Global Engineering Skills Development during an International Research Experience

Andrea Schuman and David Knight
Dept of Engineering Education
Virginia Tech
Blacksburg, Virginia
aschuman@vt.edu, dbknight@vt.edu

Nicole Sanderlin
College of Engineering
Virginia Tech
Blacksburg, Virginia
npsander@vt.edu

Christine Burgoyne
Dept of Materials Science and Engineering
Virginia Tech
Blacksburg, Virginia
cbala@vt.edu

***Abstract*—This research paper describes the learning outcomes that students believe they developed during an international research program. Research to solve the grand engineering challenges is advanced more quickly and effectively when engineers from around the world collaborate. Since 2006, the National Science Foundation has funded International Research Experiences for Students (IRES) programs in which cohorts of U.S. students travel to an international partner for a limited period to collaborate on a research project. These programs abroad are an opportunity for experiential learning as students are embedded in a global engineering research workplace. The IRES programs were created to strengthen universities' cross-cultural relationships, advance global research, and cultivate effective technical and professional skills in students. Prior work shows that the location, logistical aspects, and program leaders' decisions all influence students' learning outcomes. There is a need for further research on student learning across IRES programs to better understand the expanse of and variation in IRES programs' outcomes based on specific design decisions. This study will add to the literature by exploring data from one cohort of students to understand which learning opportunities are the most salient to them based on their perceptions vocalized during interviews conducted a few weeks after their IRES experience. The data for this exploratory study are from students from multiple engineering disciplines who spent a summer conducting engineering research at a university in the United Kingdom. The research question organizing the study is: What do students highlight following their IRES experience as key lessons learned and skills developed? Interview data were coded through the lens of global engineering competency's three dimensions: technical, professional, and global. The results indicate that the students strongly identify that they gained professional skills by experiencing research projects in a new workplace context. This study builds evidence of the value of IRES programs with respect to future workforce development beyond specific research products to justify the continued investment from the National Science Foundation and faculty mentors. The results included can be used to advertise the program's outcomes accurately to future cohorts and to identify the ways that future iterations could encourage students to become global engineers.**

***Index Terms*—Global engineering, student research, cultural competency**

I. Introduction and Background

International collaborations are vital to nearly all engineering work [1]. The International Research and Education in Engineering (IREE) NSF grant was created to fund engineering students to work on an existing international research project with the goals of benefiting the students enrolled in the program and sparking new research collaborations [2]. The NSF mandated continuous assessment of these programs in 2010. Since then, it has been renamed International Research Experiences for Students (IRES), and the funding structure has changed to support new grants for student mobility in research instead of only supporting opportunities that were tied to preexisting NSF grants [3].

Prior work shows that the location, logistical aspects, and program leaders' decisions all influence students' learning outcomes, so it is important to define the logistical aspects of the current case [4]–[6]. The IRES case in the current study was led by the College of Engineering at a large research-intensive institution that has a longstanding collaboration with a university in the United Kingdom. In the year of data collection, the cohort also included one short-term research project another U.K. university. Originally, both programs were going to be abroad for the same amount of time, but the shorter program was abbreviated due to external circumstances. The longer program provides a ten-week research experience to undergraduate and graduate students with five internationally recognized research groups. In the year of this study, eight students participated in the program, including three undergraduates and three graduate students who traveled to the United Kingdom for six weeks, and two undergraduates who visited for two weeks.

The ten-week research program had three parts: monthly preparation meetings the semester before, a four-week research seminar, and six weeks of research abroad or remotely. The monthly meetings took place between February to April and focused on program requirements, travel logistics, preliminary meetings with advisors in the United Kingdom, and completion of a Mentor-Mentee Agreement. This agreement was developed by the research team as a collaborative document that required all participants (students and research advisors) to agree on research processes, project outcomes, and mentoring and professional development activities (e.g. weekly meetings and feedback) specific to the IRES program.

The four-week Research Seminar aimed to prepare the IRES student cohort for their research projects abroad through meet-

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ing two objectives: a) conducting lab and preparatory work at the U.S. university, and b) preparing a realistic summer project plan. The research plan included: a problem statement with specific objectives and deliverables; an overview of important social, economic, and/or environmental needs met by the research; the current state of technology for the research work; relevant theories and methodologies; identification of required facilities, equipment training, and procedures in the United Kingdom; a realistic timeline; and the relevant connections between U.S. and U.K. collaborators. At the end of the four weeks in the United States, the students presented their plan and their progress of work for all advisors to provide feedback before traveling abroad to conduct their research in person. Following their return to the United States, students prepared a final presentation to summarize their research deliverables, and identify any next steps in the research project.

II. Purpose and Research Questions

The purpose of this exploratory qualitative study is to understand what learning outcomes, observed in the framework of global engineering competency, students find most salient after an international engineering research experience.

The research question organizing the study is as follows:

1) What do students highlight following their IRES experience as key lessons learned and skills developed?

III. Relevant Literature

Previous research has explored what collaborative projects during international programs teach students. When compared to other programs, programs involving service-learning projects had significant gains in intercultural development [7]. In a similar program, collaborative projects led to increased global preparedness and technical competency development [8].

International research programs were funded by the National Science Foundation specifically to improve research outcomes and relationships between universities [2]. An early assessment of a program in China found through surveys and interviews that students were gaining language, cultural, and global competencies [3]. The case in the current study will differ from that study because the destination has a closer cultural distance and a shared language with the United States, which prior work has shown to be an important influence the learning outcomes of an international program [9].

Other studies have examined the sending faculty members' perspectives [5]. Faculty and alumni across IRES programs identified learning outcomes related to career and future goals most strongly during interviews. Programs in locations with low cultural distances emphasized noticing work-life balance differences. Destinations with high cultural distances led to more learning about cultural values and practices [5]. Research outcomes tended to be weaker, but enrolling in IRES earlier in an engineering program, participating in more fieldwork, and publishing improved technical learning [5]. These interviews were done with alumni who had more time to reflect-post program. A prior exploration of global and research competencies in a different IRES program through surveys and a global engineering scenario found that students demonstrated increased confidence in research skills and proper identification of areas in which to improve their skills [4]. Our current research will extend the previous work by examining the most significant learning outcomes students identify immediately after a program, instead of measuring their level of advancement in a preset suite of outcomes dictated by program leaders.

Overall, the current study will contribute to existing knowledge by exploring what students experience as the most significant learning outcomes during IRES. It is useful to have this information so that the alignment between the NSF's priorities, program leaders, and the participants themselves can be examined. Areas where students are growing can be emphasized to potential participants and the program can be adapted to incorporate learning outcomes that are not currently realized.

IV. Theoretical Framework

The theoretical framework for this study originated from a conceptual mapping of students' outcomes in IRES's predecessor, IREE [1]. The three aspects are professional, global, and technical competencies. Allert et al. [10] defined this as three dimensions that can be integrated into global engineering competency. Professional competencies are outcomes that allow someone to succeed in any workplace, such as leadership, communication, or teamwork. Technical competencies are engineering-specific knowledge. Global competencies are intercultural openness, awareness, and skills [10].

Rosenberg [11] used the Global Engineering Competency theoretical framework to guide the outcomes and assessment for a domestically taught course about Global Systems. The students were graded by their ability to demonstrate that they could communicate in teams, understand global engineering, and grow as a global citizen and engineering professional through exams, presentations, and self-assessed reflection. The outcomes of this study indicate that by developing our understanding of how students learn global engineering competencies, they could be implemented as learning outcomes in domestic courses, which could be another outcome from this study.

This framework is used as a lens to interpret the participants' responses to the open-ended interview question: *What do you think are some of the key things that you learned through the IRES program?* The three dimensions of the theoretical framework are operationalized into a codebook, defined in Table I, which are used to code the data.

V. Methods

This study is an exploratory qualitative analysis of interview data. All students in an IRES cohort were invited to participate in interviews when they returned to the United States following their experience abroad. The following sections describe the data collection, data analysis, quality, and limitations of the project.

A. Data Collection

Two different research locations were included in this IRES program. Six students participated in a six-week research experience that has run for several years, and two students participated in a shorter, new experience at a different university. This IRES program has projects for multiple disciplines including materials science, industrial, electrical, and mechanical engineering. Most student participants were near the end of their undergraduate program and two were graduate students. All were invited to participate in a post-program interview for assessment that occurred a few weeks after students returned to the United States. The students were asked for their feedback on the program, significant incidents that were meaningful to them, and difficulties they experienced during their programs. The relevant interview question for the current study was a variation of: *what do you think are some of the key things that you learned through the IRES program?* Five students from the longer IRES and both students from the shorter IRES agreed to participate in the study, for a total of seven participants. The interviews were transcribed before analysis.

B. Data Analysis

First, the data were structurally coded in order to find the portions of the interview transcripts where the students described their most salient learning [12]. These responses were coded with provisional coding, starting with codes based on the global engineering competency framework [10], [12]. Provisional coding refers to analysis with a codebook that is based on prior research. The three themes of professional, technical, and global competencies are "lean codes" and defined in Table I. For provisional coding, the list can be expanded during analysis into subcodes or integrated into more complex global engineering learning. The a priori codes come from literature focused on IRES, so they are a good fit for this study [1]. The codes are defined in Table I and are adapted from [1], [10].

Development of the codebook and initial coding were done by the first author. For research quality, the codebook was reviewed with another author. The coding results of quotes that were harder to categorize were confirmed with another author.

Code	Definition
Technical competencies	Technical research and engineering skills that students need to succeed as researchers in their engineering discipline
Professional competencies	Workplace interpersonal skills that are important in multiple inter and intracultural professions
Global/cultural competencies	Abilities, attitudes, or attributes necessary for success in global teams in any discipline

TABLE I
GLOBAL ENGINEERING COMPETENCY CODES FOR ANALYSIS

C. Limitations

The limitations for this study include that it has a small sample size and is focused on a single program, so transferable results may be found but not generalizable ones [13]. The full range of the participants' experiences were explored in this study but more participants would give us a richer understanding of the program as a context. The short-term program's plan changed and the time abroad was abbreviated, so this study captures a particular, unique iteration of the program that will not be repeated identically. There is also a concern of social desirability bias, if the students believed that the program was seeking a specific response. This potential issue was mitigated by an external assessor performing the interviews and emphasized anonymity.

VI. RESULTS

The results of the presence of individual and integrated codes are shown in Table II. Table II demonstrates that the technical, professional, and cultural dimensions were each present in at least one participant's answers, though no student demonstrated all three dimensions in their response. Professional competency was mentioned by the most students and technical competency was also discussed frequently. The integration of multiple dimensions was less common, although professional-cultural and professional-technical competencies appeared. Integration of technical-cultural dimensions and the integration of all three dimensions were not observed. One student did not describe any competency development in their answer and instead focused on describing what they experienced.

An exploration of each code's representation in the data is also included to answer the research question: *What do students highlight following their IRES experience as key lessons learned and skills developed?*

A. Cultural Learning

Students did not seem to have significant cultural learning as a whole, potentially because of the relatively small cultural distance and shared language between the United Kingdom and the United States. Cultural competency was only described by one student, who additionally integrated it with professional competency. Their main framing of learning was about working across cultures and observing cultural differences in business practices. An exemplary quote is:

> I remember they did like a cultural overview and were kind of like telling us, so these are some ways that it's different. And they were saying like, you know, meetings in America will start off very like businesslike, to the point. But in Britain, they want to like chat first and have a conversation...I was kind of surprised to see that there were differences (between cultures). Just in how people kind of communicate and sort of approach solving problems. Even though they warned us of that, I guess I did not believe it.

An interesting additional point the student made in the prior quote is the importance of experiential learning. The pre-program orientation described some cultural values in U.K. workplaces, but the student did not truly absorb that information until they experienced it firsthand.

Pseudonym	**Student 1**	**Student 2**	**Student 3**	**Student 4**	**Student 5**	**Student 6**	**Student 7**
Program	Long	Long	Long	Long	Long	Short	Short
Degree Program	Grad	Grad	UG	UG	UG	UG	UG
Codes							
Technical competency				X	X		X
Professional competency			X	X	X	X	X
Global\cultural competency	X						
Integrated Codes							
Technical and professional					X		X
Technical and cultural							
Professional and cultural	X		X				
Cultural, professional, and technical							

TABLE II
SUMMARY OF GEC CONSTRUCTS AS THEY APPEAR ACROSS INTERVIEWS (NOTE: UNDERGRADUATE STUDENT IS INDICATED BY UG)

B. Technical Competency: Research and Engineering

Subcodes of both research and engineering skills were observable in the students' responses. Multiple students mentioned learning how to program better, with quotes such as:

> I can definitely see myself becoming more proficient in MATLAB, just my overall syntax. It's more optimized. A code can run much quicker. My codes now can run much quicker now than before.

Research-related technical outcomes were more common than purely engineering-related outcomes. Reviewing prior research publications was emphasized during the orientation and this stood out to one student as the first thing they mentioned learning:

> Definitely just compiling literature and breaking it down and using what's useful to me. Just learning how to read papers a little better.

Many participants were assigned to a research project that they were able to fully implement during the duration of the program. Along with reviewing literature, they gained research skills in the lab. One student described their research and technical skill development by summarizing:

> The IRES program really helped me become a more independent researcher just with the amount of preparation that went into everything, whether that be literature review or testing... workshops, tutorials that we had to go through, reading textbooks, doing hand calculations.

IRES allowed them to practice the entire process of research, giving them a better perspective on what a career in engineering research would look like and practice for future projects.

C. Research Projects: Integrating Technical and Professional Dimensions

A couple of participants were able to integrate their learning about research and professionalism into an idea of engineering research projects with technical and project management skills. One student described:

> I learned some concrete things that I already mentioned, like Unity and setting up a human subjects research trial, all the things that go into that, including just having a script or a protocol ready, and having all the things prepared and how to recruit participants, that process and lessons learned from that. But then I think I also learned more about research in general. Kind of how to manage your expectations around that and keep to a schedule when things are so unpredictable, was one of the biggest things that I learned. So keeping the eye on the end goal.

Although their answer did not incorporate cultural outcomes, it is a holistic description of managing technical research projects. Another student anticipated the benefit of this experience in their future technical research by experiencing research and design work. They described:

> (IRES) really helped me strengthen myself to become more academically in touch as a researcher and as a student as well. So I think that's going to really help me prepare for student design and all my classwork.

D. Prevalence of Professional Development

Professional competencies were referenced the most commonly by students, both alone and integrated with other dimensions. In the shorter program, the students practiced resilience and flexibility because of the late-stage change in plans. One student in this program said:

> (We were) still able to do productive research, even though it wasn't what we envisioned. Stay focused on what I had to do and it all worked out well in the end.

Adaptability is an important skill to develop from being in an engineering workplace, as hand-on experiences can often have more issues than classroom work. Another student specifically talked about overcoming challenges, saying:

> I thought I was pretty good dealing with problems... but definitely some(times), I wasn't sure how to deal with them and I just got frustrated. But with the help of coworkers or (another student) who I was working with, I was able to solve them better, more efficiently too. So I realized that I should work on those traits

more. And calm down and think slowly instead of just being emotional about the challenges.

E. Adapting Professional Attitudes from Another Culture

In the longer IRES program, the students tended to learn professional skills from observing the way research was conducted in the research group they were embedded in abroad. Multiple students mentioned learning how to work at a sustainable pace instead of pushing until burnout. An example quote is:

> Working with U.K.'s culture on doing research was fascinating and I hope to incorporate it in (U.S. University). They were very passionate about what they did, but also they like made sure to take their time doing so and make sure they're not rushing anything and make sure like everything isn't, everything's good in detail, instead of rushing things here and getting progress right away.

Another student expressed a similar thought while adding that taking breaks is important:

> I think being at (the U.K. University), just the healthy research practices, just a couple hours doing it, but allowing yourself to take a break, take a step away, and then coming back to it later, while before it was more of a burnout. You just kept trying to go until you figured it out. But now I feel like telling myself it's okay to take those breaks and step away from the problem.

And a third student paired a specific skill they developed with strategies for studying, describing using the pomodoro method of alternating work with rests:

> I've learned how to study more efficiently. Whether that be at work, 50 minutes straight, and take a 10 minute break just to kind of keep the mind fresh or learning how to find what I'm looking for when I'm doing my bibliography analysis.

Students said they wanted to continue their new habits when working in the United States in the future.

F. Absence of Global Engineering Competency

One student did not list any learning outcomes in their response. They answered the question by describing the experience of working in the United Kingdom as great and saying that they will take their new professional dimensions into future work. Elsewhere in the interview they described learning outcomes from IRES, so it may be that the wording of the question used in this study did not bring any competencies to mind for this participant.

The other students typically they anchored their response in one dimension and potentially paired another with it. No student integrated all three dimensions into their response. It is possible that these outcomes are a result from the data collection method more than their experience and that since students were speaking without preparation during the interview, the first dimension on their mind served as an anchor for all of their salient points. It is also possible that these programs are not long enough to lead to fully integrated learning. Upcoming research from this project with that uses alternative reflection data sources will be able to explore if the data type is leading to grouping of outcomes.

VII. Contributions and Implications

This study answered the research question of: *What do students highlight following their IRES experience as key lessons learned and skills developed?* The set of outcomes differed between students, indicating that students' specific experiences within the same program can affect what they view as the most significant learning. The learning outcomes based on the coding were not drastically different between the short- and long-term programs. Within the quotes, one difference that could be observed is that the students in the long-term program often stated that they had learned from the research group they were working in, whereas the short-term program taught flexibility and using available resources for research. The full results are in Figure II.

The results indicate that professional outcomes were the most commonly referenced by students and were integrated with other learning. We recommend that program leaders should emphasize the professional competencies that students will gain when advertising IRES programs to students. A notable difference is that the graduate student participants did not emphasize professional outcomes, with one focused on cultural outcomes and another not listing learning outcomes. Every undergraduate student noted professional learning. This difference may be explained by the fact that graduate students had substantial professional and technical learning opportunities in their degree programs; such opportunities may be new to undergraduates, a finding that is corroborated by Knight et al. [5] who found that students earlier in their degree experienced more technical learning in these kinds of programs.

There were multiple experiences during the program that students said contributed to their learning. Engaging in the entire research process gave students the opportunity to advance their research, engineering, and professional skills. The research projects did not seem to correlate with intercultural development, which differs from previous research [7]. Cultural learning and professional development came from being embedded in a research group abroad, which allowed the students to see the differences between U.K. and U.S. work styles. The work-life balance outcome was previously found in studies of IRES programs in locations with lower cultural distances [5]. An area for future investigation by the sending university is exploring how engineering students are being taught that research should be done. Multiple students said that in previous research experiences, they would try to solve a problem until they burned out. IRES was the first time they tried to take a break before returning with fresher ideas. This lesson could be worth emphasizing in domestic research programs more broadly.

A significant point that one participant made was that learning the information from orientation and experiencing it while abroad were completely different types of learning. Even topics that had been covered in orientation were not absorbed until the student experienced it. This difference should be considered when planning the information to be imparted during orientation. Other ways of communicating the information whether from alumni or hand-on experiences could be considered.

A future area of improvement is finding a way to measure or encourage the integration of all three dimensions into global engineering competency. Technical-cultural integration was also not found in the program. This could look like the outcomes described in Jesiek et al. [3] by learning how different cultures define engineering problems and approach research, or differences in international ethics and regulations. Sociotechnical incorporation is a difficult but essential goal for engineering programs trying to impart that engineering is a cultural practice [14]. Specific cultural components to the research projects could add the final dimension to professional and technical learning in the research work.

The results of this study adds to the continual assessment and improvement of IRES programs, which is a goal of the project [15]. It expands upon previous research that has explored the faculty program leaders' perspectives on students learning. It is important to build evidence of the value of IRES programs with respect to future workforce development beyond specific research products to justify the continued investment from the National Science Foundation and faculty mentors.

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