Comparison of the Impact of Two Research Experiences for Undergraduate Programs on Preparing Students for Global Workforces

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Abstract— *The impacts of globalization, changing socio-demographics, and technological advances are uniquely altering the role of engineering in society, identifying significant challenges in the way colleges and universities address the engineering profession, engineering education, and associated engineering student assessment processes and practices. Schools of engineering have been challenged to reconsider how they prepare their graduates to bring high level skills and strategies including team focused innovation, a comprehensive engineering problem-solving approach, cultural competence, globally focused ethics, and leadership to the workplace. Numerous prominent organizations including the National Academy of Engineering, the National Science Foundation, and the National Research Council have charged engineering schools to task on preparing engineers for global workforces. In response, many engineering programs are experimenting with strategies and programs designed to prepare students to solve important engineering problems that stretch far beyond national boundaries geographically, technologically, culturally and socio-politically. Sparse research exists, however, that comprehensively assesses globally focused outcomes associated with such engineering efforts, and the simple question remains: Are international efforts effective?*

The researchers compare the experiences of students participating in two Research Experiences for Undergraduates (REU) programs funded by the National Science Foundation; the NanoJapan International REU Program in Japan and the domestic Rice Quantum Institute (RQI) REU at Rice University. NanoJapan is a twelve-week summer program through which twelve freshman and sophomore physics and engineering students from U.S. universities complete research internships in Japanese nanotechnology laboratories. The RQI is a ten-week undergraduate REU in which sophomore and junior students from U.S. universities complete research in atomic, molecular, optical, surface, materials, chemical and biophysical sciences with faculty at Rice University.

The students completed the Engineering Global Preparedness Index (EGPI), a multi-dimensional engineering global preparedness index that measures students' preparedness for global workforces. The four subscales in the EGPI directly align to important "soft" or professional skills needed by both engineers and other globally prepared professionals. By comparing EGPI results among participants in a domestic and international research experience, the researchers sought to gain insight into what global workforce competencies were developed in an international setting in comparison with the experience of conducting research in a domestic lab setting. Results indicate that the students in the NanoJapan program demonstrated greater increases in engineering global preparedness than the RQI students, and that the RQI students, who did not go abroad, actually declined on most measures of global preparedness at the end of the summer. The researchers posit that this may be attributed to the NanoJapan curriculum that encouraged participants to actively reflect on cultural aspects of research and to the nature of the international experience itself. Moreover, the NanoJapan experience may more closely mirror the typical global workforce/team experience students will encounter after graduation once entering the workforce. The researchers discuss implications for the design of international research and internship experiences.

Keywords—*engineering education, global preparedness, study abroad, undergraduate research*

I. INTRODUCTION

The impacts of globalization, changing socio-demographics, and technological advances are uniquely changing the role of engineering in society, identifying significant challenges in the way colleges and universities address the engineering profession, engineering education, and associated engineering student assessment processes and practices. Schools of engineering have been challenged to reconsider how they prepare their graduates to bring high level skills and strategies

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including team focused innovation, a comprehensive engineering problem-solving approach, cultural competence, globally focused ethics, and leadership in the workplace. The American Society for Engineering Education has reinforced this message stating that American engineering colleges “ … must not only provide their graduates with intellectual development and superb technical capabilities, but … those colleges must educate their students to work as part of teams, communicate well and understand economic, social, environmental, and international context of their professional activities.”[1]

Numerous organizations – such as the National Academy of Engineering (and its widely quoted *The Engineer of 2020*), the National Science Foundation, and the National Research Council – have also charged engineering schools to task on preparing engineers for global workforces. [2,3.4] In response, many engineering programs are experimenting with strategies and programs designed to prepare students to solve important engineering problems that stretch far beyond national boundaries geographically, technologically, culturally and socio-politically. Sparse research exists, however, that comprehensively assesses globally focused outcomes associated with such engineering education efforts, and the simple question remains: Are international efforts effective?

In this paper, the researchers use the Engineering Global Preparedness Index (EGPI), a multi-dimensional engineering global preparedness index that measures students’ preparedness for global workforces, [5] to compare the experiences of students participating in two Research Experiences for Undergraduates (REU) programs funded by the National Science Foundation and based at Rice University. The NanoJapan International REU Program is a twelve-week REU program through which twelve freshman and sophomore physics and engineering students complete nanotechnology research internships in labs at Japanese universities. The Rice Quantum Institute REU is a ten-week program in which sophomore and junior students complete quantum-related research internships with faculty at Rice. The purpose of this paper is to compare results of the EGPI among participants in a domestic and international research experiences to understand the level of engineering global preparedness that was developed in an international setting in comparison with the student experience of conducting research in a domestic laboratory setting.

II. REVIEW OF THE LITERATURE

A. Undergraduate Research Programs in Context

The Institute for International Education’s (IIE) 2013 Open Doors report indicates that science and engineering students continue to represent a relatively small percentage of the overall number of students studying abroad. In 2011-2012, the last year for which data is available, just 3.9% of the students who studied abroad majored in engineering, 8.6% in the physical or life sciences, and 1.7% studied in math and computer science.[6]

The small number of U.S. engineering and science students who pursue an international experience is a particular concern for the preparation of career scientists, given the increasingly multinational nature of research collaborations. In its 2014 Science Indicators, the NSF reported that 35% of U.S. articles published in 2012 were internationally coauthored, up from 32% in 2010 with U.S. Japan co-authored papers comprised 7% of this total. Internationally co-authored papers now comprise one-fourth of all papers worldwide. [7] The percentage of U.S. papers published in 2012 with international co-authorship in engineering was 35.9% and in physics was 45.8%. [8,9]. In its 2006 – 2011 fiscal year strategic report, the NSF acknowledged the importance of international research collaboration and identified as a key performance goal the need to “keep the United States at the frontiers of knowledge by increasing international partnerships and collaborations.” The strategic plan went on to say that, “As science and engineering (S&E) expertise and infrastructure advance across the globe, it is expected that the United States will increasingly benefit from international collaborations and a globally engaged workforce leading to transformational S&E breakthroughs.”[10]

B. Domestic and International Research Experiences

The National Council on Undergraduate Research defines undergraduate research as “An inquiry or investigation conducted by an undergraduate student that makes an original intellectual or creative contribution to the discipline” and identifies six key benefits of these experiences which include: a) enhancing student learning through mentoring relationships with faculty, b) increasing retention, c) increasing enrollment in graduate education and providing effective career preparation, d) developing critical thinking creativity, problem solving and intellectual independence, e) developing an understanding of research methodology, and f) promoting an innovation-oriented culture.[11] The National Science Foundation has a long-standing grant program to fund Research Experiences for Undergraduates in engineering and science fields at universities that are designed to “…support active research participation by undergraduate students…” and “…involve students in meaningful ways in ongoing research programs.”[i] While the majority of REU programs funded by the NSF support research at domestic universities, some

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funding for international research is provided through specialized grant programs such as the International Research Experience for Undergraduates or Partnerships for International Research and Education (PIRE) grant programs. The goal of these international research programs is to support the "development of globally-engaged U.S. science and engineering students capable of performing in an international research environment at the forefront of science and engineering." [12, 13]

A report on research programs funded by the NSF-fund International Research Experience for Engineering found that, in addition to the technical and professional impacts, the global or transcultural aspect of international research experiences include a) fueling the emergence of 'best practices' effective in sustaining transcultural collaborations, b) encouraging the innovative development of a 'shared work space' to accommodate cultural differences, c) developing and extending research communities beyond the U.S., d) increasing non-English language proficiencies, e) affirming the centrality and power of language, and f) contributing to solutions of the 'Global Grand Challenges.' [14]

Despite these benefits, there remains a significant need for more assessment of specific outcomes. A workshop report issued by Sigma Xi specifically identified as a necessary research agenda the need for studies that examined the motives for a scientist's or engineer's desire for international collaboration, including the relationship to education and career development. [15]

C. *Global Competence versus Global Preparedness*

In addition to providing students with technical research skills, a primary goal of international research experience is to prepare students to work effectively as part of cross-cultural research collaborations. This is most commonly referred to as global competency in STEM fields, but is alternately referred to as cultural competency, multicultural competency, intercultural maturity, cross-cultural adaptation, cross-cultural awareness, or intercultural sensitivity. Deardorff defines intercultural competency as the particular knowledge, skills, and attitudes that can be developed or learned and is evidenced by individuals' "effective and appropriate behavior and communication in intercultural situations." Parkinson has suggested the attributes of a globally competent engineer, [16] while Deardorff has identified twenty-two agreed upon components of intercultural competence. [17]

Global preparedness extends the concept of global or intercultural competency to include a readiness to engage and effectively operate in ambiguous situations and in different cultural contexts to address engineering problems. Global preparedness brings together the set of congruent behaviors, attitudes, and policies in a system, agency, or among professionals, enabling that system, agency, or those professionals to work effectively in cross-cultural situations. [18, 19] The concept of global preparedness frames this particular study because it examines not just the knowledge, skills, and attitudes required to work cross-culturally, but their specific application for the engineering profession.

III. STUDY DESCRIPTION

A. *Research Experiences for Undergraduates*

The NanoJapan International Research Experience for Undergraduates (NanoJapan IREU) and the Research Experience for Undergraduates (RQI) programs were selected for comparison for this research because both programs recruit participants from universities nationwide via a competitive selection process and enable students to participate in cutting-edge inquiry in fields related to nanoscience research. Both programs also require participants to present topical research posters on their summer projects at a summer research colloquium as a capstone experience.

The Rice Quantum Institute's (RQI) has been in continual operation since 1996 with funding confirmed through 2014. [20] The program provides highly promising undergraduate students an opportunity to train during the summer in an intensive, interdisciplinary, collaborative research environment and involves them in a program of discussions and interactions with faculty and graduate students. Students from schools nationwide spend ten weeks at Rice working on cutting-edge, fundamental research projects in quantum-related research laboratories under the advisement of an RQI faculty fellow advisor. In addition, each participating student is expected to attend special seminars and group discussions for REU participants, make a report of the project and participate in the RQI Summer Research Colloquium at the end of the summer.

Participating students are frequently recruited from populations traditionally underrepresented in STEM fields and from schools with limited research opportunities and resources. The objectives of the program are for students to acquire the capacity of reading and understanding advanced scientific publications, to understand and experience how to bring a research project to successful completion, to be able to successfully present their work to an audience, and to understand principles for ethical and responsible research.

In contrast, the NanoJapan: International Research Experience for Undergraduates Program is a twelve-week summer program through which twelve freshman and sophomore physics and engineering students from U.S. universities complete research internships in Japanese nanotechnology laboratories. [21] It is funded by a Partnerships for International Research and Education (PIRE) grant, a program, which seeks to tightly integrate high-level international research collaborations with educational opportunities for student engagement. The program was awarded five years of funding in 2006 and received a five-year renewal in 2010 with funding confirmed through 2015.[22] Research projects with this PIRE grant focus on study of the emerging research area of terahertz (THz) dynamics of nanostructures and student research projects for the NanoJapan IREU are tightly integrated into the PIRE team's ongoing international research collaborations in these areas. NanoJapan recruits high-potential first and second year engineering or physics undergraduates to conduct cutting-edge research eight-week internships in Japanese laboratories focusing on terahertz nanoscience. Before beginning their research internships, students in the program complete a three-week orientation program based in Tokyo that combines 45-hours of Japanese language instruction, an orientation to Japanese life and culture, and an introductory seminar to the emerging research area of terahertz nanoscience. The capstone of the program is the presentation of a poster on their international research project at the RQI Summer Research Colloquium at the end of the summer.

The learning objectives for the NanoJapan IREU are: i) to cultivate an interest in nanotechnology as a field of study among college students; ii) to cultivate the next generation of graduate students in nanotechnology; iii) to add to the skill set of active nanoscience researchers; iv) to create students who are internationally savvy and have a specific interest in and knowledge of Japan; and v) to educate students in culture, language and technology, in order that they may be more effective when addressing global scientific problems. The program has been nationally recognized by both the National Academy of Engineering and the Institute of International Education as a best practice in the expansion of international opportunities for STEM students. Since 2006, 130 students have participated, representing 43 universities. NanoJapan has been particularly successful with recruiting groups underrepresented in STEM fields; 33.8% of participants are women, and 13.8% represent diverse ethnic groups in STEM fields.

IV. NANOJAPAN PROGRAM DESIGN FEATURES IMPACTING STUDENT LEARNING

While the NanoJapan Program and RQI REU are both structured research experiences for undergraduate students, some key program design features that set NanoJapan apart from a traditional REU include:

International Co-Advising Structure: NanoJapan students are integrated into existing PIRE international research projects in Japanese partner research laboratories, are mentored by English-speaking Japanese graduate students or post-doctoral researchers, and are co-advised by both their Japanese host professor and a U.S. PIRE co-advisor. This gives NanoJapan students experience working as part of a true international research collaboration and, over the course of the summer, they must learn to successfully navigate not only differences in approaches to research in the U.S. and Japan, language barriers within their research labs lab in Japan, but must also develop skills sets necessary to enable them to overcome logistical barriers, such as time differences, to enable them to remain responsive and engaged with all members of the PIRE international research team.

Weekly Written Reflections: Throughout the twelve-week program, NanoJapan participants are required to submit weekly reflections on questions related to intercultural adjustment and a research project update. The formal nature of these assignments, required to receive a grade and credit for the program, ensures that all participants reflect on the nature of their experience in Japan, issues related to cultural adjustment and understanding, gender and career development in nanoscience, and differences between research in the U.S. and Japan. One alumnus, who was participating in another international REU the year following NanoJapan, even asked if the NanoJapan weekly report questions could be used by her new program. As she shared, "I think that the weekly entries we submitted… allowed us to "capture the moment" as we experienced things rather than summarizing everything up at the very end. I also think that everyone in our group benefitted a lot f[r]om the questions you posted as prompts, and that they really helped us reflect on our experiences in a way that was meaningful to people who read our entries. So I was thinking it would be helpful to me and the students in Beijing with me to do the same…" ~ *GM, NanoJapan 2012*

Fostering U.S-Japanese Student Engagement: Each NanoJapan participant is assigned an English-speaking Japanese graduate student or post-doctoral research who is working on the larger overall PIRE research project within that lab to serve as their day-to-day research mentor. The PIRE Japanese student often works with multiple NanoJapan students over the course of their master's or PhD program, and benefits from the opportunity to mentor young U.S. undergraduates and strengthen their conversational English skills. Japanese professors report that the U.S. students' enthusiasm and motivation for research positively impacts the lab. One Japanese professor shared, "[The NanoJapan students] never hesitate to ask questions to our colleagues. Seeing these good attitudes, our Japanese students also get more active, and even change their attitudes for their research in a good way. This is definitely a big benefit for our laboratory."

Alumni Engagement: NanoJapan seeks to develop a shared network of peer students with a keen interest in nanoscience research across all program years. A formal part of the program structure is the *NanoJapan Alumni Mentor Program*. Once selected into the program, each current year NanoJapan participant is matched with alumni from the year prior; typically the student who conducted research in the same host lab that the current participant has been placed into. Mentors engage with the current year students prior to departure regarding what to expect in their host research lab and city in Japan. This program also provides the alumnus with an opportunity to reflect back on their NanoJapan experience to better understand how to best convey the impact of the program to the next generation of participants.

The inter-generational NanoJapan Alumni Network has proven particularly helpful when students are considering future graduate schools or program. Of NanoJapan alumni who have graduated to date, 65 percent are pursuing or have received a graduate degree in a STEM field; representing 31 different graduate institutions. NanoJapan alumni also have a strong track record with major fellowships and frequently turn to each other for advice about applying to these programs. Alumni fellowships to date include eleven NSF Graduate Research Fellowships, one Hertz Fellowship, four Goldwater Scholarships, and one Churchill Scholarship. Informal NanoJapan alumni groups have developed among graduate students at universities such as Stanford, with seven alumni, and the Massachusetts Institute of Technology, with eight alumni.

V. *METHODOLOGICAL APPROACH*

Data from the two described programs were investigated comparatively. This study utilized a pre-post program approach. Accordingly, data was collected on the study participants before and after they completed their research experiences using a closed set questionnaire. In addition to this questionnaire, program features were analyzed qualitatively to determine practice based program impact.

A. Study Population

The demographics of the participating students were roughly similar. Twelve students participated in both the NanoJapan and RQI REU in 2013. The NanoJapan participants consisted of ten men and two women; at the time of participation, nine students were under twenty years old, two were between 20 and 29 years old, and one student was greater than 30 years. The twelve RQI participants included seven men and five women; four students were under 20 years old, seven between 20-29 years, and one student was older than 30 years.

B. Instrumentation

The NanoJapan participants and RQI students in Summer 2013 completed the Engineering Global Preparedness Index (EGPI) as a pre and post-assessment. The EGPI is aligned to both ABET's more difficult to measure professional skills and the NAE's, *Engineer of 2020*. The EGPI directly measures how prepared students are for global workforces, and is grounded in global citizenry theory and engineering education research. [5,19] It utilizes four subscales each of which have been validated using item response theory [23] and extensively tested for reliability:

Global Engineering Ethics and Humanitarian Values refers to the depth of concern for people in all parts of the world, with a view of moral responsibility to improve life conditions through engineering problem solving and to take such actions in diverse engineering settings ($\alpha = .90$).

Global Engineering Efficacy refers to the belief that one can make a difference through engineering problem solving and is in support of one's perceived ability to engage in personal involvement in local, national, international engineering issues and activities towards achieving greater global good using engineering problem solving and technologies ($\alpha = .85$).

Engineering Global-centrism refers to a person's value of what is good for the global community in engineering related efforts, and not just one's own country or group. It is associated with an individual's ability to make sound judgements based on global needs in which engineering and associated technologies can have impact on global improvement ($\alpha = .79$).

Global Engineering Community Connectedness refers to one's awareness of humanity and appreciation of interrelatedness of all people and nations and the role that engineering can play in improving humanity, solving human problems via engineering technologies, and meeting human needs across national boundaries ($\alpha = .72$).

C. Data Analyses

Analytically, the EGPI questionnaire data was statistically analyzed descriptively and comparatively. Specifically, correlational comparison and pre-post t-tests were conducted to both compare the groups to themselves pre and post program (paired sample t-test) and against one another programmatically (independent sample t-test) using the questionnaire data.

VI. *STUDY RESULTS*

As previously described, the EGPI was used to measure the participating students global preparedness before and after participating in the two described programs. Results revealed some interesting comparisons. The means of each EGPI subscale were deliberately compared by subscale of the instrument pre and post program and comparisons were computed in an effort to determine the impact that the RQI and NanoJapan programs had on preparing undergraduate engineers for globally focused workforces. These results are interesting and diverse and vary by EPGI construct.

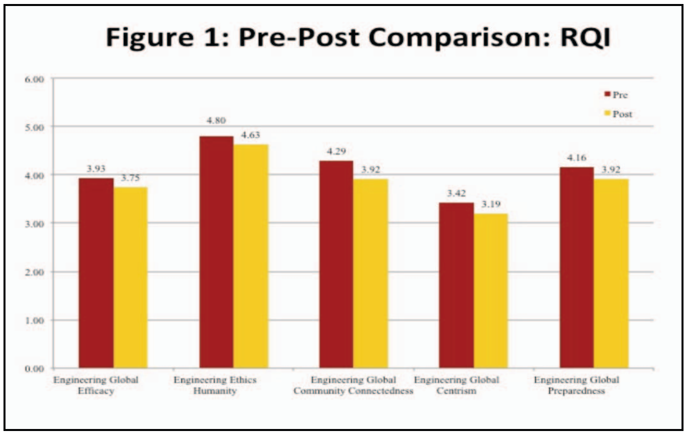
Figure 1: Pre-Post Comparison: RQI

Figures 1 and 2 illustrate the means comparisons for each of the EGPI subscale constructs for all participants before and after the RQI and NanoJapan experience in each group. These figures offer comparisons by subscale means. The final figure (3) represents a post comparison across the two groups.

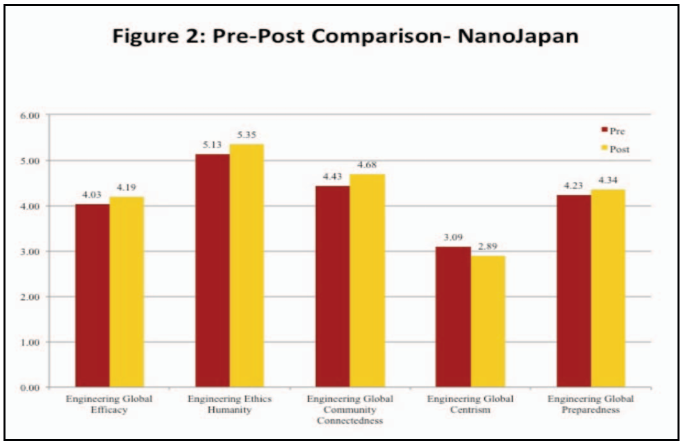
Figure 2: Pre-Post Comparison- NanoJapan

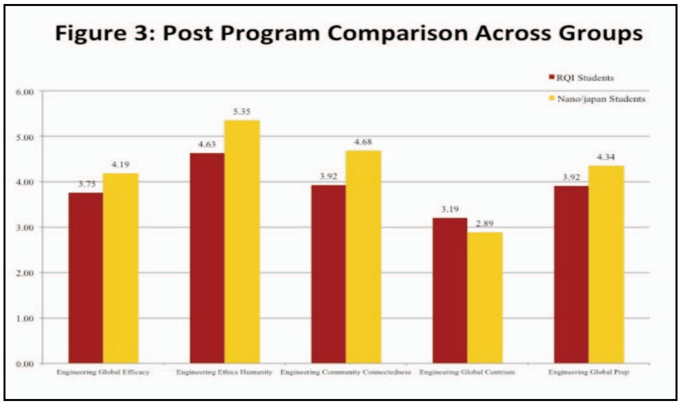
Figure 3: Post Program Comparison Across Groups

In summary, the RQI student participants in RQI decreased slightly in overall engineering global preparedness (M_{pre}=4.16; SD=.724; M_{post} = 3.92, SD= .763; 6-pt Likert-type scale). In contrast, student participants in NanoJapan increased slightly in overall engineering global preparedness (M_{pre}=4.23; SD=.420; M_{post} = 4.34, SD= .400; 6-pt Likert-type scale). This difference was statistically significant in RQI [$t(11)$= 2.53, p <.05; Cohen's d = -0.27]. However, it was not statistically significant in NanoJapan [$t(10)$=-1.17, p=.269]. Perhaps this difference could be explained by the close proximity of administration between the pre and post assessment administration or other experiential or sociodemographic factors present in the research. Both groups had statistically significant changes in Engineering Global Communication Connectedness in the Pre-and Post-program. Student participants in RQI a had significant decrease [M_{pre}=4.29, SD=.981 M_{post}=3.92, SD=1.203; $t(11)$=3.59, p<.005; Cohen's d=0.34; ; 6-pt Likert-type scale]; while participants in NanoJapan had a significant increase [M_{pre}=4.43, SD=.662 M_{post}=4.68, SD=.690; $t(10)$=-2.35, p<.05; Cohen's d=-0.37; ; 6-pt Likert-type scale]. Generally speaking, scores of participants in RQI had larger SDs than those in NanoJapan. More information about the specifics of the two programs and their similarities and diffentces is required to draw additional inferences from these results. Additionally, due to the modest sample size (N_{RQI}=12; $N_{NanoJapan}$=11), no other pre-post nor correlational comparisons could be reliably computed from the two participant group data.

VII. *CONCLUSIONS AND IMPLICATIONS*

This study results indicate that after completing either of the two REU programs, the students' engineering global preparedness improved. This may be due in part to the challenge of living independently in Japan, but it may also be related to educational activities in which the NanoJapan students study and reflect on their experiences as part of an international research team. When compared to the literature, research on learning outcomes from study abroad suggests that simply being immersed in an international setting is not sufficient for student learning – intercultural learning does not happen by asking students to 'sink or swim.' Rather, students make the greatest gains in intercultural learning when they engage with a cultural "interpreter" who is able to help students make sense of the new and different environment in which they are living and learning. The three-week orientation and the weekly reflections submitted by NanoJapan students, with feedback from members of both the research and education team, may play that role for the IREU program as indicated by the study results. The results suggest that undergraduate research programs that couple intercultural learning curricula with technical preparation for the research projects may be more effective in preparing students to be globally-savvy researchers. This study's results are somewhat limited because the programs studied involved a small population of students. Accordingly, the results should be interpreted with caution. Accordingly, the programs (and those similar in structure) merit additional investigation in that they have potential to have much impact on the design of other domestic and international undergraduate research programs.

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