Impact of Undergraduate Research Experiences on Diverse National and International Undergraduate Researchers

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Abstract

This paper presents analyses of the impact of different summer Research Experience for Undergraduate (REU) programs on diverse students from the USA and India. The study gathered and analyzed the survey data from two different REU programs in two different departments and from a college-wide program for Indian students at a research university. The REU programs were funded by the National Science Foundation (NSF) for US citizens or permanent residents while the program for Indian students was funded by the college. The data showed how much the research experiences could impact the students' decision-making between graduate school and working in industry for both national and international students. A large majority of students came to favor the graduate education and research, as desired by the common goals of the national and international REU programs. Students credited their learning in their summer research experience for contributing to their interest in graduate education and research. The students also noted that these are skills that they would not have acquired at their home institutions.

I. Introduction

The National Science Foundation (NSF) has been a long-term member of federal governmental institutions that strongly support summer research programs as a means of attracting undergraduate students into graduate education and research. Their strongest desire has been to reach out to students from institutions that may not have graduate programs in an area to immerse them into a research program at a research university and thus, increase their awareness and interest in graduate school in computing, science, technology, engineering, and math (C-STEM) fields. Such undergraduate research experiences have been lauded as to their benefit to enriching undergraduate student experience in research and to further greatly impact their interest in graduate school. The REU program shares commonalities with project-based or problem-based learning in that students were engaged in projects and involved in the process like existing members of a research group.

Past research (e.g., [1], [2], [6 -13]) lauded undergraduate summer research programs for their impact on undergraduate students developing research experience and for helping these students to include graduate education in their career goals during their formative undergraduate education. Some past research had observed about 60% increase in participants eventually attending graduate or professional education as with our goal in the program (e.g., [1], [2], [6 -13]). Sadler and McKinney [10] noted undergraduate students' increases in graduate education interest, building research skills, and confidence in research. One study found that students, who participated in REUs, came to value the role that the faculty mentor played [12]. Richard *et al.* [13] found that first-year students tended to value acquiring new skills in their engineering courses. However, upper-level students had apparently come to learn to value their connections

developed since the first year (e.g., peers and professors, and what they could learn from their research and/or, internships, etc.).

Aerospace engineering tended to have relatively small numbers of underrepresented women and minorities. The disparity was even larger at the graduate level. According to the Fall 2014 *ASEE Connections* newsletter, there was only a 7% increase in African-Americans earning Masters degrees in engineering from 2008 to 2013. Underrepresented faculty of various genders could help recruit more underrepresented minority students, but the numbers of women and underrepresented minority faculty in Aerospace Engineering have remained largely stagnant. The proportion of African-American faculty changed from 2.1% to only 2.5% from 2001 to 2010 [15]. Over the same time interval, women faculty in engineering increased from 8.9% to only 13.2%. Perez and Gong [14] found that the main factors impacting minority students' access to graduate school included cost, knowledge of available graduate programs, understanding of graduate study and research in general, and career relevance of the graduate degree options. Studies showed that REUs were very effective in broadening participation in graduate school and research [16-20].

In 2017, one research university hosted REU programs and university-funded international undergraduate research programs that allow us to conduct a study of the impact of such research programs on such a diverse population. The NSF sponsored the REU program for US citizens or permanent residents while the university had a college-sponsored program that accommodate international students from a partnership with the Indian Institutes of Technology (IITs) to exchange students for summer research experiences. The existence of this cohort further enabled a broader-study to explore the impact of such research programs on diverse national and international undergraduate researchers.

We examined the NSF goals for an REU, the proposed items for assessment and sought out to define surveys to address them. While Sutterer et al. [1] viewed the REU students as “products” of the REU, we considered the data on the students to be the more important “products”, as lessons learned for those choosing an REU. This first year of the REU may not provide enough data for the intended purpose (e.g., the detailed statistical analyses as suggested by Grimberg et al. [2]), but we initiated this study as the start of a longer-term study later by providing descriptive statistics on the students, the program, and the mutual net effects. With the guidance from the previous work in REU assessment [3-6], this study conducted both quantitative and qualitative analyses for the purposes of formative and summative evaluation.

A. Purpose of the Study

One purpose of this study was to explore US and non-US students' research experiences during summer at a research university in the United States. Specifically, we tried to identify common and uncommon viewpoints from students of different backgrounds to seek out and join such research programs. Another purpose of this study was to gauge the impacts of summer research experiences on US and non-US students. The following research questions guided this study:

1. What is the REU impact on the students' career goals?
2. What is the REU impact on the students' self-efficacy about making decision about graduate school and success therein?

3. How do the REU participants perceive any changes on their research knowledge, skills, and engineering career path?
4. What is the difference in the impact of the REU between national and international students?

II. Method

A. Setting

A.1 Objectives of the REU Program

National REU Programs. The specific objectives of the two REU programs at the research university were to (a) engage about 20 undergraduates annually in rich summer aerospace engineering (AERO) and materials science and engineering (MSEN) research experiences at a tier-one research university - at least 60% women and under-represented minorities, recruited mainly from minority-serving and predominantly undergraduate institutions; (b) prepare the students for graduate school by providing GRE tutoring, increasing awareness of graduate opportunities, strengthening of resumes by publishing research, and improving written and oral communication; and (c) measure the effectiveness of the REU program in encouraging these students to attend graduate school.

International REU Program: The specific objectives of the international undergraduate research program were to immerse undergraduate students from a foreign institution into a research group at a US institution. The goals of the international REU program at the REU institution were similar to the US students' REU programs. The major goal was to have students from IITs to get an experience in research so that they may consider the graduate school option, and hopefully at the host research university. In India, due to the high demand in industry, few IIT students go to graduate school and few IIT participants of the international REU program have returned to the US for graduate school.

A.2 REU Programs at the Research University

REU Program for U.S. National Students. The REU programs had an online application process. Students can get info on the REU from that web site, other students, etc., but most of them say they found out about it from NSF's web site. The REU program coordinator emailed flyers to faculty at different supporting universities or travelled to some universities within driving distance to personally recruit students. The program coordinator reviewed the online applications with a few interested AERO department faculty. We selected and matched top applicants with faculty members who share mutual areas of interests. This meant that not one single factor dominated the reason for selection, e.g., neither highest GPA, letters of recommendation, essays, transcripts, etc., were sufficient for acceptance into the program. Some top students selected chose to go elsewhere forcing selection of a second choice. The REU program in the department of materials science and engineering (MSEN) originated in the aerospace engineering department and migrated to MSEN upon its formation. Thus, it was very much like the AERO REU. The programs shared some joint activities such as on preparing presentations, workshops, tours, etc.

REU Program for International Students. The international program began when an application went out to the students at the Indian Institutes of Technology (IITs) in 2016 at the institution. The IITs selected the participating students from their lists of applicants. The US host institution, that held the REU's, did not interfere in the participant selection process conducted by IITs. The US host institution simply found faculty in each department of the college of engineering. A faculty member, who initiated the program in the aerospace engineering department many years ago, sent out invitations to selected host faculty. This did not guarantee the perfect match of research interests between faculty and students. The IITs pay their students air transportation to the US. The US host institution pays for the IIT students' housing, transportation from and to the airport, a welcome package, and a stipend. The host faculty pays for getting a US visa.

A.3 Program Structure

The 10-week REU Sites and international undergraduate research programs at the research university had complementary components that involved: (1) matching participants with faculty and other undergraduates (peer-mentoring) or graduate student researchers under the supervision of the faculty for direct hands-on training in relevant computational and experimental research methods, (2) participation in research-oriented field trips (e.g., various labs on campus, Ad Astra Rocket Co., near the Johnson Space Center of the National Aeronautics and Space Administration [NASA], etc.) (3) participation in professional-development seminars (GRE preparation, technical writing), and (4) presenting formal research papers at professional conferences and submitting to refereed journals.

The REU programs coordinated with the college's own summer program and the international students' office programs. The college summer research program engaged undergraduate engineering students in graduate-type projects under the supervision of faculty researchers. By linking to these programs, the REU students could take advantage of an extensive supporting infrastructure, including inclusion in a larger Community of Learners, access to professional development seminars, and participation in GRE-preparation workshops. The college infrastructure also supports other departmental REUs by providing logistical arrangements, such as a welcome breakfast, GRE workshops, seminars/luncheons, vouchering invoices, and provides the same for this proposed REU Site. The registrar's office provides academic registration. The college summer research program provided additional support, such as recruitment, coordinating seminars and an end-of-program symposium.

In addition, a university-wide office established in the Office of the Vice President for Research coordinated and supported undergraduate research across the entire campus, including NSF REUs as well as other undergraduate research activities. This office coordinated university-wide activities for all undergraduate research programs. Each May, the Honors and Undergraduate Research (HUR) office and the Office of Graduate Studies hosted a training seminar for graduate students who would be working with REU students entitled "How to Mentor Undergraduates in Research."

In addition, HUR and the Office of Undergraduate Programs and Academic Services jointly sponsored the REU Summer Scholars program, an additional supplemental program specifically for all REU students from underrepresented minority groups. The program provided a way for minority students, who may not have many minority peers in their working environment, to connect with each other and form a multidisciplinary community within a community. The REU Summer Scholars program exposed students to professional development and social activities. For example, the REU Summer Scholars were invited to weekly informal lunch discussions featuring university administrators and other special guest with topics, such as how to apply for graduate school, how to compete for graduate fellowships and how to make effective presentations. The program also sponsored informal dinners off campus that provide students with the opportunity to socialize with each other and with potential faculty role models. One of the simplest forms of community-building started with housing REU students with other similar summer programs at the same or neighboring apartment complexes. Grimberg *et al.* [2] found that participants highly valued in accomplishing the building of a community.

A.4 Nature of Student Activities

Under the umbrella of a cohort experience, the participants (a) engaged in community building activities with other REU students, the local university undergraduates and graduate students, and faculty, (b) conducted cutting-edge aerospace engineering research, (c) received professional development opportunities, (d) received tutoring concerning graduate school, and (e) attended field trips which connected the research to real-world problems.

Community Building. Development of collegial relationships and interactions was an important educational research practice of this REU Site. Research indicated that a significant contributing factor in students' cognitive development and retention were socially based [20-23]. This prompted the College of Engineering to invest time and effort to develop learning communities among students and faculty. According to Engstrom and Tinto [24], "survey data revealed that students in the learning communities were more engaged in their studies, perceived themselves as having more support, and were more successful than similar students not in such programs" (p 50). The REU adopted the College's undergraduate research model, using teams, and mentoring to achieve community building within the cohort of REU students and among the REU students, faculty, and graduate students. The undergraduate research office, the college or the department held community-building social activities (not with NSF funds) for summer students (not just only for REU) by.

REU Program Components. The program coordinator and supporting faculty matched each REU student to a faculty advisor for an in-depth research experience. Support by a graduate student mentor as well as an undergraduate mentor was part of the experience given that peer-mentoring was highly valued [25]. The undergraduate mentor pool does not just have faculty, postdocs or graduate students, but may include undergraduates who previously participated in a research project. The first two weeks of the REU programs included (a) developing technical writing and presentation skills, (b) using data analysis tools, (c) applying tools to support code development for computational fluid dynamic (CFD) models, and (d) handling and modifying hardware in the machine shops. The engineering faculty conducted the technical workshops, with support from the graduate and undergraduate students. Each REU student met weekly (at least)

with his/her entire research group. Research mentors were expected to select meaningful research projects (see Sample Research Activities below) and involved the student in many aspects included in such research. This included activities such as the literature reviews and research, research design and implementation, solution brainstorming, being resourceful, dealing with unexpected challenges, data analysis and publication of results.

We arranged field trips to give the students a better understanding of how theory, methods, and research connected to real-world applications. The travel time during the field trips also allowed for extended one-on-one contact with faculty during which students had the opportunity to discuss graduate education and careers in an informal setting.

Students had an opportunity to work one-on-one with a member of the university writing center to refine their research papers in the last two weeks of the program. Students could then present the refined papers at professional society meetings and refereed journals. This experience could give the students a better understanding of how findings were subjected to review and disseminated.

Sample Research Activities - Ionized Plasma Flow Modeling: This research involved modeling plasmas from room temperature plasmas to electric propulsion (EP) systems, such as the VARIable Specific Impulse Magneto-plasma Rocket (VASIMR) that astronaut Dr. Franklin Chang-Diaz developed at NASA Johnson [26 - 28] and is under further development by Ad Astra Technologies, established by Dr. Chang-Diaz, as well as ion thrusters. Field trips included tours of Ad Astra Rocket Co., which students said they “enjoyed” whether their research was directly related or not. Our research was conducted using the meso-scale Boltzmann equation instead of continuum-based approaches (e.g., Navier-Stokes) or the Direct Simulation Monte Carlo (DSMC) often used in EP modeling. VASIMR could reduce travel time to Mars by several months, it could do the same for deep space missions or for keeping the space station in orbit. Our goal was to quantify the impact of plasma turbulence and other effects on performance. While EP system thrust was typically smaller than chemical rockets, EP systems could run for so long that a spacecraft could achieve much higher velocity. VASIMR uses a magnetic field to accelerate plasmas to tens of kilometers per second instead of an electric field as used in ion thrusters. These systems are very relevant to the nation’s strategic plan and space exploration initiatives. Models of plasma jets have shown also useful for flow control [29]. A previous REU student developed spectral solvers of Maxwell’s equations. Another helped developed the spectral Boltzmann solver. Another helped developed a data structure for the object-oriented program (OOP) to incorporate detailed particle physics in the computational cells of the solvers.

The research is applicable to plasma devices from propulsion [30 - 32] to medicine [33], [34], treating wounds, sterilization, etc., using plasma-enhanced chemical vapor deposition [34]. Materials applications include nano-tube formation [36] and materials synthesis [37], [38]. Plasmas can appear in nano-fluidic devices for drug delivery pharmaceutical applications [39], [40]. Plasmas appear in micro-gas sensors for homeland security [41].

REU students had also written code to use the Immersive Visualization Center (IVC) to view turbulent magneto-hydro-dynamic (MHD) plasma structures from computational simulations.

Other research with other faculty included un-inhabited autonomous vehicles (UAV), materials analyses, and wind tunnel experiments, from low-speed to hypersonic.

B. Participants

During the summer 2017, in total, 40 students with diverse backgrounds joined one of the REU programs: 12 domestic students invited by Department of Aerospace Engineering (AERO), 12 domestic students by Department of Materials Science and Engineering (MSEN), and 16 international students from some of the IITs by Engineering Global programs.

While domestic students invited by the departments matched up with a professor of the departments, international students had mentor professors from one or more of the 14 departments in College of Engineering. Therefore, international students' engineering programs for REU were diverse.

Among 40 students who joined the REU programs at the southwest public research university during Summer 2017, 36 students responded to at least one of pre- and post-surveys to assess the REU program effects on students' career goals, research experiences, and mentoring. Table 1 describes demographic characteristics of the participants. Average GPAs of participants were 3.82 for the AERO program, 3.59 for the MSEN program, and 3.54¹ for the Engineering Global program.

Table 1. Demographic Characteristics of Summer 2017 participants

Category		Domestic				International		Total	
		AERO		MSEN		IITs		N	%
		N	%	n	%	n	%		
Gender	Female	5	41.7	5	41.7	4	31.3	14	38.9
	Male	7	58.3	7	58.3	8	68.8	22	61.1
Race/ Ethnicity	Hispanic	2	16.7	2	16.7	0	0.0	4	10.8
	American Indian or Alaska Native	1	8.3	0	0.0	0	0.0	1	2.7
	Asian	0	0.0	3	25.0	12	100.0	15	41.7
	Black	2	16.7	0	0.0	0	0.0	2	5.4
	Multiracial	1	8.3	1	8.3	0	0.0	2	5.4
	White	6	50.0	6	50.0	0	0.0	12	32.4
Student Level	Sophomore	2	16.7	—	—			—	—
	Junior	5	41.7	—	—			—	—
	Senior	5	41.7	—	—			—	—
Total		12	100.0	12	100.0	12	100.0	36	100.0

Note. AERO = Aerospace engineering; MSEN = Materials Science and Engineering; IITs = Indian Institutes of Technology; '—' = no response

¹One student did not report GPA. The 10 point GPA scale of India from 11 students was converted to 4.0 point scale.

C. Procedures

We utilized pre-post surveys for undergraduate students to assess their expectations and changes in the perceptions of the REU experiences. The areas of assessments in the pre-survey included career goals after graduation, self-efficacy in decision making for a graduate school, motivation to apply for the REU program, prior research experiences, research expectations, perceptions of research knowledge, skills and engineering career paths, mentoring expectations, and the REU program admission logistics. The post-survey inquired about career goals after graduation, self-efficacy in decision making for a graduate school and success in graduate school, research skills learned from the REU program, summary of the research project, engagement with the research project, perceptions of research knowledge, skills and engineering career paths, mentoring experiences, and overall experiences with the REU program. We analyzed several common measures in both pre-post surveys, aligned with the NSF REU program objectives, such as career goals after graduation, self-efficacy in decision-making toward graduate school, and perceptions of research knowledge, skills, and engineering career paths to explore the impact of the REU programs. The format of the measures was diverse, including open-ended questions, ranking, and seven-point Likert-type items, ranged from 1 (strongly disagree) to 7 (strongly agree). Data collected included demographic data, GPA, and type of undergraduate institution attended.

D. Data Analyses

For quantitative data on the Likert-type questions, we only applied descriptive statistics, such as mean and standard deviation, due to the small number of respondents for both pre-post surveys by total and by program. For qualitative data on the open-ended questions, two researchers of this study closely scrutinized students' raw responses to supplement details in the change of participants' perceptions appeared in Likert-type questions [42, 43].

III. Results

In this section, we presented student responses on the pre-post surveys to reveal if the program met the criteria for success intended for goals of the program. These would reflect any increases that favor pursuing graduate education.

A. Impact of Program on Career Goals

Figure 1 shows students' changes in their career goals after the REU programs by program and by total. The number of students that responded to the corresponding survey questions were in total $n_{\text{pre}} = 32$ and $n_{\text{post}} = 28$ (in AERO, $n_{\text{pre}} = 12$ and $n_{\text{post}} = 11$; in MSEN, $n_{\text{pre}} = 12$ and $n_{\text{post}} = 11$; and in IIT: $n_{\text{pre}} = 8$ and $n_{\text{post}} = 6$). Figure 1 shows the percentages of each students in each program who chose graduate school, a job or were undecided, before and after the program. Most students (74%) had interests in graduate school at the start of the program and after REU programs, 68% of the respondents were interested in graduate school after finishing undergrad.

The program met its goal of at least 60% of the REU participants going to graduate school and as in past REU research [2], [8]. After the REU experience, there was one particular AERO student who wanted to go to private industry first by the end of the program.

Some US students opting for industry instead of graduate school wanted to work at a company where they would still be involved in conducting research. For example, one students said:

“I would like to pursue a research and development job in either industry or a government laboratory. Eventually I will return to pursue my Ph. D. and then teach in academia.”

Figure 1. Impact of the experience on student career goals.

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“I would like to pursue a research and development job in either industry or a government laboratory. Eventually I will return to pursue my Ph. D. and then teach in academia.”

One US student simply started out wanting to be in the field after graduation but was more into “an industry job” by the end of the program. An impact of having conducted research on one student is in this quote:

“I hope to work in a place where we are developing, or working closely with people developing, innovative/ new things in the field I join.”

B. Impact of Program on Self-efficacy

Figure 2 shows two types of self-efficacy in students’ decision making for graduate school and their success in graduate school. Note that only AERO and IIT students responded to the self-efficacy questions. The number of students who responded to the pre-post questions were $n_{pre} = 12$ and $n_{post} = 11$ for AERO and $n_{pre} = 8$ and $n_{post} = 6$ for IIT, totaling $n_{pre} = 20$ and $n_{post} = 17$. Figure 2 shows the average scores in the Likert scales from their survey responses before and after the program.

Figure 2. Impact of the experience on student self-efficacy.

Figure 2 indicates that the research experience had influenced their decision whether for graduate school or industry. One student in the AERO REU program, at the start of the program, said:

“Currently I am fairly split between going immediately into industry and pursuing graduate school.”

The impact of the REU program on the student’s decision-making appeared in a later statement from the post-survey as the same student mentioned:

“Ideally, I would work in industry for a few years to build experience and save for graduate school. After that period, I would return to pursue a doctoral degree.”

It also indicated an increase in their self-efficacy in succeeding in future endeavors. This reflects the similar results from other studies on undergraduate summer research programs [7], [10].

C. Impact of Program on Research, Knowledge, Skills and Career Path

Figure 3 shows the changes in average scores before and after the REU program from three different areas on students’ perceptions of research knowledge, research skills, and career path in engineering. Note that AERO and IIT students only responded to the perception questions. The number of students who responded to the pre-post questions were $n_{\text{pre}} = 12$ and $n_{\text{post}} = 11$ for AERO and $n_{\text{pre}} = 5$ and $n_{\text{post}} = 5$ for IIT, totaling $n_{\text{pre}} = 17$ and $n_{\text{post}} = 16$.

Figure 3. Impact of the experience on student research knowledge, skills, and career path in engineering.

The summer REU had an impact on the participants' research, knowledge, skills as well as their career path in engineering. Figure 3 shows the increases in their perceptions of these three areas. Sutterer et al. [1] and Grimberg et al. [2] observed similar increases in knowledge and skills in their review.

An indication of an increase in a student's confidence is in the following quotes. At the beginning of the program, a student in the AERO REU program said:

"I would like to utilize my broad coursework background to achieve exciting and innovative feats in engineering. Whether this means working for NASA, private industry, or academia, I want to work on groundbreaking research in the field of aerospace/aeronautical engineering."

At the end of the program, this student wanted to: *"Direct my own research lab in private industry."*

One international IIT student addressed a realization of his/her potential as a researcher after the REU program.

"I realised that I am capable of working in research and that it is a viable career path for me."

IV. Discussions

A. Career Goals and Self-efficacy in Decision Making for Graduate School

Some students became undecided about their future career goals after the program. This happened for both national and international participants. The apparent decrease of IIT students' self-efficacy in decision making for graduate school might be due to the mismatch between students' interest and faculty's research area. This is because matching the IIT students to faculty mentors was largely due to the availability of faculty. Therefore, the IIT students did not have quite the same view of their research experiences as the US students, nor if any impact on their decision toward graduate school. It then seems to suggest how important it is to match the students' research interests with the faculty research area.

B. Impact of Program on Research Knowledge, Skills and Career Path

In terms of student perceptions of learning research knowledge and skills as well as engineering career path, the results showed positive impact of increases on all three areas. While not all decisions favored going to graduate school, the results showed that the program had an impact on both national and international students' experiential learning of research knowledge and skills as well as engineering career path more.

C. Other Program Impacts

Students attributed their sense of community strength to co-habiting with their fellow program participants. However, some comments from students in the post-survey included requests for more icebreakers than simply having a student introduce the neighbor student and that student's research. There are also interests in more external social activities.

Being housed near each other did provide opportunities for students to plan their own social activities during weekends, such as trips to amusement parks, touring the much bigger neighboring cities, etc. The international students were particularly grateful for these trips because of more chances to get exposure to the US culture while staying in the country.

So far, students have found that they learned research skills that they would not have found in their home institutions. Those who had previous research experience had greatly improved their research skills. Some students expressed that they did not spend sufficient time with their professors as they spent with peer undergraduate researchers, graduate students and/or postdocs. However, most found that they learned a lot from their peer researchers, with whom they enjoyed their working and some community-building social relationships. The international students had more positive feedback about working with their research groups. The US and international students agreed on the research university being bigger and having impressive facilities being more of a positive than a negative. Many also found improvements in nontechnical skills, like presenting their research results.

E. Limitations and Suggestions for the Future Work

Some non-research experiences can have an impact on the research experiences. Gathering more data on how housing, social activities, community-building activities, etc., will enable us to explore the impact such experiences different from research experiences on students. While those activities may seem secondary to the main program goals, or, at least, of lower priority, student comments in the survey of this study suggest that they can be quite favorable to students' experience.

F. Conclusions

This paper presented the results of diverse national and international students' surveys before and after their summer undergraduate research experiences. The results showed that the national and international students could have the same perceptions of the programs if their experiences are very similar. A major difference was in that the international students did not have as much control on the choice in the selection of research area due to the limited faculty mentors. This mismatch might be the biggest reason for more of them selecting not to pursue graduate education and research after the REU program. In general, students valued their increase in research skills benefitted from the experiences. A large majority of students planned to pursue graduate education and research in their future career goals.

Acknowledgement

This material is based upon work supported by the National Science Foundation Grant (Award Number:1560424). Any opinions, findings, and conclusions or recommendations expressed in this document are those of the authors and do not necessarily reflect the views of NSF or its affiliates. The university credits the Haliburton Global Engineering Program for their support of the international student research program.

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