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A Case Study Assessing Program Outcomes of an International Research Collaboration between the US and Germany: Developing Students as Global Engineers

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Abstract

An International research collaboration between researchers in US and Germany was conceived to provide teams of graduate and undergraduate students in the US the opportunity to conduct collaborative research with scientists from Germany, both in the US and in Germany. The program takes place over a period of two academic semesters and involves extensive pre-trip preparations, ten weeks conducting research internationally in various areas of Aerospace research, and the option for research continuation upon return. Outside of research, the students promote international engineering through outreach. This work reports a case study on the technical, professional, and global impacts of this unique program and assessment of the program itself. 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 pursuing higher degrees. Upon completion of the program, students were found to be influenced by their experiences to pursue higher degrees than originally intended. The students also perceived that the program had helped in improving their technical, professional, and global skills as engineers. Based on the survey results and the students' final reports it was observed that these improvements were attributed by leveraging world-class facilities and scientific mentorship in both countries. It was also found that formalizing extensive pre-trip activities prior to research abroad improved participant outcomes. The findings support the conclusion that exposing undergraduate and graduate students to the challenges of an international research environment has impacts that carry on to the future workplace.

Index Terms

International programs, Intercultural competence, Research evaluation criteria

I. Introduction

Engineering challenges and problems are increasingly global in nature necessitating an international effort to address varied issues pertaining to sustainability, health, and security [1]. This globalization of engineering is continuously developing and demands a workforce of engineers with the competency to perform across nations [2], [3]. For an engineer to achieve global competency, they must be able to work effectively with people who define problems and whose approach towards finding a solution to these problems are different than oneself [4]. Researchers have been challenged to define what makes a globally competent engineer and what attributes an exemplary global engineer would encompass [2], [5]–[8]. In summary, a global engineer must demonstrate competency in technical, global, and professional aspects. Technical competency is achieved by demonstrating knowledge of the engineering science fundamentals, project management skills, and innovation [5]. Global competency derives from working effectively in diverse and multicultural international environments [7]. Professional competency is best defined by the ability to communicate and work in diverse teams effectively [6].

Colleges are answering the need for global engineers by offering its students various international experiences through internships, projects, study abroad and academic exchange, collaborative research projects, service learning projects abroad, and graduate-level international programs [9], [10]. A survey of international engineering programs reported on the types of programs available, their challenges, and best practices [11]. Student recruitment, program scaling, and assessment methods are some of the major challenges faced by these programs. Previously used assessment methods include self-reporting, student reports of their experiences, and survey data [1], [10]. These assessment methods are selected based on the overall objectives of the program, student learning outcomes, and program-specific objectives.

The National Science Foundation funded International Research Experience for Students (IRES) program, focusing on US-Germany collaboration for materials in extreme environments for propulsion and power generation systems offers a unique approach towards answering the demands of the global industry. The students participants are exposed to world-class facilities and expert mentors in both an international and domestic setting. This research collaboration originally included a joint three-way collaboration between researchers from the US university, the German Research organization, and scientists at a US National Laboratory, but has since expanded to encompass other research institutions based on the project demands of the student researchers, including additional National Laboratories. The collaboration from this program exposes both undergraduate and graduate students to the technical, global, and professional environment ideal for fostering the skills necessary in the next generation of competent global engineers while also providing the conditions towards advancing research in their given research

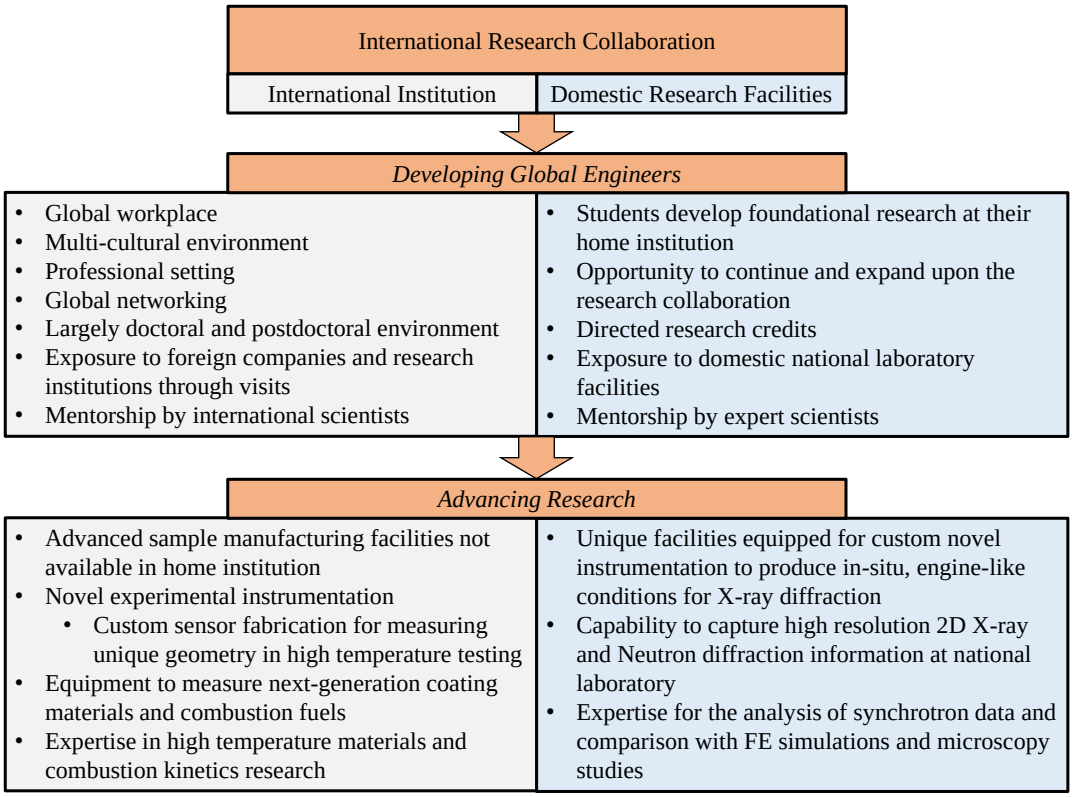

Fig. 1. Key aspects of international and domestic research collaboration aiding in the development of globally competent engineering students.

topics. The contributions of developing global competency in the engineering student participating in the IRES program, from both the domestic and international research settings, can be seen in Fig. 1.

The US-Germany research collaboration described here focuses on extending the capabilities of high temperature material systems as well as better understanding and evaluating the combustion performance of new fuels for aircraft turbine engines and power generation. This collaboration was for initiated in 2012 through the National Science Foundation (NSF) Catalyzing New International Collaborations program. The outcomes and successes of the students and researchers from this program laid the initial foundations for a productive international collaborative team composed of researchers at a US university, German Research Institute and US National Laboratory and led the way for additional students to continue, strengthen, and expand this collaboration through the introduction of the NSF IRES program in 2015 and its most recent renewal in 2020. As of today, these programs have enabled 27 student researchers to participate in a global team, enriche and continue their academic careers, and make impactful contributions to their scientific fields.

II. Program Goals and Assessment Methods

The qualities of a global engineer have been well defined in literature as someone who demonstrates a globally competent engineer should demonstrate technical, global, and professional proficiency, [2], [5]–[8], and this is one of the major goals of the IRES program. The IRES program, through international collaboration, exposes students to both national and international research environments to transform them into globally competent engineers. This objective is achieved while also supporting advanced gas turbine and hypersonic materials initiatives for extreme environment applications. Opportunities are provided to the students to participate in novel and leading-edge research in advanced materials and combustion fields in order to expand the capabilities, reliability, and durability of gas turbine engines for propulsion and energy generation purposes.

The total number of student participants who have completed the IRES program research collaboration is 27, which includes the following years; 2012, 2016 - 2019, and 2021-2022. It should be noted that the slight break in 2020 was the result of the COVID-19 pandemic and issues stemming from the pandemic required the 2021 Cohort to be adaptive and not follow the typical program schedule. Participating students were classified by their enrollment status in the spring semester. The classification of the participants are as follows: 10 graduate students and 17 undergraduate students. The majority of the undergraduate-designated students who participated in this program were senior-level undergraduate researchers who proceeded to continue into graduate school the fall following their return to the US from the international component of the program. Participation

Activity	Schedule	Tasks	Broader Impact
Pre-Trip preparation	**Fall/Spring**	*Student Interviews; Literature survey; Team introduction; Design of sample geometries and fixtures; simulation inputs; Experimental plan*	*Student recruitment; Logistics; Mentoring, Orientation; Pre-trip survey, outreach activity with high schoolers*
Summer Research Experience in Germany (4 students)	**Summer**	**I) Strain evolution in high temperature coatings under in situ conditions (1 Grad + 1 UG)** *Sample manufacturing in Germany; Coating at coating facility; Thermal gradient mech. load cycling of samples; Measurement preparation (thermocouples); FE simulation development*	*Students will be mentored by International scientists. They will work alongside scientists and graduate students in Germany. Some of the activities they will participate in include: Orientation activities and tour of facilities; Visit to other German research institutes and Industry in Germany; Participation in German organization annual events Graduate students will each mentor the senior level undergraduate student*
		II) Damage propagation in ceramic composite under extreme environments (1 Grad + 1 UG) *Sample development; Non-destructive testing of samples; Numerical simulation; Development of stages, fixtures and measurement for tomography under both heat & load.*	
Experiments, US National Labotory with Intl participation	**Fall**	*Experimental calibration, collection parameters; quantitative strain data and tomography collection in two 1-week sessions at National Laboratory (with International participants)*	*Students will be mentored by US, German and national laboratory scientists. German participants visit US; team presentation of research at lunchtime seminar.*
Data analysis, assessment and dissemination	**Fall/Spring**	*Analysis of synchrotron data, comparison with simulations and microscopy studies; Joint assessment of results; Presentations and Publications*	*Participation of undergraduate programs; Post travel survey & assessment; International Research Week presentations*

Fig. 2. An example of a typical schedule and structure the IRES program will follow for each cycle.

in research as an undergraduate has been seen to have a positive educational impact. In a study by Burkett et al, it was found almost half of the 34 total undergraduate students who participated in a research experience continue to pursue graduate degrees [12].

Internal and external assessment methods were used to evaluate the effectiveness of the program and to strengthen areas needing improvement. Internal evaluation components were conducted by the PI of the program and consisted of regular meetings to discuss the activities of the students and of their progress, achievements, and final reports. Meanwhile, external evaluation components were conducted by an independent evaluator, focusing on pre-experience and post-experience questionnaires and interviews [13].

III. IRES PROGRAM STRUCTURE

The recruiting efforts to promote the IRES program and to determine the cohort for the upcoming program cycle begins in the preceding Fall semester. Informational events, such question and answer panels with IRES program Alumni, are used to advertise the program. The selection process will involve two phases: an application phase, which is open to all students who are interested, then proceeding with an interview phase. The PI and typically one or two IRES Alumni are present during the interview phase and ask questions to determine the students whose interest and goals align best with the program. Those selected form the cohort for the upcoming program cycle and begin the program the following academic semester.

Overall, the IRES program is structured into three main phases combining intensive research preparation in the US, collaborative research in Germany, and joint research experiments in the US at both the home institution and national laboratories in an approximately year-long cycle for each cohort team. An example of a typical schedule for a cycle of the IRES program is shown in Fig. 2. Prior to traveling, the students spend at least one academic semester on the technical preparation for international research.

A. First Academic Semester: Pre-travel Preparations

The first academic semester mainly focuses on introducing the new students to the program and begins to prepare them for their research topics. These research topics are open-ended, allowing students to develop their own new topics or to adapt and elevate an existing topic they were working on in their research to the international collaborative level. Basic technical competency is established as each IRES student participates in extensive literature review, experimental planning, communication with their collaborators and German mentors, initial data collection and analysis, and through hosting outreach programs and sessions. Studies in similar international oriented programs, such as by Parkinson [11] and Arzberger et al. [14],

TABLE I
SUMMARY OF THE CUMULATIVE SCIENTIFIC OUTCOMES PRODUCED BY STUDENTS AS A DIRECT RESULT OF THE IRES PROGRAM AND THE COLLABORATIONS ESTABLISHED BETWEEN THE STUDENTS AND THEIR MENTORS.

Category	Undergraduate Student[a]	Graduate Student
First-Author Journal Publications	8	9
First-Author Conference Proceedings	8	11
Awards, Grants, and Fellowships Awarded	7	6
Pursued Graduate School[b]	8	-
Invention Disclosures, Patent Applications	2	-

N = 27 total students (17 Undergraduates and 10 Graduates)
[a]Students enrolled as undergraduates during their first semester of the IRES program are considered as such within the scientific outcomes.
[b]Only applicable to students considered as undergraduates at the start of the program.

TABLE II
THE PRESTIGIOUS AWARD, GRANTS, AND FELLOWSHIPS AWARDED TO STUDENTS SINCE PARTICIPATING IN THE IRES PROGRAM.

Award, Grant, or Fellowship	Number of Students Awarded
Order of the Pegasus	1
Fulbright Fellowship	4
Christine Mirzayan Science & Technology Policy Graduate Fellowship	1
NSF's Graduate Research Fellowship Program (GRFP)	3 (2 Honorable Mentions)
National Defense Science and Engineering Graduate (NDSEG) Fellowship Program	1
NASA Minority Serving Institution Fellowship	1
Aviation Week Network's 20 Twenties Awards	2

have shown having a preparation period is crucial for students to be better prepared for their research and study abroad. This preparation period and the formation of a research timeline also aids to reduce the transitory period students experience upon their arrival abroad, allowing students to continue making progress on their research.

Within the first month of the program, the students fill out the pre-travel questionnaire and complete their interviews with the evaluation team to establish a baseline before fully engaging with the program.

Throughout the semester, each student communicates with their collaborators abroad at the research institute in Germany through emails, reports, and bi-weekly conference calls to formulate, discuss, and review an agreed upon timeline for equipment and experiments to be performed once the student is abroad. Previous alumni of the program also join the meetings to aid in guiding the current IRES students. It is during this time additional meetings with the collaborating scientists at the national laboratories are held for preparing student-led experiments in collaboration with the German scientists. Initial and small experiments might be conducted and its subsequent data analyzed during this semester prior to the student's departure to better inform and refine these experiments to be conducted abroad and at the national laboratories.

STEM outreach is another key focus during this semester. The students will coordinate STEM-oriented activities and panels for middle and high school students both locally and internationally through educational entities working with K-12 students around the world in order for the IRES students to share their knowledge while developing their communication skills on technical topics to a diverse and international general audience. Information further expanding upon the outreach the IRES students engage in can be found in the *Broader Impacts* section.

B. Second Academic Semester: Research Abroad

The second academic semester is when the IRES students travel abroad for 10 weeks to their respective research sites across Germany. During this time, students work with their international supervisors to complete the research goals established during the previous semester with access to state-of-the-art and one-of-a-kind equipment to perform high-quality research and novel publishable work. During this time, they additionally immerse themselves in the work culture and environment, learning to professionally develop themselves as well as develop their communication skills to a highly technical international audience. The IRES students also update their advisors in the US weekly on their progress. It is during this time that the students are able to prepare samples and run tests in preparation for complex experimental setups they will conduct with their German counterparts at the US national laboratories upon the completion of their 10 weeks in Germany.

The IRES program also makes arrangements for visits among the student sites, hosting seminars at each site and institution, government agencies within Germany, such as the European Space Agency and engineering companies at the site. During these visits students develop their global proficiency learn about current industrial capabilities and challenges presented to them in both the US and internationally on an international scale, giving students a more complete understanding of practical real-world applications of their research in scientific and commercial environments.

C. Post-travel Involvement and Research Continuation

Shortly after the IRES students return back from Germany, they complete the post-travel questionnaire and their interview with the evaluation team. Students also evaluate what was accomplished during their time abroad and make adjustments to their plans in continuing their research moving forward. This typically would include additional experiments and measurements required to complete their data set and even starting to compile and prepare a manuscript draft for publication. It is also during this time that students would focus on continuing their collaboration with the German research institute to finalize their preparations for experiments at a national laboratory within the US. More recently, the IRES program has expanded its collaboration to include scientists at other national laboratories. Students would spend about one week at the laboratory with their German advisors and other German scientists to perform novel and ground-breaking high-energy X-ray diffraction and tomography experiments that the team has been preparing for over the past few months.

Alumni, especially undergraduate IRES students often still continue their collaboration into graduate school to not only publish papers on their resulting experiments, but also expand upon the work they completed within the IRES program and introducing additional collaborators.

D. Broader Impacts

Throughout the IRES program, the IRES students not only develop themselves technically, globally, and professionally, but also enrich their surroundings through STEM outreach. STEM outreach is a key component throughout the IRES program. In the first academic semester, IRES students provide interactive technical activities involving their research at a K-12 level. These activities also introduce language elements to the students, such as learning the German words for components of a turbine engine, and provide a platform for the K-12 students to provide words in their native languages apart from English. This multi-lingual component is further developed through international outreach through organizations such as Skype-A-Scientist. The most recent cohort of students participated in Skype-A-Scientist with K-12 students from Canada, Malaysia, and the Philippines.

Each year, the IRES students organize a weekly blog updating their progress technical, professionally, and personally, and on their thoughts and experiences of the IRES program as a way to share with others their development and to inspire the readers to learn more about the German culture and current challenges researchers are trying to solve. This blog also aids to increase the exposure of the IRES program to potential prospective IRES participants and to students who may be interested in applying for the program when applications are open.

Another vital component is to disseminate and share the research the IRES students perform to the scientific community. This is achieved through publishing journal publications [15]–[19], attending and presenting at both domestic and international conferences [20]–[22], participating in an AIAA joint special international session to industry leaders and researchers [23]–[25], through news articles and podcasts discussing their experience with the IRES program and their research, patents and invention disclosures [26], and through organizing and hosting an IRES Symposium Teaming Aerospace Researchers (STARs) symposium filled with collaborators of the IRES program.

E. Scientific Outcomes

A major metric on the effectiveness of the IRES program and its effects on the scientific community can be measured through conference papers and journal papers published by the IRES student Alumni, patents granted, as well as research awards, grants, and fellowships awarded to them. Table I summarizes these achievements. Table II expands upon the awards, grants, and fellowships, awarded to the 27 students since their participation within the IRES program.

IV. Assessment results

The following section are the results from the independent evaluator [13]. These results come from the pre-travel and post-travel questionnaire and interview questions given to an IRES Cohort of students who fully completed the program. It should be noted that these results are reflective of a case study for the specific Cohort in the IRES project itself and cannot fully be generalizable since the sample size of students who participated in the program is small (3 students).

The questionnaires and interviews were structured to collect data focusing on the students' expectations and experiences about their research preparations and study abroad as well as the technical impact on their research skills and knowledge; professional impact on developing cross-cultural teamwork, technical communication, and leadership skills; and their cultural perspectives and awareness and the globalization of their scientific research perspectives.

More specifically, the pre-travel questionnaire aimed to measure perceptions about the application and enrollment process, expectations about the program, and included responses used for pre-post comparisons. The post-travel questionnaire aimed to measure overall project satisfaction, frequency of interactions with program staff including mentors from US and Germany, the quality of mentoring and support provided, satisfaction with the program, aspects of the experience that could be improved, and big ideas for how they would describe the experience overall. Meanwhile, the student interviews focused on measuring the students' responses to the quality of activities and mentoring support, what they found to be the most challenging, the

most rewarding, and what benefited them the most about the research experience. More information involving the variables and constructs to formulate the questions asked to the students can be found in more detail within the published report [13].

A. Technical Competency - Research Skills and Knowledge

In both the pre- and post-travel, the students felt that the IRES program and their time abroad in Germany helped to enhance their research capabilities from the goals in research, their skills in research, and their understanding of their topics and knowledge about the scientific community around them. The survey summary of these results are shown in Fig. 3.

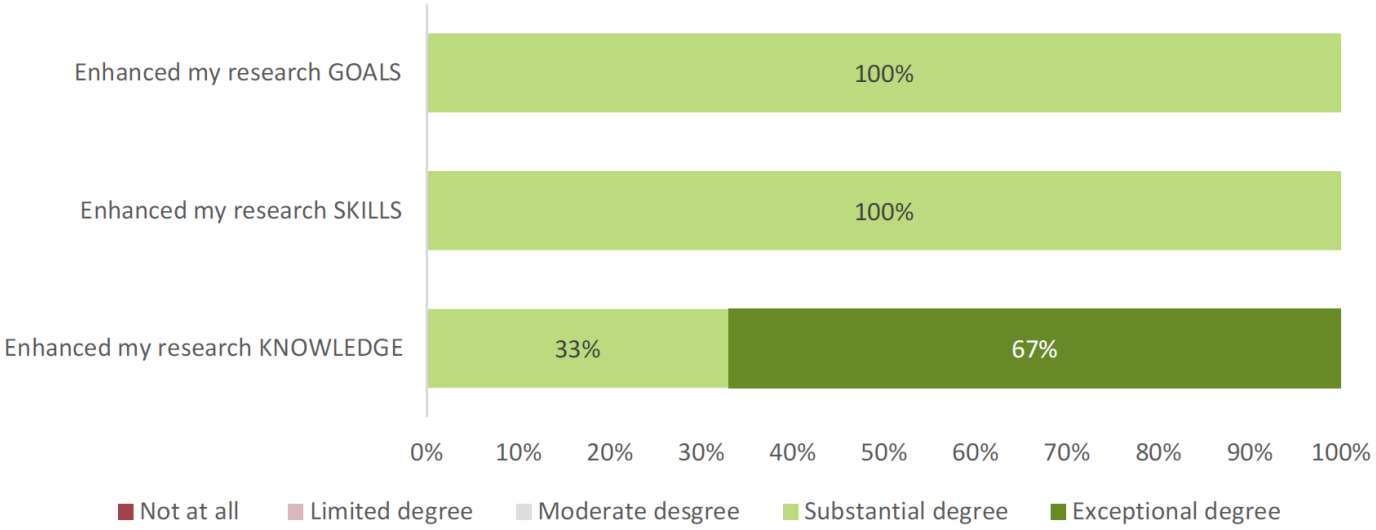

Fig. 3. Student perceptions on the IRES program enhancing their research goals, skills, and knowledge. Figure reproduced from [13].

The IRES students also found that overall their mentorship experience was a positive one. Feeling their mentors abroad were typically accessible in filling in the gaps of knowledge in the research and in providing resources to aid in further comprehension of the student and mentor's topics. The students also perceived that their mentors listened to their ideas and suggestions and provided constructive and useful critiques of the student's work throughout the research process.

B. Global Competency - Cultural Impacts and Global Awareness

Some difficulties did arise in the daily lives of the IRES students resulting from the cultural differences between the US and Germany; however, these differences were able to be overcame through adaptation and learning more about these differences. Overall, experiencing these difficulties firsthand helped to expand their cultural awareness and perspectives, becoming a more informed global citizen. Fig. 4 compiles a summary of responses the students had both pre-travel and how those same responses changed post-travel after their 10 weeks abroad.

A summary of the student's perspectives of their global awareness regarding research within their fields for both pre-travel and post-travel is shown in Fig. 5.

After their travel abroad, the IRES students felt that they had a better overall understanding of the global aspects of scientific research and how their topics are issues being worked out across the world. The students also felt more confident to conduct, work with, and present their research in an international setting.

C. Professional Competency - Development and Career Impact

The IRES students were asked both in pre-travel and post-travel about how their professional careers would be effected by the IRES program. A majority agreed the experience help them in developing in and expanding their research skills and experiences, provided excellent opportunities for professional networking, and in their career decision-making after the program. The program aided in increasing their confidence and cementing their decisions regarding their professional careers.

It should also be noted that the confidence of the students in their work was increased, as described in Fig. 5. The IRES students reported feeling more equipped to effectively present their technical research work to an international audience in a professional setting. This was achieved during their time abroad through giving seminar talks on their research to their peers, their departments, as well as to each others. Even after completing the IRES program, some of the students went to present the work they conducted during the IRES program at both domestic and international conferences to a diverse, yet highly technical audience.

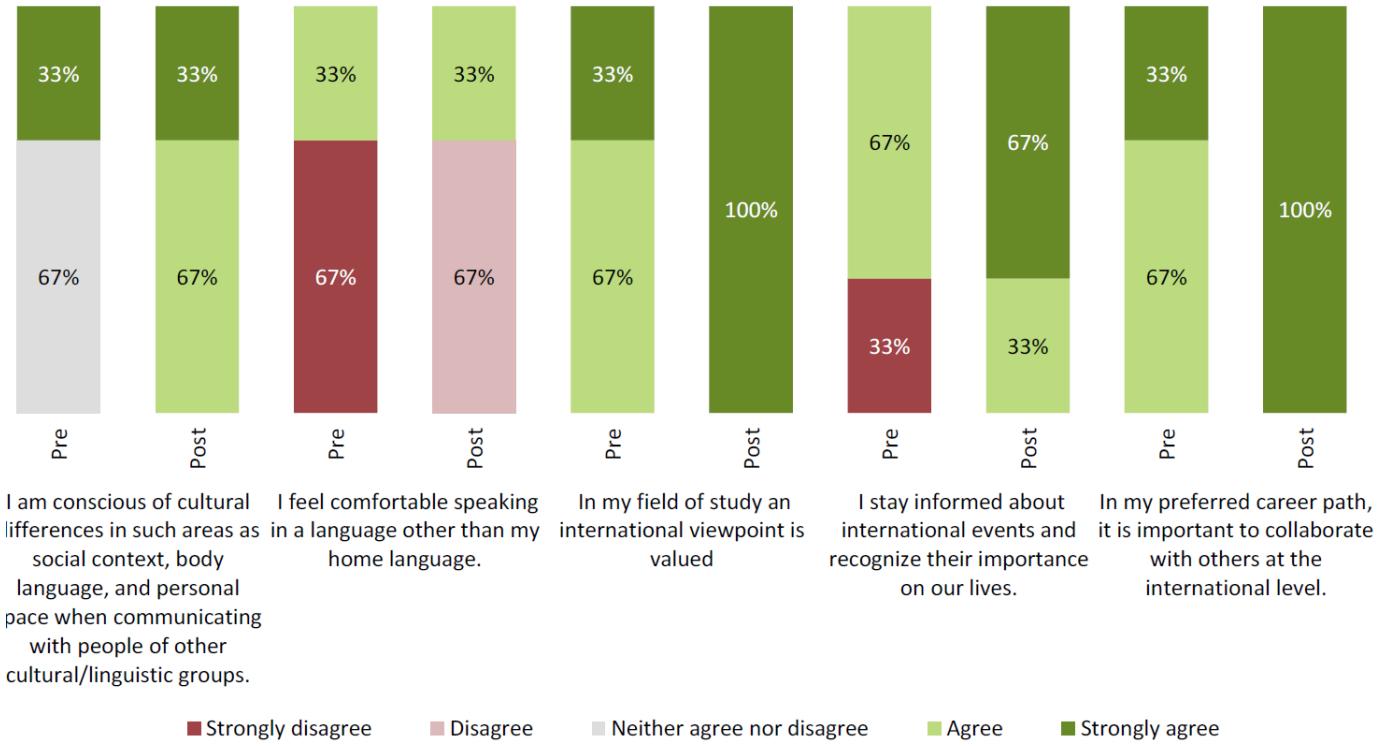

Fig. 4. Students' pre- and post-travel perceptions in their cultural awareness. Figure reproduced from [13].

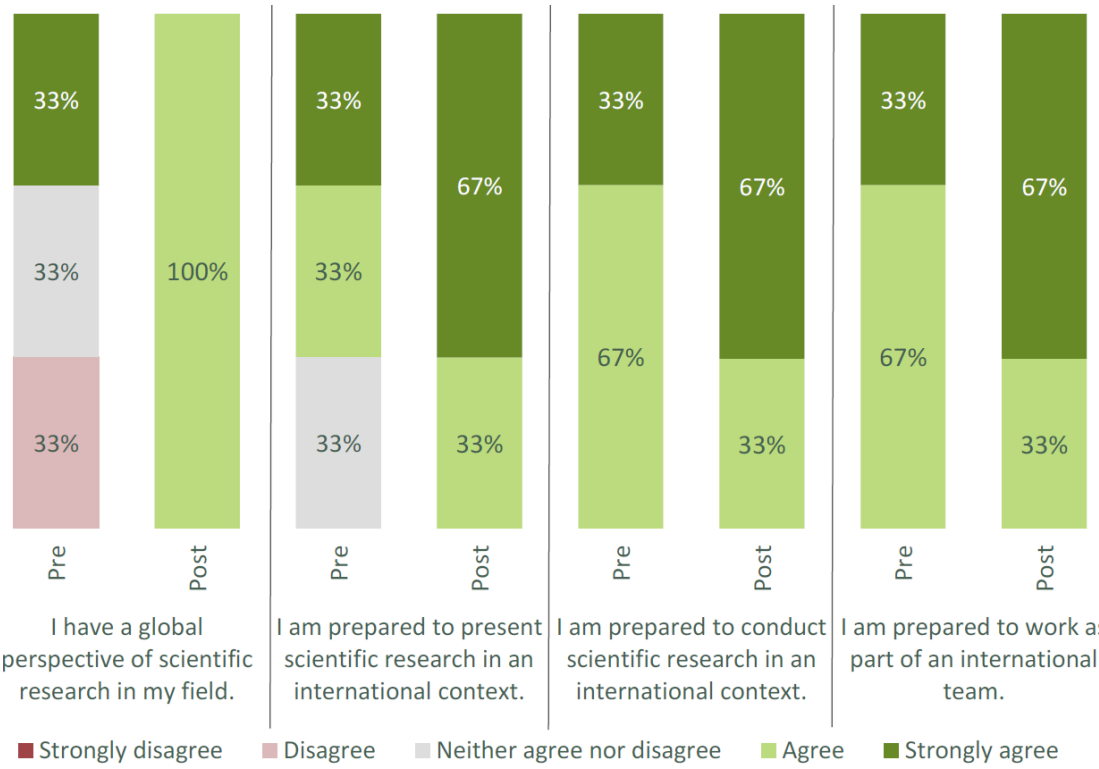

Fig. 5. Students' pre- and post-travel global perceptions of scientific research. Figure reproduced from [13].

D. Final Student Reports

As part of their completion to the IRES program, students must provide a report that technically explains their research topic, the results of their research throughout the IRES program, and plans moving forward in terms of research continuation. Additionally, the students often devote a section discussing the personal and professional impact the program had on them. One student stated being part of an international research environment has improved their research skills and overall understanding of how others internationally approach engineering problem solving. Another stated being presented the very uncommon opportunity to not only conduct research as an undergraduate, but to also be able to travel abroad to conduct research as an undergraduate too has presented tremendous growth in their learning and in the potential future opportunities in their growth moving forward in terms of begin admitted to respected universities and obtaining prestigious fellowships. The general conscience of the students are that the program has had a technical, professional, and global impact on them. This demonstrates attributes of a global engineer and often aids in setting up further future success in the student's academic and professional careers after completion of the IRES program.

V. Conclusion

The technical problems faced today within industry are a complex and often global issue. International collaboration focusing on better understanding and in finding solutions to these problems are often necessary; however, this also results in a greater demand for globally competent engineers who demonstrate high levels of proficiencies in technical, global, and professional skills. The approach in this particular case study, funded by the National Science Foundation International Research Experience for Students (IRES), focusing on collaboration between researchers of the US and Germany collaboration between a US university, German research Institute and US national laboratory aids in developing these key aspects that a globally competent engineer embodies. Not only did the perceptions of the students who participated fully in the program demonstrate that they felt the experience enhanced their research, professional, and personal development, using words such as "unforgettable, life-changing, collaborative, challenging, and enriching " to describe the program, but many of these students continued after the program to publish their results as well as be awarded highly competitive and prestigious awards, grants, and fellowships as both undergraduate and graduate students. The overall outcomes from the evaluation demonstrate the importance to continue international collaboration opportunities for students as well as to continue to evaluate the technical, professional, and global impacts that arise from these international collaboration opportunities.

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