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International Research and Engineering Education: Impacts and Best Practices

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International Research and Engineering Education: Impact and Best Practices

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ABSTRACT
The National Science Foundation (NSF), through the Divisions in the Directorate for Engineering (ENG) and the Office of International Science and Engineering (OISE), created the International Research and Education in Engineering (IREE) initiative. Launched in 2006, the IREE program aims to "provide opportunities for international research and education for early-career researchers, i.e., undergraduates and graduate students, postdoctoral fellows, and early-career faculty members, and to enhance U.S. innovation in education and research through closer interaction between U.S. institutions and their foreign counterparts."

In 2006, the IREE program funded 115 proposals from 82 U.S higher education institutions. Researchers and their faculty attended and presented their trip report at a 3-day conference held at Purdue University in November 2007. The first grantees conference was attended by 170 people, including 47 faculty members, 113 graduate students, 6 undergraduate students, and 6 NSF staff members. The 2007 IREE Grantees Conference was to provide a venue and facilitated opportunity for the IREE awardees, both students and faculty, to share experiences and what they gained from their time abroad under IREE:

Based on both verbal and written responses of the IREE grantees, common themes were identified regarding the impacts and the usefulness of conducting international engineering research. The common themes are organized into a set of 18 impact areas that are organized into three categories: technical, professional, and global/ trans-cultural. The paper also presents set of best practices and recommendations that maximize learning and research outcomes of international research and engineering education.

The Cause: Globalization of the Engineering Profession

Increasing economic globalization is transforming the very nature of the engineering profession. Today, the conceptualization, design, and manufacture of devices and systems involve global market analyses and implementation through distributed work centers and worldwide supply chains. As companies expand their operations across international borders, international assignments of U.S. engineers have become a common business practice. More recently global enterprises are setting up engineering as well as research and development centers worldwide, and staffing those with a combination of domestic and foreign engineers and scientists.

The profession now routinely deals with globally-distributed manufacturing and multinational design and marketing teams. To flourish in this environment, future engineers need not only be proficient in the technical subjects, but also be informed about international technological trends and business practices and familiar with languages and cultures. These are some of the attributes of a global engineer.

Globalization brings many opportunities along with these significant challenges. Diverse groups can develop innovative solutions to problems that may not be created in more homogeneous teams. The

requirements for resources in order to advance science and engineering, including facilities, equipment, and support staff, continue to grow, so leveraging global expertise and global infrastructure is a substantial opportunity for our nation. Opportunities that enable students and early career professionals in science, engineering, technology and mathematics (STEM) to participate in global teams and experience research abroad can have a profound impact on development of the individuals and of the STEM workforce of the future.

Globalization has also provided us a laboratory to test the hypothesis that global teams of scientists and engineers can accelerate the innovation cycle and develop higher-impact research. The IREE program places US researchers in international labs and allows both the educational experience and the research output to be enhanced. It also allows systematic study of the impact of international collaboration.

The Challenge: Answering the Call for Global Engineers

The National Academy of Engineers recently addressed the need in a report entitled *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*, which concludes, "U.S. engineers must become global engineers .... The engineer of 2020 and beyond will need skills to be globally competitive over the length of her or his career."[1] It is essential for the experience of engineering students as well as faculty members to include a global perspective and an appreciation of the societal implication in their work.

There are substantial obstacles and challenges to the pervasive integration of international experience into mainstream engineering programs at academic institutions. Examining 24 U.S engineering colleges and schools across the nation, Parkinson (2007) synthesized the following obstacles for participation in international experiences[2]:

1. Difficulty in scaling
2. Negative impact on time to graduate
3. Negative impact on finances
4. Lack of faculty incentives
5. Unclear outcomes assessment
6. Rigid curriculum structure

Despite the clear need, an obvious gap still exists between the need for globally competent engineering graduates and engineering education curricula. Data from the Institute of International Education and the Chronicle of Higher Education show that only about 1 percent of the students enrolled in U.S. colleges and universities go abroad each year for academic-credit-bearing international experiences.[3] If the number of students studying abroad in a given year is normalized by the number of students graduating in that same year the resulting percentage is about 11%. Among the students going abroad on international educational exchanges, engineering majors are regarded as one of the under-represented populations, along with African American and male students.[4] The percentage for engineering is a little over 5%, see Fig. 1 below, and the majority of those are undergraduates.

Overcoming these challenges is not an easy task and will take significant time and resources. Yet, the need for global engineers is immediate and will substantially affect the future of the engineering profession. In order to accelerate our impact on this problem, both broader and deeper participation among U.S engineering colleges and schools is required. This can be achieved not only through educational programs, but also through research initiatives such as those enabled by IREE and other international funding agencies.

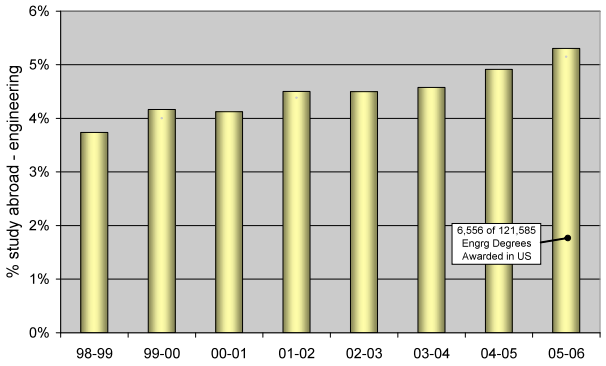

Fig. 1. Percentage of engineering students in U.S. colleges and universities studying outside of the U.S. as part of an academic program.[5]

The Rationale: Globally-Prepared Workforce and Enhanced Research

Responding to the challenge, scientists and engineers are gaining awareness of the changing landscape of the profession. Domestic and international research foundations play a substantial role as the driving force of this changing momentum. For example, the 2006-2011 NSF Strategic Plan outlines that the "U.S science

and engineering workforce must build greater capacity for productive international collaborations."[6] The IREE program contributes to that goal by funding linkages between NSF awardees and their foreign counterparts. IREE supports medium-duration visits by U.S. early-career researchers to collaborating institutions/laboratories outside of the United States. The visits must be related to the objectives of ongoing work in current projects, augmented by evidence of engagement with the cultural activities in the countries visited.

In 2006, the IREE program funded 115 proposals from 82 U.S higher education institutions. The IREE supplemental grants supported students and research professionals to spend a substantial amount of contiguous time (several months) at an international research partner facility. In addition, faculty advisors to these participants visited the international partner facilities generally for shorter times (several weeks). Within three months of completion of the research visit, faculty advisors and researchers submitted trip reports to NSF detailing their experiences. Researchers and their faculty attended and presented their trip report at a 3-day conference held at Purdue University in October 2007. The first grantees conference was attended by 170 people, including 47 faculty, 113 graduate students, 6 undergraduate students, and 6 NSF staff.

The overarching objective of the 2007 IREE Grantees Conference was to provide a venue and facilitated opportunity for the IREE awardees, both students and faculty, to share experiences and what they gained from their time abroad under IREE. The implications of IREE initiatives were discussed throughout the conference. In addition, the collective experiences of the participants and conference organizers are synthesized into a set of best practices for conducting international engineering research and education initiatives.

Impact of IREE

The IREE program is designed to have a positive impact on both the research and on the researchers. The discussions of the past IREE grantees reflect positively on that goal. The qualitative data (from discussion sessions, informal interaction, and formal presentations) gathered from the IREE conference related to that impact can be resolved into three dimensions: 1) the ***technical*** dimension, related to the quality of the research done and to the technical/research competency of the early-career professional who participated in the program; 2) the ***professional*** dimension, related to competencies in teaming, communications, etc, adequate for working in a regional capacity as an engineer or scientist, and 3) the ***global/transcultural*** dimension, related to abilities, attitudes, and attributes necessary for success in global projects and global teams. A visual illustration for these dimensions of impact is shown below:

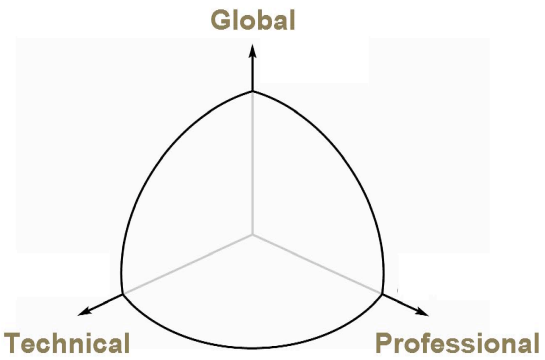

Fig. 2. Domain of impact of IREE and other international programs and experiences. Both the research and the researchers are positively influenced in three dimensions by effective global research experiences.

A summary of the impact of the IREE experience, as ascertained from the IREE Trip Reports and Grantees Conference is:

IMPACT OF INTERNATIONAL RESEARCH & COLLABORATION

Technical Impact

1. Brings Proximity to Partners/End Users
2. Enhances Research Productivity
3. Gains Access to New Research Tools
4. Improves Quality and Innovation in the Research
5. Widens Scope and Range of Applications of Ongoing Research
6. Increases Level of Robustness in Research Questions and Solutions

Professional Impact

1. Reinforces Project Management Imperative
2. Exercises a Broad Range of Leadership Options and Styles
3. Enhances Transcultural Teamwork and Collaboration
4. Expands Range of Communications Capabilities
5. Establishes Global Networks
6. Encourages Faculty-Student Interaction

Global/Transcultural Impact

1. Fuels Emergence of "Best Practices" Effective in Sustaining Transcultural Collaborations
2. Encourages the Innovative Development of "Shared Work Space" to Accommodate Cultural Difference
3. Develops/extends Research Communities beyond the U.S.
4. Increases Non-English Language Proficiencies
5. Affirms the Centrality and Power of Language
6. Contributes to Solutions of Global Grand Challenges

Technical Impact

In the 3-day conference IREE grantees explored international *research* collaborations and the impact that an international research experience may have on the quality of their research as well as on the technical competency of the researchers. Most, if not all, conference attendees support the idea of international collaborations, and agree that such collaborations have positive impact both on their research and on their educational journey to being global engineers.

1. Brings Proximity to Partners and End Users

   By extending their research effort abroad, IREE researchers find opportunities to be close to the end users of their work, thus allow researchers to see first-hand the application of their findings. This is especially true for engineering research directed towards improving the quality of human living standards and its environment in developing countries such as Vietnam, Kenya, and Cambodia, etc. In addition, proximity to research partners enhances the educational process by exposure to new ideas, new techniques, and new approaches.

2. Enhances Research Productivity

   IREE grantees find that by collaborating with international partners on projects with outcomes/results that will be deployed internationally means that they reduce the time and effort spent on deciphering foreign rules and regulations. This is true because in many cases the partners are already culturally integrated into the local cultures and customs. In addition, international partners often bring complementary expertise to the research team, allowing the US researcher to concentrate on new value-adding activities and reduce time spent working on problems that someone else has done before.

3. Gains Access to New Research Tools

   Further, in many cases there are facilities and equipments available at partner institutions that are not accessible at the home institutions of IREE grantees, or in some cases even in the US. In these cases the positive impact on research is clear as results become accessible that were previously impossible to obtain.

4. Broadens Research Perspective

   International research experiences allows IREE researchers to appreciate nation- and region-specific issues, such as energy in developing countries, differences in capital vs. labor costs …etc. IREE grantees find that international research collaboration broadens their view of how research can impact humankind, and in most cases reinforces their passion for the work. This is also relevant to research projects associated with pilot testing under foreign external environments and variables, such as climates and human factors.

5. Improves Quality and Innovation in the Research

   Reports by IREE grantees show that multiple researchers have different approaches to problem-solving and research. Different research practices evolve over long periods of time and become the primary solution. Such differences are the result of contrasting cultural backgrounds and characteristics. Therefore, research projects conducted at international sites are often viewed under a different lens, which greatly improves the range of solutions that are brought to bear on the problems.

5. Widens Scope and Range of Applications of Ongoing Research

   Research that develops in a regional context, a type of "bubble" if you will, does not factor in many aspects of the potential impact. Reports by IREE grantees have shown that international collaborations allow them to improve the overall scope and range of applications relevant to the work.

6. Increases Level of Robustness in Research Questions and Solutions

   When NSF research is exposed to international viewpoints during the early stages, i.e. long before the journal papers are published and the work subjected to traditional international scrutiny, it necessarily becomes more robust. Under IREE, multiple perspectives are factored in during the problem definition and intermediate stages of research design. As such, many of the underlying assumptions and biases that come from a possibly regional basis for the work are vetted early. IREE participants indicate that this process strengthens the research process and the final product,

reducing the possibility of other global work being ignored.

Professional Impact

In addition to the positive technical impacts of the research projects, IREE grantees also reported that international collaboration allow them to develop skills that better prepare themselves as engineering professionals for the 21st century. It is clear from their reports that IREE grantees feels that these set of professional competencies will enable them to function better in their career paths, regardless of external environmental settings.

1. Reinforces Project Management Imperative

   Project management tools developed for the private sector have not found much applicability in research labs. One of the reasons of this issue include that creativity is stifled by constraints imposed by project management approaches. The communication difficulties that are encountered in monocultural teams are greatly amplified in transcultural global teams, e.g., calibration of expectations for all team members. For this reason, the need for clear milestones and deliverables is a necessity for high-performance global teams. This reality is "learned by doing" by grantees under the IREE program.

2. Exercises a Broader Range of Leadership Options and Styles

   Leading monocultural teams is much easier than leading cross-cultural teams. It is obvious that undergraduate and graduate students who traveled under IREE who were used to learning and practicing only through their experiences at U.S. universities found a much more challenging situation when they were interjected into international teams. Students will face challenges in leadership and teamwork abilities as the diversity of cultures they experienced from their international peers and mentors. Those that seize the opportunity to learn will have a unique environment in which to exercise leadership options and styles far different from what they use at their home university with either native students or international students who are in the process of being acculturated into the U.S.

3. Enhances Transcultural Teamwork and Collaboration

   Collaboration with peers who derive from similar backgrounds or international constituents who are in the process of adapting to U.S. culture is a relatively easier process compared to collaboration on transcultural teams where many of the assumptions and accepted standards of practice and behavior are different. Working on an international research project under the IREE program puts researchers in such environments. Since students are motivated to succeed in their work (so they can progress toward graduation) and therefore motivated to collaborate effectively within a limited timeframe. Many IREE participants commented on the richness of the experience and how it will help them in future collaborations. They report that it is a learning process to adapt to foreign work schedules and lifestyles in order to achieve success in their research.

4. Expanded Range of Communications Capabilities

   Personal growth and better understanding of the world are underlying themes of the IREE grantees' discussions. IREE grantees agree that the experience of conducting research overseas allowed them to experience life in foreign settings and gain a better view of the globalization process. It also improved communication skills, which is essential to successes of any projects at hand.

5. Establishes Global Networks

   Relationships and networks are cultivated through face-to-face interaction that technology cannot achieve otherwise. By traveling and working with researchers around the world, IREE grantees are able to create a global network of contacts. This network lays the foundation of future research collaboration.

6. Encourages Faculty-Student Interaction

   A theme that emerged from the feedback sessions during the 2007 IREE Grantee Conference at Purdue University was that having faculty and students involved in the international experience together encouraged interaction. Being away from the institutional environment fuels creativity and puts students and faculty in a different context which is reported to have helped develop stronger mentoring relationships. This is positive for

effectiveness on the thesis research project and for the science and engineering community.

Global/Transcultural Impact

International engineering research experience impacts individuals, research communities, and the research process itself. Individuals report that they have grown "professionally," becoming more capable as leaders and as team members, improving their management skills, and gaining communication competencies as a result of the international experience. Similarly, it is reported that research communities benefit from the expansion of perspectives associated with more diverse participation. And, researchers report, the research itself is changed—impacted by the availability of new methodologies and by the infusion of new perspectives. The following list captures the *global* aspects of these changes; that is, those impacts that relate specifically to cultural boundaries, to working "globally" as contrasted with "locally" or "regionally".

1. Fuels Emergence of "Best Practices" Effective in Sustaining Transcultural Collaborations.

   As experience is shared and alternatives explored, "best practices" emerge that contribute to successful collaborations-- making interaction more rewarding, more efficient, and more sustainable. While emerging patterns may reflect the purposeful importing of conflict resolution and negotiating strategies already developed for use in less diverse settings, transcultural collaborations present their unique set of challenges. IREE participants emphasized that, generally, and over time, expectations of all parties evolved and "best practices" could be established; exceptions were also reported.

2. Encourages the Innovative Development of "Shared Work Space" to Accommodate Cultural Difference

   Differences in patterns of thinking and behaving are externalized in what can be termed a "shared work space" –incorporating schedules, institutional hierarchies, access to technical and professional resources, and on-going patterns of official and unofficial communications. Innovations in adapting existing "shared work spaces" are critical to efficiently working across cultural boundaries. Researchers reported a range of experience in successfully adapting to existing local work spaces, but were generally optimistic, mostly affirming that interaction does lead to innovation—to creative and greater accommodations in the work space itself.

3. Develops/extends Research Communities beyond the U.S.

   Participants frequently commented on the development and extension of their immediate network of colleagues as a result of their international experience. Such extension, it would be expected, allows individual linkages to contribute to the wider distribution and utilization of research outcomes and to wider participation in the professional activities associated with such communities, e.g., a wider distribution for peer reviewing of manuscripts, the evolution of new forums for discussion and dissemination, and to further transcultural collaborations.

4. Affirms the Centrality and Power of Language

   A frequent observation of participants was the centrality and power of language. Participants who had some fluency in the language used at their destination reported finding that their language competency proved to be much more important than they had anticipated. Even such basic vocabulary as "hello" and "thank-you" brought benefits that surprised participants, who were frequently apologetic about their lack of linguistic resources, especially the absence of formal academic coursework. Participants lacking such fluencies frequently observed that they regretted their inability to participate as freely as they would have liked, given the restrictions of English-only communications. Typically, they had expected that the English-based technical literature they shared with their foreign colleagues would translate into a comfortable work environment on-site: that expectation was often overly optimistic.

5. Increases non-English Language Proficiencies

   The immersive experience of on-site work increases fluency according to many of the IREE participants. A further impact is found in the frequently expressed interest in continuing to develop those language proficiencies that were acquired on-site after the researchers return to their home institutions.

6. Contributes to Solutions of Global Grand Challenges

   The U.S. has an obligation to help contribute to solving some of the grand challenges the world faces, clean water, sufficient energy, sustaining the environment, health care, and security. By having our students and researchers embedded around the world they experience first-hand the challenge. As such, they are better informed and able to contribute to those solutions in ways that are consistent with local cultures and practices. The positive impact is multifaceted, on our researchers, on the international partner and their culture and community, and also for the perception of the US around the world.

Without a doubt, the impact of international research and engineering education goes beyond the technical aspects of the research. Cultural understanding and intercultural sensitivity is a key element that enables IREE grantees to conduct research abroad. The cultural implications of IREE marks the intended outcomes of that this funding program has intended.

Lessons Learned and Best Practices

During the 3-day conference, IREE grantees had many opportunities to share their technical, professional, and social experiences during their international assignment under IREE. The conference sessions also provided settings for researchers to reflect upon their experience overseas and lessons learned. Synthesis of the various forms of feedback, including trip reports, breakout session discussions, and readouts allowed us to derive a set of best practices.

Pre-Travel:

1. Cultivation of Personal Relationships

   Many participants suggested that it was very important to have built a relationship with the research team and mentors at the host international institution before they went. Those that did not do this experienced a slower learning curve but did express the feeling that the experience was as effective as those who had a substantial relationship before the experience.

2. Familiarization with Target Culture

   The rigors of everyday life in an international setting can be quite challenging. This is added on to the fact that the participants are trying to effect tangible research progress in a new research environment. There is mismatch in the three dimensions of the engineering experience discussed in a previous section of this report. So any pre-familiarization that can be accomplished before the travel is shown to be helpful.

3. Acquire Target Language Fluency

   Nearly all travelers, upon reflection after their experience, wish that they had invested more time in learning the language and increasing their level of proficiency before they went abroad.

4. Leverage Existing Relationships at Home Institutions

   Building a relationship essentially from scratch starting when the researcher arrived at the international partner institution makes the experience much more difficult.

During Time on International Assignment:

5. Maintain a High-level of Interaction with Home Institutions

   For the continuity of the educational experience it was reported that it is important to maintain a high level of interaction with the home institution. The importance of this is easily lost when one is immersed in a new culture and a new experience leading to, upon return, difficulty in rebuilding relationships and plugging back into the flow.

6. Practice Language Skills

   An IREE or similar experience presents a wonderful opportunity to practice languages skills, even though English is often the operative language in the research lab. IREE researchers reported that fully engaging with the local language and culture outside of work was fulfilling and effective.

7. Adopt Local Research Community Practices

   An international experience is one opportunity to adapt to another research culture, much like many international graduate students are doing back at the U.S. home institution.

Recommendations:

Based on the trip reports and the discussion and findings resulting from the 2007 IREE Grantees Conference, and the best practices identified in the previous section of this report, the conference organizers have put forth a set of recommendation for future administration of the NSF-IREE program. This set of recommendations is also applicable to any future international research and engineering education collaborative efforts made by U.S academic institutions in general.

1. Maintain Continuity / Sustainability of Research Project

   International research and education experiences enable the creation of a global network of researchers. The network should be utilized in multiple settings and occasions. In order to maximize the impact researchers should focus on research design that allows sustainability.

2. Stress Orientation and Language Competency

   Participants in the IREE program stress the importance of language-learning. Many of them express that they would have achieved much more if they had been more capable in the native language of the country that they work in.

3. Encourage Faculty-Student Interaction

   Students expressed that being away from the institutional environment fuels creativity and puts students and faculty in a different context for richer interaction.

Conclusion

International research and education activities, such as those supported by the IREE program, are valuable in developing the STEM workforce and in the research activity itself. There is evidence that international experience improves research quality. Best practices have been developed according to region, discipline, and to type of researcher. As more and more international research collaborations develop, principle investigators and engineering educators should look ahead to formulate well-rounded relationships that are sustainable and meaningful over time. While it is useful to gather insights of the importance of international research and engineering education, policy makers and educators should focus beyond the immediate benefits and seek to cultivate long-term relationships with their partners. Linkage should be drawn between research collaborations and education initiatives in order to benefit both faculty members and students. Outcome assessment of such international research initiatives should be at the forefront of research program designs, and be carried out promptly in order to document the value of international research and engineering education.

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Disclaimer

Any opinions, findings, conclusions, or recommendations expressed in this paper are those of the authors and participants, and do not necessarily represent the official views, opinions, or policy of the National Science Foundation.

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[4] Source is from NAFSA: Association of International Educator's Subcommittee of Underrepresentation in Education Abroad.

[5] The percentages reported here are the number studying abroad in a given academic year divided by the total number of engineering degrees awarded in that same academic year. Study abroad data are from *Open Doors Statistical Summary: U.S. Study Abroad Data Tables* – Institute of International Education, http://www.iie.org. Data for engineering degrees awarded are from *ASEE Profiles of Engineering and Engineering Technology Colleges*.

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