the 14 administrators who did cite a change resulting from PIRE, 11 noted a change affecting undergraduates and 14 cited a change affecting graduate students.

5.3.1 Changes Affecting Undergraduates' International Opportunities

The most frequently mentioned change cited as affecting undergraduates' international engagement was greater faculty awareness and improved promotion of international opportunities (5 responses).

> *The greatest impact has been on undergraduate education: PIRE programs have made STEM faculty more sensitive to international collaborations and more knowledgeable about international partners. Thus, faculty are more likely to promote international study and research and better advise their students. (Administrator at a 2007 PIRE awardee)*

Multiple respondents also noted that PIRE demonstrated the value of providing international research opportunities for undergraduates (3 responses), and, as a result, undergraduates were more likely to pursue research experience.

> *[PIRE] demonstrated the need and value for research learning at the undergrad level. Encouraged undergrads to pursue graduate education and research careers. Demonstrated the value of experiential (versus strictly classroom) experience gained overseas. (Administrator from a 2005 PIRE awardee)*

> *The participation of our undergraduate students in multi-disciplinary and internationally spanned collaborative research projects and their valuable contribution reflected in some have encouraged more involvement of our undergraduate in the research labs of our institution. (Administrator at a 2007 PIRE awardee)*

Three respondents cited the new efforts to support undergraduates conducting research overseas.

> *We identified a research liaison within the Office of Research to support students studying abroad. We also developed closer cooperation with the International Student Office to help PIs organize housing, healthcare and other requirements for students working on research projects overseas. (Administrator at a 2010 PIRE awardee)*

5.3.2 Changes Affecting Graduate Students' International Opportunities

The most frequently mentioned change cited as affecting graduate students' international engagement was that expanded awareness of the value of such opportunities led institutions to increase their support for such experiences (7 responses).

> *The most profound [change] is the realization that graduate education, not only research, can be done effectively across borders, taking advantage of complementarity of expertise and facilities. (Administrator at a 2005 PIRE awardee)*

We offer greater support and encouragement for graduate students to consider spending time abroad at collaborating institutions. (Administrator at a 2007 PIRE awardee)

Two respondents indicated that the PIRE award had increased faculty awareness of the advancement of research excellence outside the U.S. (i.e., implying that graduate students were both the vector through which faculty gained this awareness and the likely beneficiary of this newly-engaged faculty).

Faculty gained a greater realization of the competitive landscape in research/innovation among different regions of the world, and how other countries have taken a quantum leap in research and higher education. (Administrator at a 2005 PIRE awardee)

After our graduate students got the opportunity to visit and work in top-ranked research facilities outside [the] U.S., they realized that some of the best research activities and outcome may be done outside [the] U.S. too. This have [sic] encouraged our research faculty members to keep themselves up to date with the latest progress in their field done in other countries, especially European, Asian, and South American countries. (Administrator at a 2007 PIRE awardee)

5.4 Challenges

Most institutional administrators (38) reported that their institution had encountered no challenges related to faculty or student activities in other countries. Among the seven who did describe challenges, two mentioned resource or funding issues:

Not being able to use grant funds to foster international relationships with researchers in less developed countries has limited the choice of institutions with which we partner. Some institutional funds have been used for support of non-grant funded researchers, but not robustly. (Administrator at a 2009 PIRE awardee)

Two mentioned inflexibility of program requirements for students in some disciplines:

The only challenges had to do with inflexibility in some engineering programs that made it hard for students to go abroad. (Administrator at a 2007 PIRE awardee)

And others mentioned safety (1), lack of administrative support (1), or intellectual property issues (1):

Some of our major research partners were located in COUNTRY. During the first year of our PIRE, we sent three students to COUNTRY to work on a long-established collaborative research project. Our students faced some safety issues. Our institution placed a policy not to send any students to COUNTRY until the time that the issue with drug cartels are [sic] resolved. As the safety of our participants were [sic] our highest priority, even though we could make an attempt to waive this restriction, we decided not to do so. This hindered our research collaboration with COUNTRY. (Administrator at a 2007 PIRE awardee)

We did not have a coordinated resource to help faculty work through the HR, legal and benefits questions to be able to send students abroad. As described earlier, we worked through this. (Administrator at a 2007 PIRE awardee)

The … universities [in COUNTRY] were not used to dealing with the [intellectual property] (IP) framework that American universities operate within. Our technology [sic] had a long discussion with the lead [COUNTRY] university, which came to a successful exchange agreement including IP terms. (Administrator at a 2005 PIRE awardee)

6. Societal Impacts

All proposals submitted to NSF must demonstrate evidence of the potential for their project's broader impacts. Given the international partnerships inherent to PIRE projects, NSF was particularly interested to learn whether or not PIRE projects have contributed to global societal challenges, loosely defined as problems facing human populations that any single nation was ill-equipped to tackle alone. In addition, for the 2012 PIRE projects, NSF's solicitation limited proposals to those that were focused on the NSF-wide investment in Science, Engineering, and Education for Sustainability (SEES):

> *A sustainable world is one in which human needs are met equitably without harm to the environment, and without sacrificing the ability of future generations to meet their needs. Meeting this formidable challenge requires a substantial increase in our understanding of the integrated system of society, the natural world, and the alterations humans bring to Earth. NSF's Science, Engineering, and Education for Sustainability (SEES) activities aim to address this need through support for interdisciplinary research and education in all fields of science and engineering. Especially encouraged is research on global sustainability issues including, but not limited to, climate change, clean energy, food security, biodiversity, and communication networks"* (NSF, 2011).

Although this fourth round of PIRE awards directly focused on a set of specific global challenges, the evaluation probed senior investigators' perceptions of PIRE's contributions to society. PIs and FIs described what they perceived to be the benefits of the PIRE project for society at large, including those who had not participated directly in a PIRE project.

This chapter presents findings related to perceived societal or broader impacts of the PIRE projects. Specifically, the findings address the following research question:

- RQ 7. How have PIRE projects contributed to research that may inform global societal challenges?

We summarize the perspectives of PIs and FIs on how their PIRE project benefited society at large and extended benefits beyond those directly participating in the project. Findings in this chapter come from PI and FI surveys and include descriptive summaries of their responses as well as specific examples provided by these senior investigators. Key findings include:

- The three most frequent types of benefits of PIRE described by senior investigators were insights about the natural environment (43 percent of PI responses, 24 percent of FI responses); technological advances that would benefit society (21 percent of PI responses) and PIRE's promotion of cross-cultural exchange (18 percent of PI responses, 32 percent of FI responses). Specific examples included scientific advances in sustainable energy, conservation, understanding climate change, and mitigating hazards from disasters.
- Senior investigators (74 percent of PIs and 78 percent of FIs) noted that their PIRE project has advanced knowledge or led to discoveries that might help address global challenges in health, environmental and other areas in which solutions appear unlikely to emerge from the efforts of one nation acting alone. Asked how their PIRE project could help address these challenges, the mechanism that senior investigators most often mentioned was that PIRE projects leveraged the expertise, resources, and perspectives of a range of international researchers.

- PIs and FIs indicated that findings from their PIRE project could inform policy and planning, provide tools or technologies applicable to global challenges, and provide improved academic models for educating the next generation of researchers.

6.1 Principal and Foreign Investigators' Perception of the Benefits of their PIRE project to Society

Prior to survey data collection, we conducted two focus groups with eight PIs each at the May 2014 PIRE PI meeting to understand how PIs would interpret the "global societal impacts" of PIRE. Virtually all of the focus group participants singled out the educational opportunities for graduate and undergraduate students that their PIRE project (or the program as a whole) was providing. As a result, we tailored the PI and FI survey items to encourage respondents to think beyond the direct benefits to PIRE participants themselves.

Exhibit 6.1summarizes the key themes that emerged from qualitative analyses of PI and FI survey responses.

Exhibit 6.1: Key Themes from PI and FI Reports of the Benefits of PIRE to Society

Benefit Reported	Percent of Responses	
	PIs (N=158)	FIs (N=78)
Insights about the natural environment (and human interactions with this environment)	43%	24%
Technological advances	21%	0%
Promoting international collaboration and cross-cultural exchange	18%	32%
Knowledge gained from cross-cultural comparisons/sharing of best practices	6%	12%
Improved program models	5%	10%
Advancing knowledge in a particular field or science in general	4%	22%
Predicting and/or mitigating hazards	4%	3%
Fostering global citizenship/public awareness	4%	5%

Sources: Principal Investigator Survey, Item G1; Foreign Senior Investigator Survey, Item E4.
Notes:
PIs: N=158, missing=10. FIs: N=78, missing=44.

PIs and FIs cited specific advances in research related to the human-natural environment, including research in sustainable energy, climate change, biodiversity, conservation and water resources or the impact of human populations on the natural environment (43 percent of PI responses; 24 percent of FI responses).

> *The PIRE project has fostered collaboration across the Pan American region to measure the sustainability impacts of bioenergy development in areas of the natural environment and socioeconomic issues. These types of measurements are largely overlooked as the various countries in this region of the world ramp up biofuel production. (2012 PI)*

> *Our research will enhance [sic] quality of large wind farm designs of the future. This will enable larger penetration of this renewable energy source for our electricity grid. Such outcome [sic] would have transformative societal impact. (2012 PI)*

More than 20 percent of PIs' responses cited potential benefits of technological advances resulting from their PIRE projects.

> *Our research project is [creating] "meaning representations" that can improve automatic machine translation and all forms of multi-lingual information processing. This could vastly*

improve world-wide communication, lower language and cultural barriers and encourage cooperation and collaboration. (2005 PI)

The coupling of technological solutions with social considerations at the outset. And looking at the types of technological solutions that might cause behavioral change in energy use. (2012 PI)

Nearly one-fifth of PIs (18 percent of PI responses) and nearly one-third of FIs (32 percent of FI responses) cited the cross-cultural exchange as a key benefit of PIRE to society: respondents credited this type of collaboration with allowing researchers to better address global challenges.

[The] PIRE project is a good example that people at different countries can work together to produce useful results. This give[s][a] very good example that we can work together to resolve global issue and benefits to societies. (2007 PI)

It set an example of outstanding and equal international collaboration (many other international projects had [PEOPLE IN THIS COUNTRY] only serve as guides or logistic people). Local people benefited from the interaction with American scientists and students. (2007 PI)

It creates a critical mass of scholars who aim at advancing science regardless of National borders. (2012 PI)

[One of the benefits is the] diffusion of innovation and broader dissemination of knowledge and experience regarding water innovations. (2012 PI)

The project shows how a multi-disciplinary and multi-cultural team of researchers can successfully work together on globally important scientific questions. This is a pretty unique situation worldwide. (2010 FI)

Science is an international activity. It is best done by people working together based on their interests. Any program that supports this will help the societies involved. (2010 FI)

6.2 PIRE's Contributions to Addressing Specific Global Challenges

The National Academies of Science and Engineering (with their partners, the Institute of Medicine and the National Research Council) have identified a set of "global challenges" out of recognition that "Many of the world's greatest health, environmental, and security threats are beyond the ability of any one nation to confront by itself" (National Academy of Sciences, 2015). Examples of areas where the Academies indicated that internationally coordinated responses were needed included:

- Meeting increased global demand for energy without causing irrevocable harm to the environment, reducing the human forcing of climate change, and developing and implementing economically viable low-carbon energy technologies;
- Improving access to clean water that is threatened by rapid human population growth, increasing urbanization and poor water management;
- Addressing reduced agricultural output and increased food insecurity due to poor soil, lack of high quality seeds, and inefficient use of water or fuel;
- Minimizing risks of dual-use technologies in the life and nuclear sciences that can be used to improve lives but also to manufacture weapons;
- Promoting and protecting innovation with appropriate protection that does not stifle further advances;

- Building resilience to hazards from natural and technological disasters; and
- Addressing demographic challenges from population growth, aging, and urban population dynamics in developing countries.

Nearly three-fourths of PIs and more than three-fourths of FIs noted that their PIRE project has advanced knowledge or led to discoveries that might help address global challenges in areas in which solutions are unlikely to emerge from the efforts of one nation acting alone (Exhibit 6.2).

Exhibit 6.2: Percent of Principal and Foreign Investigators Reporting that Their PIRE Project Has Helped Address Global Societal Challenges

	PIs	FIs
My PIRE project has advanced knowledge or led to discoveries that might help address global challenges such as those listed above, or in another area in which solutions are unlikely to emerge from the efforts of one nation acting alone	74%	78%

Sources: Principal Investigator Survey, Item G3a; Foreign Senior Investigator Survey, Item E6a.
Notes:
PIs: N=166, 4 missing. FIs: N=111, 11 missing

When asked to elaborate on how their PIRE project would contribute to addressing these challenges, a common theme among both PIs (25 percent of PI responses) and FIs (35 percent of FI responses) was that the PIRE project leveraged the expertise, resources, and perspectives of a range of international researchers.[19]

> *Understanding the nature of climate/greenhouse gas interactions is paramount and extremely difficult. It is only by forging the expertise from numerous nations that we move the science forward. (2010 PI)*
>
> *Our PIRE project addresses materials under extreme conditions for nuclear systems. Leveraging unique facilities and talents at different institutions will advance knowledge and address global challenges in this field. (2012 PI)*
>
> *Understanding how humans understand speech and language is best done by studying this human facility across multiple languages—to discover language universals—and requires perspectives from multiple disciplines. No single nation has the human capital to cover all the necessary expertise, often due to historical reasons. Rather than trying to develop the expertise in one nation, it is infinitely more effective to collaborate. (2005 PI)*
>
> *[COUNTRY] part is good at the materials synthesis, U.S. part is good at the data collecting with the advanced instrument and the data analysis. (2010 FI)*
>
> *The problem of water supply quality and quantity is highly varied across the globe. The international perspective and expertise achieves far more than the efforts of one country alone. (2012 FI)*
>
> *The issues dealt with in this project are global in the sense that climate and lands changes are happening everywhere, however, the way to understand and manage these problems need [sic] regional perspectives that lie beyond the borders of the U.S. The international engagement process is the only way to truly address environmental issues that impact different regions/peoples in different ways. (2010 FI)*

[19] 115 PIs and 63 FIs gave responses (*PI survey, Item G3b; FI survey Item E6b*)

By adopting a comparative perspective across 6 countries, the PIRE project has made it possible to identify global patterns, problems and potential solutions. (2012 FI)

Other responses cited the multi-national applicability of the PIRE project's findings (10 percent of PI responses, 19 percent of FI responses), and/or the potential benefits of leveraging PIRE to build a cross-national consensus on the best possible solutions (10 percent of PI responses).

Unmet global electricity demand, in particular, has significant potential in terms of increasing/ reducing greenhouse gas emissions. Lessons learned in the U.S. & [COUNTRY] should be transferable to other parts of the world. (2012 PI)

The project is addressing many questions related to sustainability of bioenergy in various… countries [in this GEOGRAPHIC REGION]. This multidisciplinary … experience is a large effort that cannot compare to any effort from a country. Data will be comparable among dissimilar bioenergy feedstocks, nations, climates, cultures and socioeconomic realities. (2012 FI)

Results from our PIRE has led to consensus amongst world leaders in fire science—consensus that we must recognize the changing role of disturbance globally and how this relates to resource use and needs of all humans. This consensus should help guide international cooperation/policies. (2010 PI)

By demonstrating the obstacles, impediments, as well as opportunities to be recognized in making innovations both useful and adaptable cross-nationally, and in different regulatory and policy contexts. (2012 PI)

FIs in particular also focused on the positive impact the project had on education and opportunities for students (35 percent of responses), including showing them the value of international collaboration (13 percent of responses), which they believe will create an academic environment more suited to addressing global challenges.

More awareness among the graduate student of the quality of research, work ethics, and overall ability to think differently. (2007 FI)

Although only several undergraduate and graduate students were involved in the field and lab work related to the PIRE project, they have become the "seed" to intensify the interaction of geoscientists from [COUNTRY] and the U.S. in the near future. They have learnt a lot and developed friendship with American professors and students. Some of them have published papers in peer-reviewed international journals and became independent researchers. (2010 FI)

6.3 Implementation of Research Findings

Senior investigators also provided insight into ways that society could apply the results of PIRE to address challenges of global significance or scale. The most common mechanism for implementing PIRE results was by informing policy and planning (21 percent of PI responses and 14 percent of FI responses).[20]

The publications from the PIRE project offer many suggestions for changes in educational programs, policies, and practice that would increase educational opportunities for the children of immigrants. (2005 PI)

[20] 150 PIs and 21 FIs described ways that society could implement PIRE results (PI survey, Item G2; FI survey, Item E5).

Our contributions to the understanding of marine connectivity are being used to assist in the development of marine conservation planning in the PIRE region and other areas globally. (2007 PI)

This project is focused on sustainability along many dimensions, which is something that policy makers across the globe are grappling with. This project should provide fundamental information that contributes to these real world problems. (2012 PI)

Under [PENDING LEGISLATION], it may become possible to finance pilot projects in order to determine broader feasibility of renewable microgrids. (2012 PI)

Cities are considering the complexity and large supply chains of infrastructure, cities are using our methods for tracking GHG emissions, cities are interested in metrics we have developed to compare efficiency. In [the] future we hope to address the solutions and how we can best design combined social-infrastructural solutions to address sustainability and health goals of cities. (2012 PI)

We produced detailed reports for each [GEOGRAPHICAL UNIT WITHIN A COUNTRY] and handed those to several government agencies that issue permits for commercial extractions and biological collecting. We also invited main NGOs to [sic] and orally presented the general results and gave copies of the reports (also available online). Results produced on the … fauna, are now being used as the basis for more integrative and complex analyses related to global climate change. (2005 FI)

I anticipate that the growing body of knowledge arising from the PIRE project will inform decisions about climate impacts on population dynamics of wild birds, and improve understanding of the main drivers. In turn, this will yield important insights into program and policy alternatives that could mitigate such effects. (2007 FI)

Another 10 percent of PI responses (and one FI response) proposed that PIRE results could specifically aid in planning and monitoring to mitigate the dangers of natural disasters:

Society can implement dam and levee monitoring systems and can convey the information much like weathercasting is being used today in order to inform people so they are better prepared in the event of a disaster. (2012 PI)

The project facilitated the development of novel volcano monitoring solutions, which have already been tested in harsh [REGIONAL] weather conditions and will work equally well across the world. The [INSTITUTION] for example, is adopting the "multiparameter instrumentation" developed with the support of our PIRE project. (2005 PI)

Thirteen percent of PI responses and 10 percent of FI responses suggested that PIRE findings could be used by industries and other stakeholders to address global challenges:

Industry is using our academic results to develop better machine translation, in more languages (including disadvantaged and low-resource languages), and for more applications beyond defense and commercial. (2005 PI)

In order to take advantage of what we learned, and produce devices or materials with advantageous properties, it will be necessary that private companies get involved. They are the link where prototypes of potential devices could be eventually fabricated in large volumes. For this to happen, companies should receive some type of incentive to approach researchers at universities to make the initial investments. (2007 PI)

Baseline information on earth structure obtained from this project is being used by mineral and oil exploration companies to improve exploration models. This sensitive information is also being used to improve estimates of seismic hazards and risk. (2005 PI)

Some of our … research outcomes have been used by [COMPANY] and [INSTITUTION] to scale weather research forecasting to clusters of computers across the Atlantic Ocean. (2007 PI)

Some experts at nuclear power plants [in] [COUNTRY] participated for discussion and then they have been trying to implement our research findings. (2007 FI)

Seventeen percent of PI responses suggested that PIRE had (or would) lead to improved tools and technologies useful for addressing global challenges:

The method of energy conversion is very promising and could provide an important clean energy source for the important small temperature difference regime. (2010 PI)

New bio-based materials could form sustainable feedstocks of materials for energy and other engineering applications. This is aimed at more environmentally friendly technology. (2012 PI)

Respondents also said that PIRE findings could address global challenges by informing future research (8 percent of PI responses, 10 percent of FI responses) and improving academic program models (5 percent of PI responses, 10 percent of FI responses).

Increasing the number of scientists with expertise in managing and analyzing very large datasets is also vital to the future of our nation. Since this transformative technology is broadly applicable to any scientific project struggling to manage and analyze the volume of data produced, the [PIRE PROJECT] and its facilitative impacts are likely to persist long after the PIRE project has ended. (2010 PI)

The program has become a nationally recognized model for designing and managing an international REU. It is a model for increasing the number of STEM majors participating in research abroad. (2005 PI)

The new method of teaching with live, video, simulcast of lectures given by top leaders of scientific research will be followed by educators and researchers in many other fields, and probably become a standard method for higher education. (2009 PI)

[The project is] Improving the training of young scientists in the service of the [PEOPLE IN THIS COUNTRY] and international society. Generating valuable knowledge for biodiversity conservation of southern [GEOGRAPHICAL REGION]. (2005 FI)

7. Summary

Since its inception in 2005, the PIRE program has funded projects across a broad array of scientific disciplines, in an effort to catalyze long-term, sustainable international partnerships for research and education. NSF deliberately restricts PIRE to intellectually substantive collaborations in which the international partnership is essential to the research effort. Moreover, the program includes a strong emphasis on providing early career opportunities for postdoctoral, graduate and undergraduate students to participate in meaningful international research and education.

The primary goal of this first evaluation of PIRE was to assess how well PIRE is meeting its key objectives: to foster meaningful and sustained collaborations between U.S. and foreign partners; to promote research excellence—in particular, advances in knowledge and discovery that could not occur without the combined expertise and resources of an international team; and to cultivate increased global engagement among the next generation of scientists and engineers. The evaluation was also designed to document the outcomes and experiences of PIRE participants, to explore PIRE's contributions to addressing societal challenges, and to examine institutional policies and practices that might promote or impede faculty or student international engagement.

Importantly, the evaluation was aimed at investigating the value-added benefits of the PIRE program to fostering international collaboration and producing high quality research. Across NSF's many programs, PIRE is distinctive in that it requires an international collaboration, so a key question is what benefits (or unintended consequences) result from this requirement. To this end, the evaluation compared the outcomes of the first 59 PIRE awards to those of other NSF research grants with characteristics similar to these PIRE awards. Primary outcomes for which we compared PIRE to other NSF grants included: the quantity and quality of research produced; the level of foreign engagement in this research; and the nature and sustainability of international collaborations during and subsequent to the award period. The evaluation also explored participant experiences related to the grant, perceptions of the effects of PIRE, including senior investigators' perceptions of PIRE's contributions to addressing societal challenges, and examined institutional policies and practices for supporting undergraduate and graduate students' international engagement.

PIRE produces strong research outcomes.

The evaluation found evidence that PIRE is furthering its objectives with no detectable tradeoff costs to research productivity or quality. Research outcomes of PIRE projects and participants compare well to those of similar NSF-funded grants without the explicit requirement for international collaboration. Further, the evaluation findings underscore the importance of explicitly supporting foreign institutional (and investigator) involvement in order to promote international collaborations that can seed productive and impactful activities. While there were no statistically significant differences between PIRE and the comparison group in the quantity or quality of research produced, PIRE publications had a significantly higher proportion of foreign contribution. Moreover, there is evidence that PIRE is playing an important role in the research productivity of early-career investigators. At the participant level, PIRE postdocs, on average, had a larger number of post-onset annual publications and these publications had a larger impact compared to their peers working on other NSF grants; PIRE graduate students also had a higher average number of annual post-award publications.

PIRE fosters meaningful, sustainable international collaborations.

PIRE PIs, postdocs and graduate students were more likely than their counterparts in other NSF projects to report collaborating with a foreign investigator during the project. More importantly,

among participants who collaborated with a foreign colleague during their participation in the project, PIRE participants were more likely than their peers to *continue* collaborating with foreign investigators. This finding provides important evidence that the PIRE program is uniquely structured to foster meaningful international collaborations that are sustainable beyond the life of a single grant.

Given research showing that internationally coauthored publications tend to have higher citation impacts (Adams, 2013), we might have hypothesized that the PIRE program would result in higher quality research, but, due to the complexity of PIRE's multi-investigator, multi-institutional, and multi-national collaboration, it seemed equally plausible that, at least in the short term, PIRE could have resulted in lower levels of productivity or quality, if these were the tradeoffs of administering a PIRE award. The findings of this evaluation address these competing hypotheses: PIRE participants are more likely than participants in other NSF-funded projects to establish and maintain collaborations with foreign colleagues, and attaining this objective does not come with a cost to research productivity or impact, even when compared to the high standards set by NSF-funded projects.

U.S. institutions value PIRE and are working to promote international engagement.

Most administrators reported that their U.S. institutions actively support international engagement by faculty and students by helping with arrangements for research or education abroad, coordinating with a partner institution in another country, and providing faculty with grant-writing assistance, or even seed money for planning such endeavors. Many of these institutions reported that the PIRE award aligned with explicit institutional goals to raise their own global profile or build international partnerships. For undergraduate and graduate students pursuing research or educational activities abroad, institutional administrators cited the importance of their campus study abroad or international programs office and faculty support. Administrators described a greater number of barriers to undergraduate than graduate student participation in international opportunities. For undergraduates majoring in an S&E field, administrators cited departmental curricular requirements and the high cost of educational activities abroad as deterrents. Fewer barriers were cited as impeding graduate students' international engagement, but some administrators noted that such students risked losing tuition waivers and international students on single-entry visas were reluctant to leave the U.S. Despite these barriers, institutions also reported that the PIRE award had raised awareness and demonstrated the value of having students involved in international research and education, leading to increased support for providing such opportunities.

PIRE participants cite multiple benefits of the program.

Participants valued their PIRE experience. Nearly all postdoctoral, graduate and undergraduate survey respondents would encourage their peers to participate in research and education opportunities abroad, and the vast majority (more than 90 percent) indicated that different cultural perspectives improved the quality of the research, and that the research benefitted from access to foreign expertise and data acquired in foreign locations.

Senior investigators likewise cited benefits from leveraging the expertise, resources, and perspectives of a range of international researchers, and also reported that PIRE is producing broader societal benefits. Both U.S.-based PIs and foreign senior investigators reported that their PIRE project had advanced knowledge or led to discoveries that might help address global challenges in areas in which solutions are unlikely to emerge from the efforts of one nation acting alone. PIs and FIs indicated that findings from their PIRE project could inform policy and planning and provide improved technologies in such diverse areas as marine conservation, renewable energy, and predicting and mitigating the effects of natural disasters.

8. Recommendations

Based on the evaluation findings, we propose four recommendations for NSF to consider as it looks ahead to future cohorts of PIRE awards and to the next evaluation of the program.

Collect information about PIRE (and other program) participants more systematically

Given the challenges of locating contact information for PIRE and comparison project participants prior to collecting data for the evaluation, we recommend that NSF consider developing and implementing a process to collect information from all participants in activities funded by NSF awards. Although PIs list the names of project participants in annual reports to NSF, this practice does not always yield accurate or complete information needed for NSF to evaluate its programs. Requiring PIs to report more detailed information on participants seems potentially burdensome, given the information NSF already requests. Instead, we propose that PIs distribute a short questionnaire to each participant, pre-labeled with the NSF award ID (whether or not a participant received funding directly from that award), that would ask participants to provide the following optional information (ideally, online):

- Residential address;
- Institutional and permanent email addresses;
- Date participation began;
- Highest degree earned at start of participation;
- Degree being pursued at start of participation (if applicable);
- Major field for degree or primary field of research at start of participation; and
- Gender, race ethnicity, and disability status.

In addition, NSF could consider notifying participants that they may be invited to participate in a future study about their experiences and asking the participant to specify how they prefer to be contacted. Given the ubiquity of mobile and smartphones, another possibility is to request a cellphone number and opt-in to receive news of any future study via text message to that number.

Had we begun the study with a better record of participant information, the evaluation would likely have achieved higher response rates. In addition, the information on participants who chose not to respond to a survey invitation would have allowed us to weight the survey data for non-response, thus mitigating the possibility of non-response bias in the survey data.

Consider mechanisms to alleviate administrative burden on PIRE PIs

Anecdotal reports from PIRE PIs and NSF suggest that PIRE awards impose a particularly severe administrative burden on lead PIs and some co-PIs, due to the increased logistical planning that international travel and collaborations require. Although the data collected for this evaluation do not confirm or disconfirm any hypotheses about administrative burden of PIRE, it is noteworthy that PIRE positively affected the research productivity of both postdoctoral researchers and graduate students, but did not affect the productivity of PIs (Exhibit 3.11). NSF might consider requiring PIRE projects to fund a project administrator to help manage the projects and thus allow the PIs to focus on the research agenda of the award.

Facilitate funding and support for foreign investigators participating in PIRE

Nearly one-quarter (24 percent) of foreign senior investigators reported that they had received no funding from any source (including a governmental agency or their own institution) for their participation in PIRE. Very few reported that one of the counterpart agencies NSF has identified in the United Kingdom, Japan, Russia, or the Americas (including North, South and Central America and selected Caribbean nations) had provided funding (Exhibit 4.39); the largest share of FIs who did report funding for PIRE indicated that funding came from their institution. When PIs were asked to identify challenges to participating in PIRE, seven of twelve responses mentioned a lack of funding or funding insufficient in light of their contributions to the project. In light of this finding, we recommend that NSF consider exploring new agreements and/or broadening its partnerships with research agencies in other countries to enhance opportunities for foreign partners on PIRE projects to obtain funding.

Identify best practices at U.S. institutions for minimizing barriers to student research abroad

Although most institutional administrators were, overall, positive about the opportunities for international research and education that the PIRE award provided students, some did cite barriers to student international engagement. For undergraduates, one barrier cited in particular for those majoring in science or engineering was that the structured nature of the undergraduate curriculum in these disciplines makes it difficult for students to miss a semester's coursework on campus. For graduate students, there appeared to be fewer formal institutional resources or structures to provide pre-departure assistance with travel requirements (health insurance, safety considerations) or cultural adjustment; some institutions relied on their undergraduate study abroad offices to assist graduate students traveling abroad.

We recommend that NSF consider identifying and disseminating "best practices" at institutions that are successfully sending larger numbers of S&E undergraduate and/or graduate students abroad for research. If some institutions have successfully made accommodations to allow undergraduates majoring in S&E fields to do research abroad without sacrificing completion of major curricular requirements, other institutions might benefit from knowing how these accommodations were made. Likewise, for graduate students, some institutions may have developed resources that focus specifically on the needs of graduate students traveling abroad (rather than adapting resources targeting undergraduates pursuing study abroad). Sharing these innovations across institutions could facilitate greater student global engagement than leaving institutions to invent processes for themselves. Where students have gone abroad for PIRE, institutional administrators point out that this increases faculty appreciation for the value of these experiences. Tapping faculty enthusiasm for student international experience may be one way to help foster inter-institutional sharing of these best practices.

Definitions and Acronyms

Continuing grant. An NSF award in which a full amount is authorized but released in annual sub-amounts pending satisfactory progress. Differs from a standard grant in which all funds are released at once at the start of the award.

FI = Foreign senior investigator. A non-U.S.-based participant in an NSF award who is equivalent to a co-principal investigator in the U.S.

Field normalized citation impact (field NCI). The ratio of the number of citations of the target paper to the "world average baseline" which Thomson Reuters defines as the average number of citations per paper for all reviews or research articles published in the same year as the target paper in a journal within the same journal category as the journal in which the target article was published. Information about journal categories can be found here: *http://ip-science.thomsonreuters.com/mjl/scope/scope_scie/#AA* and here: *http://wokinfo.com/essays/journal-selection-process/*

Journal normalized citation impact (journal NCI). Also known in some literatures as the ratio of observed to expected citations, is the ratio of number of citations of the target paper to the average number of citations per article for all reviews and research articles published in the same year and in the same journal as the target paper.

Percentage of foreign authors per article is the ratio of the number of authors based at non-U.S. institutions to the number of unique authors of the article. For example, for an article with 10 co-authors, 4 of whom are based in two institutions outside the U.S. and 6 of whom are based at three institutions within the U.S., the article's percentage of foreign authors is 40 percent. This indicator is available only for articles published in 2009 or later. For articles published earlier than 2009, Thomson Reuters cannot disambiguate multiple authors at the same institution. Instead, the percentage of institutions listed in author information that are outside the U.S. is used as a proxy for the relative contribution of non-U.S. co-authors to the article. See the definition for an article's percentage of foreign institutions, below.

Percentage of foreign institutions per article is the ratio of the number of unique non-U.S. institutions out of the number of unique institutions listed in author information per article. Because Thomson Reuters cannot disambiguate multiple authors at the same institution for articles published earlier than 2009, the ratio of non-U.S. institutions is used as a proxy for the relative contribution of non-U.S. researchers to the article. For example, a paper with 10 co-authors based in two institutions outside the U.S. and three institutions within the U.S., the article's percentage of non-U.S.-based institutions is 40 percent (two out of five institutions total are non-U.S.).

Percentage of foreign institutions per article for articles citing PIRE/comparison publications. Across papers citing one or more PIRE or comparison project-produced publications, the percentage of authors' institutions per citing publication that were located outside the U.S..

Percentage of foreign institutions per article for articles cited by PIRE/comparison publication(s) Across papers that were cited by one or more PIRE or comparison project-produced publications, the percentage of authors' institutions per cited publication that were located outside the U.S..

PI = Principal investigator. A senior-level, U.S.-based researcher on an NSF award, either the lead principal investigator or a co-principal investigator.

Pre-onset. The period of time prior to a PIRE or comparison project participant's first year of participation in the project.

Post-onset. The period of time including and after a PIRE or comparison project participant's first year of participation in the project.

S&E. Science and engineering. Used to refer collectively to the scientific or engineering fields typically supported by NSF.

STEM: Science, technology, engineering and mathematics. Similar to S&E, this acronym is used in the literature to refer collectively to the set of fields in these four major areas. Sometimes it includes fields not directly supported by NSF (e.g., biomedical fields).

Sponsoring institution. The home institution of the lead principal investigator on an NSF award.

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