Microelectronics Research and Global Competencies: Unpacking Research Abroad Experiences of Engineering Students

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Chibuzor embarked on his academic path at the University of Benin, earning his Bachelor's degree in Computer Engineering. His undergraduate experience ignited a passion for blending technology with education, establishing a robust foundation for his research interests. In his doctoral studies under the mentorship of Professor Gloria Kim at the University of Florida, Joseph is not only investigating the potential of AI in enhancing educational practices but also deeply exploring the aspect of global competence in engineering education. His research addresses the critical need for engineers who are technically proficient, culturally competent, and globally aware, preparing them to tackle international challenges effectively.

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Abstract

Global competencies are essential for engineering students in today's globalized world. This work investigates this aspect of an International Research Experience for Students (IRES) program funded by the National Science Foundation (NSF). The NSF IRES: Interdisciplinary Research in Korea on Applied Smart Systems (IRiKA) recruited undergraduate and graduate students from four public and private US universities with diverse backgrounds. Throughout the lifetime of the grant, three cohorts were deployed. Due to the pandemic, the program did not run in 2020 and 2022. In all, eighteen participants completed an 8-week research internship that was offered as part of the IRiKA program.

This study focuses on the experience of the 2023 cohort - specifically, a subset of the 2023 cohort that worked on microelectronics device projects. This study employed a qualitative methods approach anchored in the PISA 2018 Global Competence theoretical framework. By analyzing qualitative data from weekly blog post reflections and student interviews, this work aims to unpack the complex ways global competencies are cultivated among undergraduate and graduate engineering students with varying degrees of prior research experience. The findings of this research are expected to inform future engineering education practices, providing valuable insights for educators, policymakers, and institutions aiming to enhance the global competencies of their students through international research collaborations.

Introduction

Global competence has increasingly become a key differentiator in engineering, significantly influencing an engineer's employability and career progression [1], [2], [3], [4]. However, working with individuals from diverse backgrounds in international projects while potentially enhancing creativity in technical problem-solving through the integration of various perspectives [1], [2] also presents challenges related to collaboration across differing backgrounds [5], [6], [7], [8]. The ability to exhibit strong global competencies – such as cultural adaptability, international collaboration skills, and an understanding of global engineering issues – is not just a desirable attribute but a critical factor in the success and viability of engineering professionals in the future [4], [9], [10], [11], [12], [13].

Global engineering competency (GEC) is crucial yet still evolving, prompting engineering educators to establish various programs to develop these skills. Various frameworks have been proposed to categorize these educational experiences, including formal degree programs, study and research abroad opportunities, and internships or service learning abroad [6], [7], [14], [15]. Despite extensive documentation of these programs (Johri & Jesiek, 2014), research shows that the gap in identifying the most effective strategies for crafting experiences that enhance GEC is limited [1]. This gap is particularly evident in the U.S., where engineering education has historically not fully prepared graduates for the globalized workforce. This shortfall is highlighted

by ABET's criteria, which emphasize the need for engineers to consider a broad range of global factors in their work [16]. To address this deficiency, U.S. universities and initiatives like the National Science Foundation's International Research Experience for Students (IRES) program are developing new approaches to foster global competencies in engineering students, aiming better to prepare them for international collaborations and the global market [17], [18], [19], [20].

This research takes a step towards addressing this gap. The motivation behind focusing on microelectronics research and the global competencies of engineering students stems from the critical role that microelectronics plays in contemporary global technology. Many universities in the US offer undergraduate research opportunities in microelectronics. These programs encourage innovation and creativity, often in collaboration with industry, providing students with hands-on experience in this specialized field, but not in an international environment [4], [9], [21] .

This study focuses specifically on a subset of the 2023 IRiKA cohort, examining how their involvement in microelectronics research abroad contributed to developing their global engineering competencies. This study seeks to explore the intricate processes through which global competencies are developed among engineering students at both undergraduate and graduate levels who possess varying levels of research experience in microelectronics. Through the lens of three research questions, the study examines the influence of the International Research Initiative in Knowledge and Academia (IRiKA) on the global competency development of these students. Specifically, the research aims to address the following questions:

1. What impact does participation in IRiKA have on the global competencies of both undergraduate and graduate engineering students?
2. How does varying research experience in microelectronics contribute to developing students' global competencies within the IRiKA program?
3. In what ways do undergraduate and graduate engineering students' experiences in developing global competencies differ when engaged in international research experiences?

Literature Review

Numerous investigations have highlighted the advantages of international research programs. Research indicates that for students across various majors, engaging in international research experiences, especially when preceded by a pre-trip orientation, results in heightened global consciousness, enriched experiences while studying abroad, and deeper immersion in their research activities. Streitwieser and Leephaibul (2007) conducted before and after surveys with students from Northwestern University who took part in the Study Abroad Research Program, documenting these outcomes [22].

In a study conducted by Fleming, Burrell, Patterson, Fredericks, and Chouikha in 2012 at Howard University, undergraduate students who participated in a research-oriented study abroad program were observed to have made significant advancements in several key areas. These areas included their ability to navigate communication challenges, such as language barriers and technological issues; manage coordination and time constraints effectively, such as scheduling and accessing

necessary equipment; engage more deeply with their research projects, showing heightened enthusiasm and practical involvement; and realize the broader positive effects of their experiences, notably in forging new relationships and enhancing their global awareness [23].

In a study by Jesiek, Haller, and Thompson from 2014, the effectiveness of different orientation formats for students participating in summer research abroad programs was evaluated. The students were divided into three groups based on the type of orientation they received: one group had their orientation on their home country's soil, another group had theirs in the host country, and the last group participated in an orientation that was conducted entirely online. Findings indicated that students who underwent orientation either in their home country or the host country reported a significant boost in their preparedness for the overseas experience. Notably, the group that received orientation in the host country exhibited the most significant improvement in their perceived readiness for the journey. Conversely, the group that participated in the online orientation did not show a significant change in their readiness levels [24].

In evaluating the effectiveness and outcomes of the IRES program, our research aimed to assess if the program's objectives were being met. This evaluation sought to employ qualitative research methods, diverging from the predominantly quantitative analyses seen in prior studies. Our primary focus was determining whether participants acquired global competencies, enhanced their research skills and confidence in microelectronics, and gained insights into the advantages and challenges of conducting research internationally.

Program Overview

Interdisciplinary Research in Korea on Applied Smart Systems (IRiKA) for Undergraduate and Graduate Students was a research abroad program created with NSF International Research Experience for Students (IRES) funding. It offered a cohort of U.S. students annually the chance to engage in cutting-edge research for eight (8) weeks at leading research universities and government labs in Korea. This opportunity was extended to students from the University of Florida (UF), Louisiana State University (LSU), Michigan Technological University (MTU), and Northwestern University (NU) selected through a competitive admission process.

The research focused on smart systems, including sensors, emerging electronics, and materials and process development. Each IRiKA participant worked on individual research projects related to the overarching theme. In addition to research, they visited South Korean government research institutions and industry sites, such as Samsung, LG and Hyundai. A weekly professional development workshop on professional science communication was also offered that engaged both the U.S. participants and their Korean mentors. Upon the participants' return to the U.S., follow-on projects were offered to leverage their newly formed professional and personal network.

Over the lifetime of the grant, the program supported a total of 18 undergraduate and graduate student research projects in 10 Korean host laboratories at Seoul National University, KAIST, Korea Electrotechnology Research Institute, and CJ Group. Despite challenges posed by COVID-19 that led to two no-cost extensions, every cohort in the program traveled to Korea and was able to have an immersive experience. The participants were diverse in ethnicity (3 African Americans,

1 Native American, and 4 Hispanics) and gender (7 female students). The program has catalyzed continuing and new collaborations in the smart systems field across disciplines.

Methodology

Participant Data

This research focused on a subset of the 2023 cohort, which concentrated on microelectronics research in South Korea, as detailed in Table 1. Participants in IRiKA were required to journal their weekly experiences via structured blog posts. These posts were to include updates on research progress, advances in communication workshops, and descriptions of cultural excursions. The narratives provided a comprehensive view of various activities, observations, and personal reflections on cultural immersion and adaptation, making them a rich qualitative data source for understanding participants' experiential learning and cultural acclimatization during the program. To ensure confidentiality and protect participants' privacy, pseudonyms were used throughout the documentation process. This approach was adopted to safeguard the identities of the individuals involved, allowing them to share their experiences and reflections openly and without concerns freely.

Table 1. Participant Information

Pseudonym	**Gender**	**Year**
Student 1	Male	3rd-year undergraduate
Student 2	Male	3rd-year undergraduate
Student 3	Male	3rd year PhD
Student 4	Female	4th-year undergraduate

Research Questions

1. How does participation in IRiKA influence undergraduate and graduate engineering students' global competencies?
2. How does varying research experience in microelectronics contribute to developing students’ global competencies within the IRiKA program?
3. How do undergraduate and graduate engineering students differ in global competency development in the context of international research experience?

The first research question addresses the core of the study's motivation. It seeks to explore the direct impact of IRiKA. This inquiry is supported by literature highlighting the importance of international experiences in enhancing cross-cultural skills and global awareness in engineering education [6], [25]. This question aims to empirically examine how participation in a structured international program like IRiKA contributes to developing global competencies, which are increasingly recognized as crucial for engineers in a globalized workforce [6], [25].

The second and third questions dive deeper into the nuances of how varying levels of research experience in the specialized field of microelectronics impact global competency development. This question is pivotal as it differentiates between degrees of engagement in research, recognizing

that not all experiences are equal in intensity, duration, or focus. Literature suggests that the depth and nature of research experience can significantly influence learning outcomes and skill development. This research question came about from the different levels of participants in IRiKA undergraduate and graduate [26], [27], [28].

The first iteration of the RQs was more general, asking how international experiences influence engineering students' competencies. After reviewing literature emphasizing the importance of specific contexts and fields in such experiences, the questions were revised to focus on IRiKA and microelectronics. This second iteration was more aligned with the study's motivation but lacked depth regarding the varying experiences of participants.

This alignment was crucial for the study's objectives, ensuring that the research questions directly addressed the identified gap in the literature and the study's aim to provide insights into enhancing global engineering competencies through targeted international research experiences in engineering education. The final research questions (RQs) were validated as specific and relevant to the study's objectives through an iterative process marked by improving and agreement with academic literature. This made the RQs proper instruments for directing the research [18].

Conceptual Framework

In approaching this investigation, it was necessary to put parameters around global competence. The selection of a framework to explore the acquisition of global competencies was a critical step in assessing the acquisition of global engineering competencies [29], [30].

The Organization for Economic Co-operation and Development OECD's (2018) position paper, "Preparing Our Youth for an Inclusive and Sustainable World: The OECD Programme for International Student Assessment (PISA) Global Competence Framework," defines global competence as "the capacity to examine local, global and intercultural issues, to understand and appreciate the perspectives and world views of others, to engage in open, appropriate and effective interactions with people from different cultures, and to act for collective well-being and sustainable development" [31].

According to the OECD's 2018 framework, global competence encompasses the goal "to live harmoniously in multicultural communities; to thrive in a changing labor market; to use media platforms effectively and responsibly; to support sustainable development goals" [31] . Emphasizing the importance of thriving in an interconnected world, the handbook addresses the frequent occurrence of daily intercultural encounters, highlighting that the term 'intercultural' appears 74 times within the 48-page document [31]. The framework also detailed how the Program for International Student Assessment (PISA) was used to measure at which stage 15-year-old students were developing global competence and examined the role of schools in nurturing this attribute [31].

The PISA assessment of global competence includes a cognitive test for students and background questionnaires for students, teachers, and school leaders [31]. The cognitive test is "designed to elicit students' capacities to examine global issues critically; recognize outside influences on perspectives and world views; understand how to communicate with others in intercultural

contexts; and identify and compare different courses of action to address global and intercultural issues" [31]. The student background questionnaire probes "how familiar they are with global issues; how developed their linguistic and communication skills are; to what extent they hold certain attitudes, such as respect for people from different cultural backgrounds; and what opportunities they have at school to develop global competence" [31]. The OECD's position paper from 2018 defines global competence through four essential "target dimensions" [31]:

1. The ability to scrutinize issues and situations of local, global, and cultural importance, such as poverty, economic interdependence, migration, inequality, environmental risks, conflicts, cultural differences, and stereotypes.
2. The capability to comprehend and value various perspectives and worldviews.
3. The competence to engage positively with individuals of different nationalities, ethnicities, religions, social or cultural backgrounds, or genders.
4. The ability and willingness to contribute constructively towards sustainable development and collective well-being [31].

These "target dimensions" are reinforced by four fundamental components: knowledge, skills, attitudes, and values, as stated on page 11 of the paper. Additionally, the framework pinpoints specific skills necessary to facilitate these dimensions, including "reasoning with information, communication skills in intercultural contexts, perspective taking, conflict resolution skills, and adaptability" [31]. The framework explains that attitudes are "the mindset that an individual adopts towards a person, a group, an institution, an issue, a behavior, or a symbol," which "integrates beliefs, evaluations, feelings and tendencies to behave in a particular way" [31]. It highlights the importance of maintaining an "attitude of openness, respect for people from different cultural backgrounds," and the conviction to be a global citizen with duties and responsibilities. Following attitudes, the framework discusses values, described as "more general beliefs about the desirable goals that individuals strive for in life, reflecting modes of conduct or states of being that an individual finds preferable to all other alternatives" [31].

Research Design and Analysis

Qualitative research seeks to provide depth instead of breadth of understanding by diving deeply into the stories and experiences of a few [32], [33]. Johnny Saldaña, in his work on qualitative research methodologies, emphasizes that qualitative research is primarily about depth and understanding the nuanced experiences of individuals or small groups. When discussing qualitative data sources like interviews and journals, Saldaña highlights that these tools are precious for capturing detailed, personal narratives that reveal the complexities of human behavior and interactions [32]. Interviews in qualitative research are used to gather rich, in-depth data directly from participants, allowing researchers to explore their thoughts, feelings, and experiences comprehensively. This method is especially effective in uncovering the "why" and "how" of participant perspectives and decisions. Journals, or diary methods, serve as another pivotal tool in qualitative research [34]. They allow participants to document their daily experiences and reflections, providing a continuous, introspective account of their lives or specific phenomena over a period [34]. This method can yield highly personal, contextualized insights that might not emerge in more structured data collection settings. Saldaña advocates for the use of these qualitative methods to engage deeply with participant experiences, encouraging researchers to analyze data

iteratively and reflexively to understand the underlying meanings and patterns that emerge from these narratives [32].

Interview prompts were designed to collect information that could address the research questions, and student weekly journals were collected as qualitative data to address the research questions and to give us a glimpse of their eight weeks (about two months) in South Korea. Each of the 4 participants was interviewed and kept a weekly blog post addressing the research questions. The semi-structured interviews lasted 45 minutes and were conducted virtually using Zoom software and then recorded for data analysis. During the interview, students were asked to elaborate on the following points in their weekly blog post:

- Outline the most impactful components of the study abroad program in developing global competencies (global awareness, global understanding, and ability to apply intercultural knowledge effectively).
- Consider global competencies and discuss the experiential learning process while abroad with examples. (Students were provided with a diagram and explanation of the model.)
- Describe helping and hindering factors in the development of global competencies while abroad.

Interview Questions

Students were asked the following interview questions:

1. What was the overall purpose of your research project in South Korea?
2. What were the key challenges you faced during your research?
3. How did you overcome these challenges?
4. Did your time in South Korea help you develop your global competence in engineering?
5. How did you collaborate with your Korean research colleagues?
6. How has your research experience in South Korea changed your perspectives on engineering and your chosen field?
7. Did your lack of experience before the commencement of the program affect you in any way before the commencement of your program.
8. What are some of the most important things you learned about South Korean culture during your time there?
9. What cultural differences did you encounter while working in South Korea?
10. How did you adapt to these cultural differences?

The selection of these interview questions is grounded in the understanding that research experiences abroad significantly contribute to developing global competence, particularly in STEM fields. The questions explore various dimensions of international research experiences, focusing on challenges, cultural encounters, collaboration, and personal growth.

Understanding the objectives behind international research projects is fundamental in aligning them with developing global competencies. Downey et al. [6] emphasize the necessity of clear objectives in international engineering programs to yield significant outcomes. The literature on

international education, including Parkinson [7] highlights the transformative nature of challenges encountered abroad, marking them as essential for personal and professional development. Hadis [35] underscores the development of adaptability and problem-solving skills through navigating these challenges. Furthermore, Olson and Kroeger [36] discuss how international experiences enhance students' global perspectives, particularly in addressing complex engineering problems. Cross-cultural collaboration is also crucial, as Parkinson [7] Point out the importance of intercultural communication in fostering global competence.

Moreover, international research experiences can significantly alter students' perceptions of their discipline and its global relevance. Lohmann et al. [13] note how these experiences expand students' understanding of engineering's societal role. The influence of students' backgrounds and prior experiences on their learning and adaptation in international settings is analyzed by Jesiek et al. [37], highlighting the impact on their initial adjustment and overall experience. The importance of cultural immersion and understanding is further elaborated by Deardorff [38], who argues that deep learning occurs through cultural encounters. Encountering and adapting to cultural differences is integral to developing global competence, focusing on the necessity of adaptability and intercultural competencies for a successful international experience [39].

In guiding the analytical process of this research, the Critical Incident Technique (CIT) was utilized as a pivotal tool to elucidate key moments of learning and development. Furthermore, CIT is characterized as “a qualitative interview methodology that allows for the exploration of significant events (incidents, processes, or issues) as identified by the participants, detailing the management of these events and their outcomes from the perspective of their impact ” Consequently, participants in this study were prompted to recount experiences or incidents that markedly influenced their global competence development, providing detailed contextual descriptions of these pivotal moments [40]. This study aimed to delineate the attributes that either facilitated or impeded the cultivation of global competencies, aligning these findings within the PISA Global Competence framework [41], [42], [43].

The study aimed to systematically identify and analyze the specific characteristics and dynamics that contribute to enhancing or obstructing global competence by employing the PISA global competence framework as a lens through which to interpret these critical incidents. This approach allowed for a nuanced understanding of how individuals navigate and interpret intercultural encounters and their impact on their global awareness and competencies.

Data analysis was carried out using a blend of inductive reasoning and systematic procedures, facilitating the emergence of significant themes [44]. Transcriptions of the semi-structured interviews and the weekly blog posts were meticulously performed and subsequently analyzed using NVivo, chosen for its cloud-based capabilities that enhance collaborative efforts among the research team. Through memoing, as recommended by [45], the team familiarized themselves with the dataset, ensuring alignment with participants' narratives. Initial codes were crafted after thorough engagement with the transcriptions, leading to creating a dynamic codebook, a strategy supported by [33]**.** Regular team discussions facilitated the refinement of this codebook, incorporating peer debriefing to enhance validity and align interpretations [46]**.**

Further analysis employed the dimensions of the PISA 2018 Global Competence Framework as a deductive lens, leading to the development of a specialized codebook tailored to this framework [33]. This rigorous process involved line-by-line analysis, ensuring consensus among researchers. The research team unified their understanding and interpretations through this iterative process, including memoing and inductive and deductive coding. The codebook (Table 2) was further enhanced with operational definitions, linking the theoretical underpinnings of the PISA framework to the study's context and justifying the application of specific codes.

Table 2. PISA 2018 Codebook

Code	Definition	Operationalized definition	Gem Quote
Knowledge	Examine local, global, and intercultural issues.	The knowledge gained and examined in South Korea, knowledge from research, or knowledge about the culture of South Korea.	"The search for a way to simulate and calculate the electric field of a parabolic reflector, fed by a circular waveguide antenna, at distances of one hundred and two hundred meters, with higher resolution and without exhausting computer resources, continues. I believe it is possible to achieve this simulation using the shooting and bouncing ray (SBR) approach. However, the software seems to be having issues launching the necessary module. It could be a license or installation error." –Student 3
Skills	Take action for collective well-being and sustainable development	The ability or lack of students to take necessary actions concerning their research in a global environment.	"I applied my knowledge in RF engineering to assist them with what they needed. I built a bandpass filter within their specifications and modeled a certain type of antenna setup per their requirements." –Student 1
Attitudes & Global Mindedness	Engage in open, appropriate, and effective interactions across cultures	The ability of the students to communicate their ideas and research to diverse groups of people of different cultural backgrounds.	"I learned a lot of interesting things. What I found most interesting and appreciated about the Korean culture was how they respect each other, especially the elderly and pregnant women. For example, on a completely packed bus, nobody would sit in the seats reserved for the elderly, pregnant, or disabled people. Another thing I found interesting was their approach to trash. People are responsible for their trash, so there are not many trash cans outside, and they take trash collection and recycling very seriously." – Student 4
Values & Intercultural Understanding	Students appreciate cultural diversity, understand and appreciate the	The students demonstrated an appreciation of cultural diversity, effective communication and	"So, the biggest adaptation to the cultural differences was. I spent a lot more time in contact with the different members of the lab. So, I would. You know, there is much time spent socializing. So, people showed

	perspectives and world views of others, and respect.	collaboration in a multicultural setting, respect for different perspectives, and adaptability to new cultural environments.	me YouTube videos, which are just on the side. Besides the research, the research was more self-guided. You repeat the question." –Student 2

Findings

Three themes were identified that addressed the three research questions. Table 3 summarizes the research questions to which each theme is linked.

Theme 1: *Engaging in IRiKA significantly enriched the participants' development, fostering the acquisition of knowledge, honing research skills, instilling core values, and fostering a heightened sense of global appreciation among participants.*

Students discussed accessing research knowledge internationally and learning about South Korean culture and its people. Participants detailed their process of relearning and unlearning, which they encountered during their research journey. Student 3 expressed how he was able to carry out research in his lab and how he was able to assist in the research work going on in the lab. Student 3 mentioned how he could contribute to his lab research besides the research he was assigned. He also mentioned how he mainly worked on his research project and some of the challenges he faced.

> My purpose was to assist in the development of a wireless power transfer system. Specifically, I made a filter for a device testing the direction of arrival of a signal […]. All these experiences were learning experiences toward the never-ending path toward personal growth and professional development, which will hopefully be retired early. So, join me in the tapestry of exploration and learn of my small setbacks […] I believe it is possible to achieve this simulation using the shooting and bouncing ray (SBR) approach […] Nevertheless, I will persist in troubleshooting until the problem is solved. However, realistically, the next steps from here will require exponentially more time and effort. (Student 3)

Student 3 expressed how he was actively involved in research related to wireless power transfer systems and was also making contributions to research beyond his primary research task, which indicated his proactive involvement and eagerness to contribute more than what was expected of him. Student 3 faced several challenges, both in his technical work and during personal endeavors. He perceived these challenges as integral to his path toward personal growth and professional development. Student 3 described a process of relearning and unlearning during his research journey. This indicated an openness to new methods, perspectives, or ideas that may have differed from his previous understanding or experiences. Such an approach was critical in global competence, as it allowed individuals to adapt their knowledge and understanding when considering new cultural contexts and information.

Table 3. Summary of Themes

Research Questions	Themes

How does participation in IRiKA influence undergraduate and graduate engineering students' global competencies?	Engaging in IRiKA significantly enriched the participants' development, fostering the acquisition of knowledge, honing research skills, instilling core values, and fostering a heightened sense of global appreciation among participants.
How do undergraduate and graduate engineering students differ in global competency development in the context of international research experience?	There was little difference between undergraduate and graduate students achieving or developing global competency. Both groups acquired knowledge specific to global issues and appreciated South Korean culture.
How do different degrees of research experience in microelectronics affect students' global competency development in IRiKA?	The graduate students in IRiKA adapted well to the research pace and experience in their various labs. Undergraduate students faced a learning curve while adapting to the research life in South Korea.

Other students had expressed how they achieved global competence in engineering through their ability to communicate their ideas and research to diverse groups of people from different cultural backgrounds. Student 2 reflected on how he had a research mentor in his lab who helped him settle in, who helped him get familiar with everyone in the lab and everything going on in the lab. Student 2 narrative touched upon various aspects of communication, mentorship, social integration, research collaboration, and professional guidance, all within a culturally diverse setting.

> So, getting to my lab I had a mentor. And he helped me sort of get familiar with everyone in the lab. and he sort of, you know, taught me the ropes there was. Also, I had another mentor who helped me out socially. He invited me to a live night, which was, basically you want to see a bunch of concert performances out underground things so that helps socially. There was the PI He helped me guide the research and specifically what I was doing with the research publication. There was another person who also helped me with that because that was his area of research. So, I worked with him. I had to collaborate with a bunch of different people for just these different parts of there. So, I got to know a lot of people in the lab. Very well. (Student 2)

Beyond the professional environment, Student 2 also had a mentor who assisted in his social integration. He was invited to local events like a live night with underground concert performances, which provided him with an opportunity to experience the local culture more deeply.

Student 2's work in the lab required him to collaborate with various individuals, each contributing differently to his research and publication efforts. This kind of collaboration was essential for global competence, as it involved communicating and working effectively with people from diverse backgrounds. His interaction with the Principal Investigator (PI) and another research expert for publication guidance indicated his involvement in advanced research activities and the communication skills required to navigate these professional relationships.

Student 2's experience encapsulated several dimensions of global competence: adapting to and integrating into a new cultural and professional environment, building practical communication skills with diverse groups, and developing collaborative relationships. These skills were precious in engineering, where teamwork, cross-cultural communication, and adaptability were crucial to success in an increasingly globalized world.

Students expressed how they achieved global competence in engineering by demonstrating their appreciation for cultural diversity, respect, and an appreciation for the South Korean culture.

Student 1 expressed how he had spent his first week in South Korea exploring the city with friends and how fun it was to experience the culture of the people for a whole week.

> The next day after arriving, I visited a park nearby (a small palace), got sim cards, and then went to Ansan-si with Student 3 to our long-term home. That Saturday, we went to N-Seoul Tower, where I bought an expensive keychain and went to the top. Then I walked through downtown to Gyeongbokgung Palace at night (so pretty). Sunday, Student 3 and I went to a park (I joined a basketball game!), and we got accustomed to our area (explored Lotte Mart). The following Thursday, we went to a festival at Hanyang University, got a taste of Korean college life, and attended a K-pop concert. That Friday, we went to the Hongdae district, where I saw the nightlife in Seoul and saw so many foreigners. I also learned of the pain of traveling from Ansan-si to Seoul. On Sunday, Student 1 and I went hiking on Bukhansan Mountain and Baegundae Peak. It was one of the most amazing things I have done. So far, I have eaten Korean BBQ, grilled duck, pizza, a lot of Kimchi, fried rice, noodles, cereal (for breakfast), cafeteria food (Korean style), sandwiches, pastries, and many more. (Student 1)

Student 1 stay in South Korea featured immersive cultural experiences, from historical site visits like N-Seoul Tower and Gyeongbokgung Palace to participating in local activities and events. His engagement with the culture extended to everyday interactions, attending a K-pop concert, and exploring Seoul's vibrant Hongdae district. These activities deepened his appreciation for South Korean heritage and contemporary life and provided insights into the country's youthful and urban culture, highlighting its international appeal.

Student 4 appreciated how the South Korean people were respectful and kind to each other, incredibly respectful to the elderly and pregnant women.

> I learned a lot of exciting things. What I found most interesting and appreciated about the Korean culture was how they respect each other, especially the elderly and pregnant women. For example, on a completely packed bus, nobody would sit in the seats reserved for the elderly, pregnant, or disabled people. Another thing I found interesting was their approach to trash. People are responsible for their trash, so there are not many trash cans outside, and they take trash collection and recycling very seriously. (Student 4)

Student 4's focus on Korea's trash management practices highlighted an interest in environmental sustainability within different cultural contexts. This awareness underscores the importance of integrating sustainability into fields like engineering, where environmental considerations are

crucial. By understanding and appreciating Korea's approach to environmental challenges, Student 4 demonstrates cultural sensitivity and respect while gaining insights that could inspire sustainable practices in their professional endeavors.

All participants noted that being intentional about activating global competencies, specifically by engaging in research work and observing and communicating with others from diverse backgrounds, was an essential part of their development in global competence.

Theme 2: There was little difference between undergraduate and graduate students in achieving or developing global competency. Both groups acquired knowledge specific to global issues and appreciated South Korean culture.

Student 3 was the only PhD student among the four participants in his third year. Despite the differences in research knowledge and experience, the other students were able to display or acquire global competence skills in engineering, particularly in microelectronics. The varying levels of research experience did not hinder their appreciation of South Korean culture, communication with people from diverse backgrounds in the labs, and application of skills in the labs. Participants in the cohort could acquire global competence irrespective of their level of research experience, whether at the graduate or undergraduate level. Student 3 had experiences like those of the undergraduate students Student 1, Student 4, and Student 2.

The NSF IRES program encouraged cohorts and participants to carry out activities together to help strengthen the relationship between the cohorts and the culture of the people in South Korea. Student 3 and Co carried out many activities together, like visiting the National Museum and the Gyeongbokgung Palace.

> When I first arrived in Korea after long travel and severe jet lag, I realized I was not in Kansas anymore. Everything, from what my eyes saw to my nose smelling, was different […]. First stop: the fantastic sights and history of Gyeongbokgung Palace. This palace is from the Joseon dynasty, way back when it was destroyed and rebuilt twice. As fun as history is, the Palace's center building (Gyeonghoeru), the royal banquet hall, has an artificial lake surrounding it, so I suppose it was not only a banquet hall. Later, some cohort members and I visited Hongdae, where I had the chance to do a little busking and make new friends. (Student 3)

Sightseeing with fellow cohort members, including visits to vibrant areas like Hongdae and hiking at Bukhansan National Park, was vital in building camaraderie and fostering team spirit for Student 3 and his peers. These informal interactions were crucial for forming strong interpersonal relationships and enhancing their professional collaborations. Experiencing contemporary South Korean culture through these activities provided a comprehensive understanding of the country. Additionally, reflective learning from these cultural explorations helped Student 3 and his peers, including Student 1, to grow personally and develop global competence by comparing cultural norms and values.

> Friday evening, the cohort went to Hongdae, and I loved the sheep cafe we went to. We shopped around, and after it got late, some of us stayed and went clubbing. I found the

> environment entertaining but mentally and physically taxing. Since some lived outside Seoul, they stayed the entire night, but I left at 3 to brave the night buses. Because of their adjusted night schedule and the distance, it took me until 5 to get home. I think I learned my lesson. I saw the National Museum the following afternoon. I do not think I saw enough of it, so I want to go back eventually. Sunday, I spent the entire day hiking Bukhansan National Park with Student 2, and we saw a fantastic view from the peak. (Student 1)

Theme 3: The graduate students in IRiKA adapted well to the research pace and experience in their various labs. Undergraduate students faced a learning curve while adapting to the research life in South Korea.

Student 3, the only Ph.D. student in the cohort, was the only student with a good amount of research experience before the start of the program; he was currently very active in research, working as a research assistant before the commencement of the summer program. The undergraduate students had no research experience in microelectronics, and IRiKA helped set them up for the engineering research part. Student 3 expressed how it was easy for him to communicate his findings to an international audience; he would often present at group meetings and a conference in South Korea; the Language barrier was not a limiting factor for him since engineering research had a universal language in drawing and numbers and charts.

> how did you communicate your research findings to an international audience? Student 3: Engineering relies heavily on pictures and numbers, which are cross-cultural. I could understand the presentations through diagrams and mathematics at a wireless power transfer conference in Korea. Pictures and numbers serve as a universal language to communicate across cultural lines. I could present my findings at a conference in South Korea because it relied heavily on images, numbers, and graphs; many engineers could understand English, making it easier for me to present my research findings. (Student 3)

In his reflection, Student 3 noted that despite cultural and linguistic differences, elements like diagrams and mathematics in engineering serve as a universal language, enabling understanding across diverse backgrounds. He shared his experience at a wireless power transfer conference in Korea, where he could grasp the content through visual and numerical information. This insight underscores the role of universal elements in facilitating cross-cultural communication in engineering.

> However, the available tools limit the ability to accurately inspect the boards and trace for dimensional correctness. After soldering connectors and characterizing several devices with a vector network analyzer, it became evident that all three-simulation software used produced an unacceptable amount of error. Despite reviewing everything with others, no error could be located, and as the results were consistent, another iteration of design and fabrication was undertaken. (Student 3)

Initially lacking research experience, all undergraduate students began their program by acquainting themselves with relevant literature and receiving mentorship in the lab to understand ongoing research. Unlike Student 3, who did not require such guidance early on, Student 2 encountered his first challenge at the program's start.

> The first challenge was that I was unfamiliar with fluidics, and I had to spend a decent chunk of the first time just researching the basics to understand the systems they're using because it is all very high-level. (Student 2)

Student 2 reflected on the first challenge he encountered at the start of his research in South Korea and how he navigated the challenge.

> So, I spent the first 3 or 4 weeks reading many research papers and getting familiar with what everyone did in the lab. I watched it. I read like a textbook, like different chunks significant to what they wanted me to help them with. It was both. It was both a general sense of learning and specific areas. Moreover, I think that was what helped me overcome it. (Student 2)

Student 2 explained how he overcame his lack of experience by studying for the first four weeks, interacting with others in the lab, and discovering their research.

> So, before going on this program, I was unsure. If I wanted to do industry or grad studies, I just wanted to accept my bachelor's degree and go into industry. However, after the experiments, I decided I liked grad research. However, I also discovered that I do not know. Microfluidics is for me because it is a highly complex process. You are not doing experimentation. It made me like the science that I am doing here at . . . better, which is more cell sciences and protein purification. (Student 2)

Student 2 initially faced uncertainty regarding his future career choice, debating between entering the industry or pursuing further academic studies. His participation in the program, marked by engaging experiments and experiences, helped him discover his passion for graduate-level research.

Student 4 was also asked if her lack of research experience before the program challenged her during her time in South Korea doing research.

> I do not think it was a significant factor. There was a bit of a learning curve regarding how they communicate within their lab culture, but I do not think that was due to my lack of research experience before I went. (Student 4)

Student 4 talked about how much her lab mentor helped her settle in the lab and get started with research.

> My primary lab mentor reviewed the current research projects within their lab, and we discussed which project would best suit my current experience and the amount of time I have within the lab. After our discussion, I joined the neuromorphic device group under PI’s supervision. Together, we set out a rough plan of goals for the eight weeks (about two months), which made me very excited to think about everything I would learn during this time! I then spent most of the week studying the relevant published research and creating a mock design of a neuromorphic circuit with the goal of ulcer prevention. (Student 4)

Student 4 explained how her lab mentor was crucial in guiding her early lab endeavors. They assessed the available research projects, selecting the most fitting one for her based on her prior experience and available time. This early phase of diving into the research and planning showcased her proactive attitude and readiness to contribute.

> My labmate showed me most of the steps for fabricating the synaptic transistors, including cleaning the glass substrates, creating the solution, and then applying the solution to the glass substrates using spin-coating [...] My labmate was encouraging and assured me that no one gets it perfect on their first try. My labmate also showed me how to use the Semiconductor Device Analyzer to take measurements of the synaptic transistors that my labmate and I had fabricated [...] My labmate was very patient as she showed me how to properly connect the probes and set the proper parameters within the program. (Student 4)

Student 4 detailed how her lab mates guided her in preparing and applying solutions to problems and challenges she encountered in her research, during which she also got her first hands-on experience with a glove box. Despite the challenges, she was encouraged by her team. Additionally, she learned to use the Semiconductor Device Analyzer under her labmate's patient instruction, focusing on the delicate task of connecting probes to the tiny synaptic transistors she and Sean fabricated. Student 4's experiences highlight the lab's collaborative spirit and her colleagues' supportive role in her hands-on learning and skill development.

Discussion

Our investigation into the IRiKA program has revealed significant impacts on fostering global competencies among engineering students, particularly in microelectronics research. Drawing upon the conceptual framework that segments global competence into knowledge, skills, attitudes, and values, our findings delineate how participation in IRiKA enhances these dimensions [24]. These outcomes align with the constructs of the PISA Global Competence framework [42], [43], [47], [48], [49], prompting us to consider the strategic integration of global competencies into the engineering curriculum [19]. Participation in IRiKA notably advanced the global competence of both undergraduate and graduate engineering students by broadening their knowledge base, enhancing skillsets, and enriching their attitudinal orientations and value systems. The unique educational setting, characterized by hands-on microelectronics research and cultural immersion in South Korea, provided an exemplary platform for cultivating intercultural competence. This enabled students to navigate and appreciate cultural diversity effectively, fostering an adaptive mindset conducive to collaborative international research endeavors [23]. Students acquire a nuanced perspective of global engineering practices by engaging in real-world research projects and navigating cross-cultural communication, preparing them for diverse work environments. This approach highlights the importance of experiential learning beyond traditional classroom settings, emphasizing cultural immersion and international collaboration as critical components of global competence in microelectronics. [10], [50], [51].

The literature underscores that students face many challenges in study and research abroad programs[35], [52], [53], [54], [55]. When researching in a new environment, international students face many challenges, including communication and language barriers, isolation, and imposter syndrome. [17], [19], [24]. These challenges may hinder the student's progress, but

overcoming them leads to the more remarkable achievement of global engineering competency. IRiKA students demonstrated challenges that they were able to overcome during the program, andthese challenges activated their global competency [24]. The official communication language in the IRiKA Program lab was English, effectively minimizing language barriers. The principal investigators and lab mates were proficient in English, facilitating the research process and enabling the IRiKA students to achieve competency. Students acquired proficiency in Korean, enabling them to navigate daily activities, such as utilizing transportation systems and ordering meals, through linguistic interaction with local residents. This linguistic engagement fostered an appreciation for the cultural practices and societal values inherent within the community [5], [26], [27], [39], [56], [57].

Interestingly, our study finds minimal differences in global competency development between undergraduate and graduate students, suggesting that program participation positively impacts all students regardless of academic level [22], [26], [27], [58], [59], [60]. However, graduate students adapted quicker to the research pace and environment, likely due to their prior research experiences. These insights were corroborated by analyzing participant feedback from interviews and blog posts, which provided a rich narrative of their experiences and adaptations in a cross-cultural context [20]. The experience of conducting research plays a pivotal role in shaping a student's acclimatization to the research environment within a laboratory setting; it influences the rapidity of their adjustment, which may range from swift integration to a more gradual process that necessitates extensive learning and development. Furthermore, the study delineates a distinction in the modality of research communication between graduate and undergraduate levels.

The graduate student in question detailed his adeptness in conveying complex research findings to a broad audience using illustrative diagrams and graphs, a skill honed through repeated presentations of microelectronics research [20]. Additionally, the graduate student had the privilege of participating in an international microelectronics conference in South Korea, where he remarked on his ability to comprehend various research presentations with relative ease. Undergraduate students enhanced their research capabilities by engaging with innovative research concepts and disseminating their findings during laboratory meetings. They encountered novel experiences, notably the autonomous operation of the Semiconductor Device Analyzer, marking a milestone in their academic journey. The students underscored the crucial role of laboratory mentors and peers in fostering their research proficiency across different settings. Student 4 particularly noted the patience and instructive support provided by her lab mates, which was instrumental during the initial phase of her research endeavor. Scholarly literature consistently accentuates the significance of mentorship in international academic and research programs, emphasizing its pivotal contribution to easing the transition during the initial weeks in an unfamiliar environment [61], [62], [63], [64], [65].

The study's methodology, which combines interviews and analysis of participants' blog posts, provides a rich, in-depth understanding of the participants' experiences. This approach, supported by the PISA Global Competence framework, allows for a detailed exploration of how international research experiences impact students' development of global competencies. This approach highlighted the critical role of mentorship, peer collaboration, and cultural immersion in fostering global competence. Implications of this study extend beyond the immediate context, suggesting that international research experiences are vital in preparing engineering students for the global

workforce. The findings advocate for integrating global competency development into engineering curricula, emphasizing the importance of experiential learning, cultural immersion, and cross-cultural communication.

Implications

The study on the IRiKA program's impact on engineering students' global competencies carries profound implications for educational strategies in a globalized world. It endorses integrating international research opportunities within engineering curricula, underscoring them as critical in nurturing the global competencies necessary for effective cross-cultural collaboration. The findings advocate for developing inclusive professional growth programs that emphasize soft skills as much as technical acumen, suggesting that such skills are indispensable in a diverse workplace. There is a clear call for more inclusive access to such programs, signaling the need for initiatives that reach students from various backgrounds, particularly those typically underrepresented or with limited research experience. The significance of mentorship also emerges from the study, highlighting the role of experienced researchers in guiding novices through international research ventures.

Language and communication skills are shown to be vital, pointing to the need for these to be woven into the fabric of student preparation for overseas research, thereby enhancing cultural understanding. The implications extend to policy and funding, where there is a discernible need for more significant support and expansion of grants that enable international experiences. Additionally, the study suggests that longitudinal research into the long-term effects of such programs could offer valuable insights into their influence on career paths and professional development. Additionally, the research highlights the profound impact that cultural excursions and local festival participation have on students' cultural immersion. The experiential learning gained through such activities and collaborative group endeavors in the laboratory setting is instrumental in shaping well-rounded global engineers. These elements should be considered vital components of future programs, enriching the academic journey with a tapestry of cultural and collaborative experiences that extend beyond the confines of the laboratory.

Conclusion

This study delved into the international research experiences of the students in the IRiKA, a program funded by NSF IRES. It addressed three research questions to uncover how undergraduate and graduate students obtain global engineering competence. Utilizing the PISA Global Competence framework, this study investigated the development of global competencies among engineering students through the prism of international research experiences OECD (2019). It revealed that engaging in these experiences enables students to cultivate global competencies. This approach shifts the focus from solely leveraging social capital to utilizing structured experiences and reflections aligned with the PISA framework's dimensions of global understanding, attitudes, skills, and knowledge, illustrating a comprehensive method for engineering students to advance their global competencies. Findings from this study also showed that the graduate students in IRiKA adapted well to the research pace and experience in their various labs. In contrast, the Undergraduate students faced a learning curve while adapting to the research life in South Korea. By navigating the complexities of international research settings and engaging with diverse

cultures, participants developed key global competencies crucial for their future careers. The research advocates for broader integration of such international experiences within engineering education, emphasizing the need for a global perspective in the ever-evolving technological landscape. Future research should aim to include a broader and more diverse participant pool, encompassing students from various demographic backgrounds and academic levels, to enhance the generalizability of findings on global competence development.

Future Plans

The study utilized qualitative data gathered from students' weekly reflections and interviews. Such data collection methods can carry inherent biases. For instance, participants may give answers they think are expected of them or might not fully recognize the subtleties of their skill growth. Incorporating a mixed-methods approach could mitigate some of the limitations of qualitative research alone. Combining quantitative measures of competency development, such as pre-and post-program assessments, with qualitative insights could offer a more nuanced understanding of the impacts of international research experiences. Future studies could also examine how similar programs in different cultural or geographical settings impact global competencies. Cross-cultural comparisons could reveal the influence of various local factors on the effectiveness of international research experiences.

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