US-Germany Collaboration in Materials for Extreme Environments: Developing an International Research Pathway Towards Creating Global Engineers for the Future

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Abstract

The US-Germany Collaboration in Materials for Extreme Environments program was conceived to provide teams of graduate and undergraduate students from the University of Central Florida (UCF) the opportunity to conduct collaborative research with scientists from the German Aerospace Center (DLR), both in the US and in Germany. The program takes place over a period of three academic semesters and involves extensive pre-trip preparations, ten weeks conducting research abroad, and research continuation upon return. Outside of research, the students promote international engineering through mentoring. This work reports on the technical, professional, and global impacts of this unique program. Experiences gained at both their home and partner institutions improved the students' research, professional, and global skills measured through publication outcomes, surveys, and propensity for graduate studies. Upon completion of the program, students were found to be more likely to pursue graduate studies. The students also perceived that the program had helped in improving their research, professional, and global skills as engineers. The program delivers these improvements by leveraging world-class facilities and scientific mentorship in both countries. Exposing undergraduate and graduate students to the challenges of an international research environment has impacts that carry on to the future workplace.

I. Introduction

In 2012, the US-Germany Collaboration was initiated through the National Science Foundation (NSF) Catalyzing New International Collaborations program. The subsequent successes of both students and researchers laid the foundation for the productive international collaborative team composed of researchers at University of Central Florida, the German Aerospace Center (DLR), and the Advanced Photon Source (APS) at Argonne National Laboratory (ANL). The success of this initial collaboration allowed for the introduction of additional students to the US-Germany Collaboration through the NSF International Research Experience for Students program. Together, these programs have enabled ten student researchers so far to participate in a global team, continue their education, and make meaningful scientific contributions.

These programs were created to support international research and collaboration for science and engineering students, with the aim of contributing to the development of a diverse, globally-engaged work force with world-class skills. The US-Germany Collaboration aimed to achieve these goals by engaging undergraduate and graduate students in intensive research preparation, experimentation, and collaboration both in the US and Germany. Projects such as these provide students the skills needed to meet the ever-evolving demands of the global aerospace engineering industry. A global engineer must demonstrate technical, professional, and global competence to remain competitive[1].

The US-Germany Collaboration combines intensive research preparation in the US, collaborative research in Germany, and joint research experiments in the US in an approximately yearlong cycle for each team. Prior to traveling, the students spent at least one academic semester on technical preparation for the international research. This included literature surveys, initial experiments, conference call meetings with collaborators, and preparation of research goals with specific tasks for their time abroad. This preparation eliminated the need for an introductory period, which enabled the students to seamlessly continue their research abroad, maximizing time spent learning. This preparation is followed by collaborative research activities in Germany over the course of 10 weeks, including analysis of prior collaborative experimental data, as well as planning and preparation for joint experimental campaigns at the Advanced Photon Source (APS) at Argonne National Laboratory (ANL). The 1-ID beamline at the APS uses high-energy synchrotron X-rays to achieve rapid 2D X-ray diffraction measurements. This is a novel approach capable of detecting changes in lattice strain, phase composition, and texturing in bulk material under thermomechanical load. ANL provides ultra bright high-energy X-rays for an unmatched opportunity to participating researchers and students to conduct ground-breaking research.

The US-Germany collaboration offers a unique approach to answering the demands of the global industry by immersing students in an international project that demands the development of technical, professional, and global skills. The achievements of the program are quantified through publication outcomes, surveys, and the propensity for continuing education and research. Through world-class facilities and mentors, this program exposes undergraduate and graduate students to the challenges of an international research environment that will allow them to develop the necessary skills of the next generation of aerospace engineers. The significant challenges presented by global teamwork inspire innovative solutions to problems that may not have been otherwise encountered. Furthermore, differences in regional and educational backgrounds mean more extreme vetting of assumptions and biases; international collaboration necessarily produces more robust research that is more likely to stand up to the rigor of the traditional international scrutiny when published[2]. These different backgrounds also amplify the necessity for high-quality communication skills due to dissimilar expectations of team members. Project management skills developed by students in global teams are the product of an environment where they are exposed to many different leadership and collaboration styles. Altogether, the experience of international research collaboration cultivates a productive attitude that allows for professional growth and a better understanding of the field as a whole[2].

II. Program Goals and Assessment Methods

The qualities of a global engineer have been well defined in literature [1, 2, 3, 4, 5]. In summary, a globally competent engineer should demonstrate technical, professional, and global proficiency. The international research collaboration is designed to encourage student growth in these areas.

Technical competency is achieved by demonstrating knowledge of engineering science fundamentals, project management skills, and innovation[1]. The rigidity of the research program pushes the students' abilities, increasing the quality of their research. The professional dimension is best defined by the ability to communicate and work in diverse teams effectively.[2]. The entirety of this program requires that the students communicate adequately and work efficiently in teams. The expansion of perspective associated with participation in a diverse research environment is necessary to achieve global competency[2].

The majority of the students who participated in this program were undergraduates or beginning graduate researchers. Participation in research as an undergraduate has been seen to have a positive educational impact. In a study that tracked students who participated in a research experience for undergraduates, it was found that almost half of the participants pursued graduate degrees (total of 34 student participants)[6].

The technical, professional, and global impacts of the on-going research collaboration are assessed through participant data measured by: learning outcomes and achievements, survey questionnaires, and the students' final reports. The assessment methods were selected based on recommendations found in literature[7]. The learning outcomes and achievements (post-participation) of the graduates and undergraduates are reported for the corresponding years. The survey consisted of self-evaluation questions that touched on the technical, professional, and global impacts the program had on the students. The final reports contain the students' evaluation of the technical knowledge gained abroad and educational impacts of the program. Intercultural experts agree that the best way to assess intercultural competence is through a mix of qualitative and quantitative measures[8]. Utilizing student reports and post-tests are among the top methods to assess students' intercultural competence[9].

III. IRES Program Structure

The US-Germany collaboration is designed to be a year-long cycle, outlined in Figure 1. The structure of this program conquers some of the challenges that are typically seen by engineering study abroad programs, outlined in [10]. For example, students are sometimes reluctant to apply to international engineering programs because it will extend graduation time. By taking place during the summer, the IRES program does not hinder graduation and research quality is maintained. In fact, it supported graduation requirements by allowing students to gain course credits through their research.

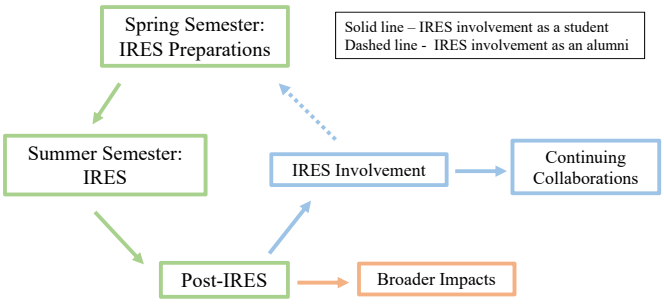

Figure 1: Flow chart showing the ideal student progression in the IRES program.

A. Spring Semester: Preparation for Research Abroad

During the spring semester, students are introduced to the area of study for their research project. The students are introduced to either individual research projects involving ANL collaborations that occurred in the previous semester, or new topics that are currently being planned between UCF and DLR. The students are also required to enroll in 3 credits of directed research and be available 10-20 hours per week during the spring semester. Each IRES student participates in: extensive data analysis, literature review, experiment planning, communicating with collaborators, and mentoring through outreach programs. Based on studies done on a similar international oriented programs, it was found through student feedback that a preparation period is crucial to better prepare for research or study abroad[10, 11].

1) Research Goals: As the time for departure approaches, research goals are established based on the results and progress made during the spring semester. A timeline is set to accommodate time to use the necessary equipment at DLR and schedule experiments. This timeline considers conference and journal deadlines that the students aim to meet. A final meeting is then scheduled with DLR collaborators to finalize the timeline and ensure that both parties agree with outcomes and schedule.

2) Communication with Collaborators: As a program focused on international collaboration, a plan for global communication is necessary to ensure proper communication between DLR and UCF while the students are abroad. Email, weekly reports, and conference calls are used to keep all parties informed throughout the program.

3) Experiments: During the spring term, students plan experiments to be conducted both at the home institution and at DLR. The students take advantage of the resources at DLR to conduct experiments. Through extensive experiment planning during the spring term, the time it takes until experiments can be conducted is significantly reduced.

4) STEM Outreach: A key component of the program is promoting international collaboration via mentoring in STEM outreach. The participants coordinate a STEM-oriented activity for middle and high school students and also write weekly blog posts accessible to the public.

The STEM activity is designed by the program participants, then facilitated by the program coordinator and UCF. The participants seek out STEM outreach events involving secondary education students in which they can volunteer. The 2017 IRES team organized a set of engineering and language learning hands-on activities in which they mentored younger students during a college STEM outreach event.

The weekly blog posts begin at the start of the program in the spring semester, and continue until the students return from their time abroad. The blog posts give the students creative writing freedom, and let them reach out to their peers about their on-going research experience. Implementing weekly blog posts in international programs is an effective way for students to reflect their experiences in meaningful ways[12]. The blog posts also serve as mentoring for future applicants by providing a sense of what to expect during their time abroad. Both forms of outreach are intended to promote international collaboration and engineering in STEM and inspire fellow students.

B. Summer Semester: Research Abroad

During the summer, the students spend ten weeks at a DLR facility in Germany. In collaboration with their DLR supervisor, the students work with the assigned research group to participate in experiments, data analysis, and research tasks based on the goals that were established during the spring. The students have access to state-of-the-art equipment to perform high-quality, publishable research, and are encouraged to immerse themselves in German workplace culture.

1) Exposure to Industry: The program also makes arrangements with UCF industry partners to introduce students to the global engineering industry in which international collaboration is imperative. All participants were given the opportunity to tour a turbine manufacturing facility. The students learned about current industry capabilities and challenges both in the US and abroad. This experience gives students a more complete understanding of the real-world applications of their research, as well as general knowledge of industry business practices.

C. Further IRES Involvement

After the students return from Germany, they submit a final report outlining their research findings and complete a post-trip survey. They also complete an exit interview with the program organizer, which is an opportunity for the students to provide feedback on the program design and suggestions for improvement. The alumni promote the program at UCF by participating in advertising events to attract applicants for the next year. These events include giving recruitment presentations and Q&A sessions at the meetings of relevant student organizations. All four of the 2017 IRES alumni participated in the advertising events. Including the alumni in information sessions for the program is an effective way to get other students to gain confidence to apply[11]. The IRES alumni also take part in the selection committee for the next group of IRES students. This includes reading applications, selecting applicants for interviews, conducting interviews, and helping in the selection process. Two of the IRES 2017 alumni helped in the selection of the 2018 IRES students and spent approximately forty-five minutes interviewing a total of ten possible candidates. Once the selection process is complete, the IRES alumni mentor the next set of IRES participants by joining in on weekly meetings were logistics are discussed and making themselves available as needed. The 2017 IRES students were mentored by a 2016 IRES alumni. Currently, both a 2016 and 2017 IRES alumni are mentoring the 2018 IRES group. By providing feedback and mentoring upon their return, students contribute to the success of the subsequent year. The alumni also often continue their collaboration with DLR, participating in experiments at ANL or collaborating in new research projects.

D. Broader Impacts

Participation in the IRES program can lead to many benefits for the students. After participating in the program, students have pursued graduate school, received internships, full employment, and prestigious fellowships and awards.

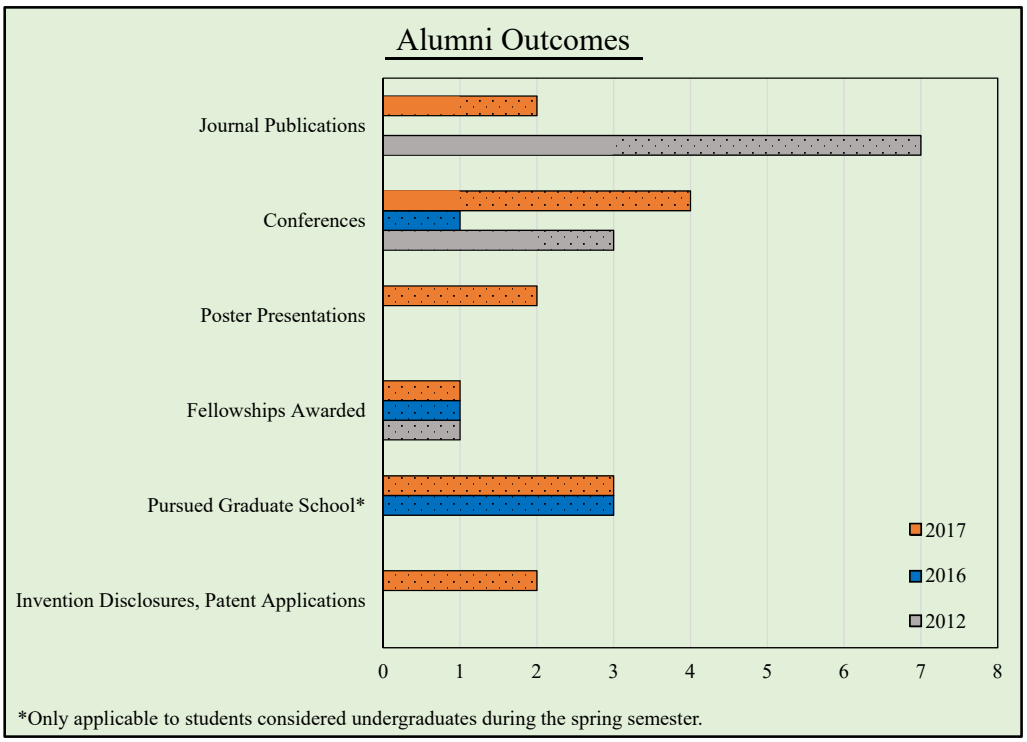

Figure 2: Cumulative collaboration outcomes. The total number of graduate and undergraduate students is 3 and 7, respectively. Undergraduate achievements are represented by the dotted sections of the bar graphs.

IV. Assessment Results

A. Program Alumni Outcomes

The cumulative success of the on-going collaboration was measured through the following achievements: journal publications, scientific conferences attended, posters presented, fellowships awarded, graduate school enrollment, and intellectual property claims. Figure 2 displays the overall results of the outcomes, only taking into consideration achievements following their participation in the program and relating to the work done during their time abroad. The outcomes that show the greatest achievement are journal publications and conferences. The international components the students had in their research are likely contributors to these achievements.

It was found that that exposure to international research may improve quality and innovation in research[2]. Reports by their program participants demonstrate that different researchers have distinct approaches to problem solving and research. These differences in research practices are a result of contrasting cultural backgrounds and characteristics. Thus, by conducting research projects at international sites, the students improve their problem solving approaches.

Another essential outcome in the US-Germany collaboration is the evolving program structure from emerging participant feedback. During the 2017 IRES spring semester, the students were required to enroll in a research credit course. This enrollment was not mandatory for the 2016 participants. Requiring the enrollment in a research credit course made the preparation stage of the program more rigorous. In turn, more time was dedicated to the extensive preparations by the 2017 students in comparison to the 2016 students. A direct result from this addition was a significant increase in student outcomes from the 2017 participants.

Out of the total number of participants, seven began the program as undergraduate students. A total of six decided to pursue graduate school and three of them were awarded fellowships. Exposing undergraduates to extensive research experiences provides important educational benefits to the students, such as influencing their decision to pursue a graduate degree[13, 14, 15, 16]. One of the benefits of undergraduate research is clarification of education paths, including intentions of graduate school[17]. Although no concrete correlation can be claimed between participation in international research as an undergraduate leading to enrollment in graduate school, it can perhaps be said that the impacts of the program were greatly influential in the students' decision. More support for the previous statement can be found under the Survey Free Response section.

B. Survey Questions

Post-trip survey questions were conducted for both the 2016 and 2017 IRES participants. The survey questions were separated into three categories by topic of impact: technical, professional, and global. The scores were evaluated similarly to an example

Survey Questions (Technical / Professional / Global)	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)	Average Score
(a) Participation in this program helped me improve my research skills.	0	0	0	0	8	5
(b) Participation in this program has helped me to increase my knowledge in a specific research field.	0	0	0	3	5	4.625
(c) Participation in this program has helped me to increase my general scientific knowledge.	0	0	1	3	4	4.375
(d) Presenting progress on my preparation helped me reach my research goals.	0	0	1	3	4	4.375
(e) This program prepared me to deliver oral presentations about my research work.	0	0	1	4	3	4.25
(f) The scientific content of this program is relevant to the degree(s) I plan to pursue.	0	0	1	1	6	4.625
(g) The scientific content of this program is relevant to a professional career.	0	0	0	3	5	4.625
(h) This program has prepared me to **present** scientific research in an international context.	0	0	0	4	4	4.5
(i) This program has prepared me to **conduct** scientific research in an international context.	0	0	0	3	5	4.625
(j) This program has prepared me to work as part of an international research team.	0	0	0	2	6	4.75

Figure 3: Survey results from 2016 and 2017 IRES participants.

found in literature[18], using a 5-point scale ranging from Strongly Disagree (1) to Strongly Agree (5). The results are summarized in Figure 3.

The technical questions focused on the impact of the program on the students' research skills. All of the participants perceived that they gained beneficial improvement in their research skills, as can be seen from question (a). The remaining research oriented questions received scores ranging from 4.25 to 4.625. This shows that the participants felt that the program helped them improve in their scientific knowledge, research goals, and research work. The high scores on research impacts can be attributed to the exposure to research continuity in addition to the international component. Participating in research experiences as an undergraduate has been seen to improve the research skills of those students by enhancing their abilities to engage in the "real work" of scientists[19].

The professional and global oriented questions all averaged above a 4. The students felt that the program was beneficial to their professional careers. The students also feel prepared to conduct research in an international environment. Students who participate in study abroad for eight weeks or less still show global-mindness, that is, they are equipped with skills to interact an compete effectively in a global environment[20]. Study abroad programs typically aim to impact professional development by helping the students find professional direction and solidifying their career plans[21].

C. Survey Free Response

Student responses from the free response portion of the post-trip survey can be seen in Figures 4 and 5. In the first student response (Figure 4), the student expresses their uncertainty about graduate school and how participation in this program solidified their decision to attend. This contributes to the idea that participation in international research greatly influences students' decisions to attend graduate school. In the second student response (Figure 5), the student is clearly inspired to continue on with research in an international context by applying to the prestigious Fulbright U.S. student program. The Fulbright program offers research opportunities abroad for graduate students. The IRES program can be seen as an influential part in the decision undergraduate students make to continue onto graduate school.

Prompt: How has your participation in the IRES program affected your future career plans or interests?
Student Response (2017)
"Prior to participating in this program, I was still debating if getting a master's degree was a career choice I wanted to make. After taking part in the IRES program, I am now entirely sure that is the path I need to take. Being part of this program has helped give me a better idea of how I want to shape my future. The knowledge I gained was more valuable than anything I could have gotten in a classroom."

Figure 4: Student response to survey free response question.

Prompt: Are there any specific courses or other projects you are planning in the near future as a result of your IRES project?
Student Response (2017)
"I am planning on continuing my research. I am also planning on applying for Fulbright in hopes of continuing international collaboration in research. I want to incorporate international collaboration in whatever projects I do in the future."

Figure 5: Student response to survey free response question.

D. Final Report Segments

Student Final Report (2017)
"This opportunity allowed me to understand the role of research in Germany and understand how German engineers approach problems that arise. I was also able to improve many research skills that can be brought back to the University of Central Florida."

Figure 6: Section from student final report.

A segment from a 2017 student final report can be seen in Figure 6. The student states that being in an international research environment has improved their research skills and overall understanding of German engineering problem solving. This program has had a professional and global impact on the student. The student is demonstrating the attributes of a global engineer, placing students into contact with engineers from other countries contributes to expanding problem solving of that engineer[22].

V. Conclusion

This study reports on the outcomes of an on going international collaboration between the US and Germany. Program outcomes were measured through post-participation student achievements and self-assessments. Due to program improvements, the 2017 participants had better outcomes than the 2016 participants. The participants were also found to be more compelled to pursue graduate studies upon completion of the program, as was seen in the alumni assessment and survey free responses. After completing the program, the students perceived that they had improved their research skills, as seen by the self-evaluation survey questions. From evaluations of the final report sections, students were seen to demonstrate global competence. It is of great importance to continue to evaluate the technical, professional, and global impacts that arise from international collaborations.

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Acknowledgments

This material is based upon work supported by National Science Foundation grant OISE 1460045. Researchers from the German Aerospace Center (DLR) and the Advanced Photon Source Argonne National Laboratory are acknowledged for their contributions and support for the international collaboration.