Impact of Research Experience Programs on National and International Undergraduate Engineering Students

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Dr. Richard got his Ph. D. at Rensselaer Polytechnic Institute, 1989 & a B. S. at Boston University, 1984. He was at NASA Glenn, 1989-1995, worked at Argonne National Lab, 1996-1997, taught at Chicago State University, 1997-2002. Dr. Richard is a Sr. Lecturer & Research Associate in Aerospace Engineering @ Texas A&M since 1/03. His research is focused on computational plasma modeling using spectral and lattice Boltzmann methods for studying plasma turbulence and plasma jets. His research has also included fluid physics and electric propulsion using Lattice-Boltzmann methods, spectral element methods, Weighted Essentially Non-Oscillatory (WENO), etc. Past research includes modeling single and multi-species plasma flows through ion thruster optics and the discharge cathode assembly; computer simulations of blood flow interacting with blood vessels; modeling ocean-air interaction; reacting flow systems; modeling jet engine turbomachinery going unstable at NASA for 6 years (received NASA Performance Cash awards). Dr. Richard is involved in many outreach activities: e.g., tutoring, mentoring, directing related grants (for example, a grant for an NSF REU site). Dr, Richard is active in professional societies (American Physical Society (APS), American Institute for Aeronautics and Astronautics (AIAA), etc.), ASEE, ASME. Dr. Richard has authored or co-authored about 35 technical articles (about 30 of which are refereed publications). Dr. Richard teaches courses ranging from first-year introductory engineering design, fluid mechanics, to space plasma propulsion.

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Ms. Maria C. Alves is the Director for the Halliburton Engineering Global Programs at Texas A&M University . She has been in this position since July 2012. In this position she is responsible for internationalizing the research and education activities of the College of Engineering. Under her leadership the college has significantly increased the number of students studying abroad, established new models of study abroad including co-op and research abroad and established meaningful connection for research and attraction of funded international graduate students. Maria started working at Texas A&M in 2005 as Assistant Director for Latin American Programs and in 2009 she was promoted to Program Manager for South America in the same office. During her time at the Office for Latin America Programs she created, managed and developed projects to enhance the presence of Texas A&M University in Latin American and to support in the internationalization of the education, research, and outreach projects of the university. She was charged with the development and implementation of a strategic plan for Texas A&M in South America. While at the Office for Latin America Programs, Maria was also responsible for the opening of the Soltis Center in Costa Rica. Maria speaks three languages fluently (Spanish, Portuguese and English) as well as intermediate French. Maria is originally from Brazil and completed her undergraduate studies

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Abstract

This study explored differences in the influence of summer research experiences on 33 national and international undergraduate students at a Southwestern public research university in the United States during the summers of 2017 and 2018. The students participated in two differently-funded programs at the same university with a variety of research topics, mentors, and their research groups. However, the two programs had a similar structure of research experiences for students, sharing the same housing and common activities for 10 weeks. Pre- and post-surveys revealed the common and uncommon areas of the impact of the programs on national and international students' career goals, self-efficacy on graduate school, perceptions of research, and research expectation and experiences. Results showed that most students came to favor graduate education and research, and their preferences did not change significantly at the end of the programs. Students' perceptions of research knowledge, skills, and engineering career path were all positively improved. While about 43% of both groups of students expected to acquire knowledge through the programs, more international students cited knowledge acquisition than national students after the programs. Instead, more national students mentioned acquisition of technical skills than international students. Professionalism was the area where all students expressed the most gains.

I. Introduction

Recent data have shown increases in graduate school enrollment but not in all areas [1]. Figure 1 shows that graduate enrollment in engineering was increasing, but recently it has been leveling off and dropping. In addition, there has been a continuous decrease in graduate applications in engineering from 2014 to 2017 with the most decrease of 7.3% from Fall 2016 to Fall 2017. Okahana and Zhou [1] suggested that the declines in international graduate applications (-8.9% from 2016 to 2017) might be responsible for the decrease, even though domestic student enrollment had a slight increase (1.6% during the same period). Considering that engineering is an international field, this trend is not desirable.

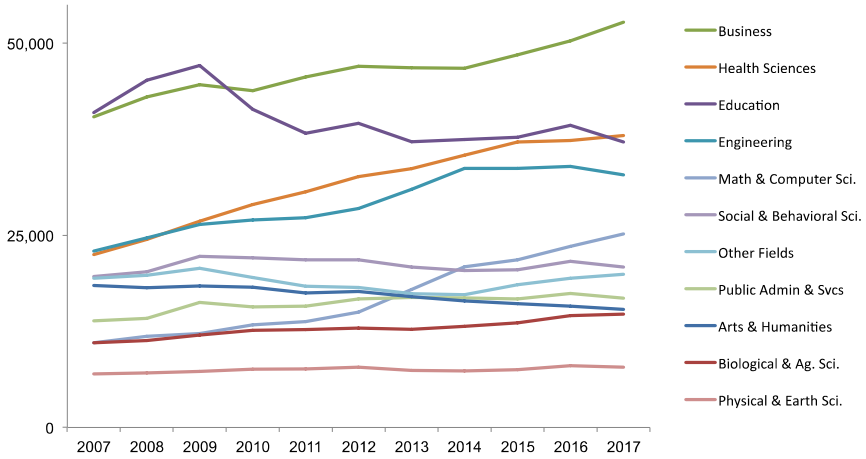

Figure 1. Trends in first-time graduate enrollment by field of study, Fall 2007 to Fall 2017 [1, pp. 17]

In addition, the recent data showed the continuing lack of diversity in engineering graduate programs [1]. Even though from 2007 to 2017, there has been a 5.1% increase in total graduate enrollment of women in engineering, engineering graduate enrollment remained heavily dominated by men (73.5%), as shown in Figure 2. However, there has been slight improvement in minority engineering graduate enrollment. The largest improvement has been for Hispanic graduate enrollment with a 9.5% increase from 2007 to 2017. African Americans showed only a 2.5% increase. The only group with a decrease in enrollment was American Indians/Alaska Natives with a change of -2.9%. Asian/Pacific Islander and White graduate enrollment each showed an increase of 1.9%. Despite positive improvements in minority graduate enrollment in engineering, White is still dominant with 63.2%. These findings indicate need for continuous efforts to improve diversity.

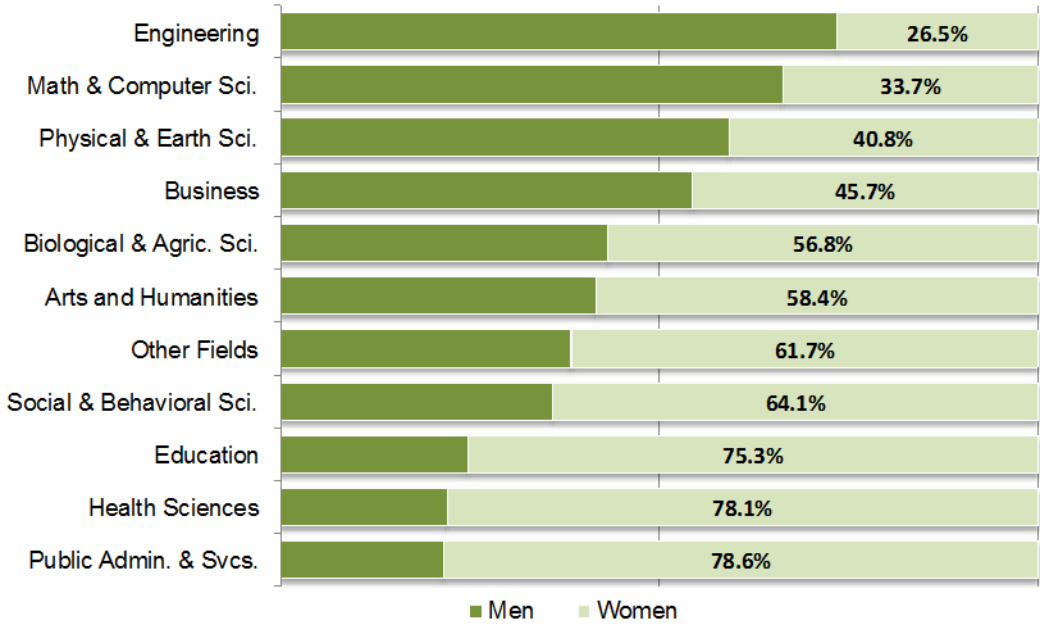

Figure 2. First-time graduate enrollment by gender [1, pp. 12]

Under these circumstances, NSF has strongly supported research programs, called Research Experiences for Undergraduates (REU), as a means of attracting undergraduate students into graduate education and research. Through REU at a university, undergraduate participants have an opportunity to integrate into research groups and thereby, increase their awareness and interest in graduate school in computing, science, technology, engineering, and math (C-STEM) fields. However, NSF funds only support United States (US) citizens and permanent resident students from institutions that may not have particular graduate programs.

During the summers of 2017 and 2018, a Southwestern public research university in the United States had an opportunity to host an NSF REU program for national undergraduate students and a global engineering program for international undergraduate students, immersing them in the same research environment. While national students were funded by NSF, the international students received support from their home institution and the host university's College of Engineering. Even though students participated in two differently-funded programs, the two programs had a similar structure of research experiences for students, sharing the same housing

and common activities for 10 weeks at the university with a variety of research topics, mentors, and research groups. Therefore, this study explored the impacts of summer research experience programs on national and international students apart from the funding support structure. The study also explored possible cultural relevance of the impacts, if any.

A. Benefits of Undergraduate Research Experiences

Studies showed REU[1] as very effective in broadening participation in graduate school and research [2] – [7]. The main goal of the REU programs is to engage students in authentic engineering research. The literature presents several benefits of REU:

1. Improvement in research literacy [7] - [10]
2. Personal development in soft and hard skills [11] – [13]
3. Improvement of employability [14], [15]
4. More interest in postgraduate school [16] – [18]
5. Networking [19], [20]

Several studies observed up to 60% increase in REU participants eventually attending graduate or professional education [13], [15], [21], [22]. Sadler and McKinney [23] noted undergraduate students' increases in graduate education interest, building research skills, and confidence in research. Several studies found that students who participated in an REU program appreciated the role of the faculty, graduate students, and/or peer mentors [13], [24] - [26].

B. Undergraduate Research Experiences for International Students

There has been a lack of literature on research experiences of international undergraduate students in engineering at a US institution. Most studies in the literature focused on national students' international research experiences at foreign institutions [27], [28]. Instead, the literature documented difficulties in recruiting international students for graduate school [29] and difficulties of international graduate students adjusting to the US culture, academia, or environment [30]. Curtin, Stewart, and Ostrove [31] found that a sense of belonging and advisor support were significantly related to both international and domestic graduate students' perceptions of their academic competence and performance. Wan, Chapman, and Biggs [32] noted that one of the factors that reduced academic stress for international graduate students in the US was the social support network.

Regarding career preferences of international students, due to the high demand in industry, few Indian students go to graduate school and few Indian participants of international research programs have returned to the US for graduate school [33]. Indian students usually favor lucrative positions in the workforce, largely out of India, over graduate school [33] – [35]. Varma and Kapur [35] showed that 79% of Indian students preferred graduate school in finance and business, relative to the high number of Indian undergraduates in engineering [33].

[1] Research Experiences for Undergraduates (REU) in this study were used interchangeable with undergraduate research experiences (URE) frequently used in the literature, for both national and international students.

C. Purpose of the Study

The main purpose of this study was to explore impacts of summer research experiences between national and international students at a Southwestern public university in the US. Specifically, we tried to identify common and uncommon viewpoints from students of different backgrounds, such as research environments and culture. The following research questions guided this study:

1. How do the research experiences influence students' career goals?
2. How do the research experiences affect students' self-efficacy of making decision about graduate school and success therein?
3. How do the research experiences change student perceptions of their research knowledge, skills, and engineering career path?
4. What are the differences in the effects of the research experiences between national and international students?

II. Method

A. Setting

Objectives of the National REU Program. The specific objectives of the REU program were to (a) engage a minimum of 10 undergraduates annually in rich summer aerospace engineering research experiences; (b) prepare the students for graduate school by providing workshops on the Graduate Record Examinations (GRE), increasing awareness of graduate opportunities, strengthening resumes by publishing research, and improving written and oral communication; and (c) measure the effectiveness of the REU program in encouraging students to attend graduate school. The selected participants were to include at least 60% women and underrepresented minorities, mainly from minority-serving and predominantly undergraduate institutions.

Objectives of the International REU Program. The College of Engineering at the university has a Global Engineering Program that works with engineering programs in many countries, such as Indian Institute of Technology (IIT) system in India. The objectives of the international REU program were similar in that undergraduate students from international institutions get immersed in the university research environment, so they consider the graduate school option.

The REU Program for National Students. The program coordinator emailed flyers to faculty at different supporting universities or travelled to various universities within driving distance to personally recruit students. Utilizing an online application process, the program coordinator and several faculty members selected and matched top applicants with faculty members who share mutual areas of interests in aerospace engineering. This meant that not one single factor dominated the reason for selection: i.e., neither highest GPA, letters of recommendation, essays, nor transcripts were sufficient for acceptance into the program.

The REU Program for International Students. During the calendar year prior to the summer of participation, an application went out to students at the international institutions in collaboration with the Global Engineering Program at the university. The international institutions selected participants from their applicant pools. The Global Engineering Program identified faculty in each department of the College of Engineering to match with international

students based on mutual research interests. However, this did not necessarily guarantee the perfect match of research interests between faculty and students. The international institutions supported their students' air transportation to the US. The university supported the international students' housing, transportation to and from the airport, a welcome package, and a stipend.

Program Structure and Activities. During the 10-week undergraduate research programs, students of both programs shared the following joint activities: (1) participation in research with faculty, graduate student researchers, and other undergraduates under the supervision of the faculty for direct hands-on training in relevant computational and/or experimental research methods, (2) participation in research-oriented field trips (e.g., various labs on campus, Ad Astra Rocket Co., and NASA Rocket Park, etc.), (3) participation in professional development workshops (GRE preparation and technical writing, etc.), and (4) submitting formal research papers to professional conferences and refereed journals.

B. Participants

During the summers of 2017 and 2018, a total of 67 students with diverse backgrounds joined summer research programs at the university: 25 national students invited by the Department of Aerospace Engineering across the US and 42 international students from India, Qatar, and China invited by the Global Engineering Program. Whereas national students were matched with one of aerospace engineering professors, international students were matched with a professor from one of the 14 departments in the College of Engineering. Therefore, international students had varied research topics. Although 58 students (86.6%) responded to at least one of the pre- and post-surveys, 33 students (49.3%) responded to both surveys that enable us to assess the effects of the programs on students' career goals and research experiences. Table 1 describes demographic characteristics of the participants.

Table 1. *Demographic Characteristics of the REU Participants from Summers 2017 and 2018*

Category	Subcategory	National		International		Total	
		n	*%*	*n*	*%*	*N*	*%*
Gender	Female	7	36.8	2	14.3	9	27.3
	Male	12	63.2	12	85.7	24	72.7
Race/ Ethnicity	Hispanic	4	21.1	0	0.0	4	12.1
	American Indian or Alaska Native	1	5.3	0	0.0	1	3.0
	Asian	0	0.0	14	100.0	14	42.4
	Black	3	15.8	0	0.0	3	9.1
	Multiracial	0	0.0	0	0.0	0	0.0
	White	11	57.9	0	0.0	0	0.0
Student Level	Sophomore	4	21.1	0	0.0	4	12.1
	Junior	8	42.1	7	50.0	15	45.5
	Senior	7	36.8	7	50.0	14	42.4
Total		19	100.0	14	100.0	33	100.0

C. Measures

We utilized pre- and post-surveys to assess the impact of the programs on participants' career goals and research experiences. The areas of assessments in the pre-survey included career goals after graduation, self-efficacy in decision-making toward graduate school and success in graduate school, motivation to apply to the REU program, prior research experiences, research expectations, perceptions of research knowledge, skills, and engineering career paths, mentoring expectation, and admission logistics. The post-survey inquired about the items in the pre-survey to follow-up, additional items about mentoring experiences, and overall program experiences.

The format of the measures varied, including open-ended questions, ranking, and seven-point Likert scales, ranging from 1 (strongly disagree) to 7 (strongly agree). Among several measures, we analyzed four common measures in both pre- and post-surveys, aligned with the NSF REU program objectives, such as (a) career goals after graduation, (b) self-efficacy in decision-making toward graduate school, and (c) perceptions of research knowledge, skills, and engineering career paths, and (d) research expectations and experiences that enabled us to explore the differences of the impact of the REU programs on national versus international students.

D. Data Analyses

First, we applied descriptive statistics for frequency data on career goals to show the changes between pre-post responses. For Likert-type responses, considering the small sample size, Wilcoxon signed rank *T*-test, which is a nonparametric counterpart of the paired samples *t*-test [36], was used to explore changes in participants' scores of the self-efficacy and perceptions of research skills and engineering career path on the scale before and after the program. We also reported effect sizes of *r* [37]. For qualitative data on the open-ended questions on research expectations to learn on the pre-survey, and research experiences acquired on the post-survey, two researchers of this study closely scrutinized students' raw responses to code the themes emerged [38], [39]. The students' open responses supplemented details in the change of participants' perceptions appeared in Likert-type responses.

III. Results

A. Career Goals

For all respondents (N = 33), Figure 3 shows that most students started with interest in graduate school. There was a minute drop at the end, indicating a student losing interest in graduate school. The trend for undecided students did not change. Note that we allowed students to select multiple options because a good portion of students wanted to get a job first after college and then come back to graduate school, so the numbers add up to more than 100%.

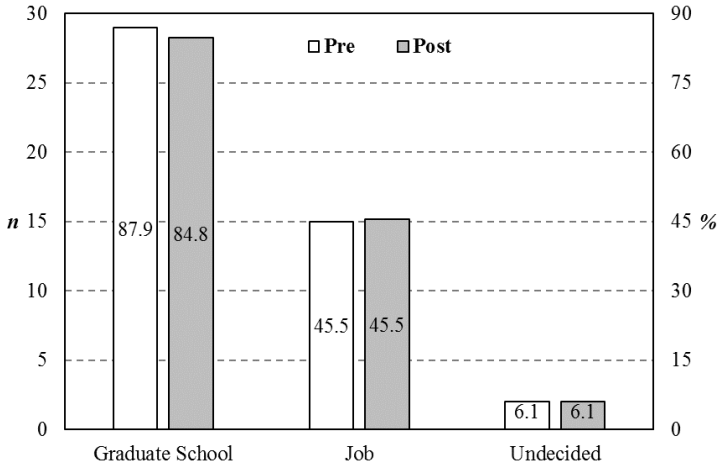

Figure 3. Changes in Student Career Goals after College (*N* = 33)

When the results are disaggregated by program, Figure 4 indicates that national students did not show any apparent changes in their career goals. However, the international students showed slightly less interest in graduate school at the start of the program, but then increased their interest in graduate school by the end of the program. However, there was a decrease of national students interested in graduate school. The international students also showed an increase in interest in getting a job after graduation.

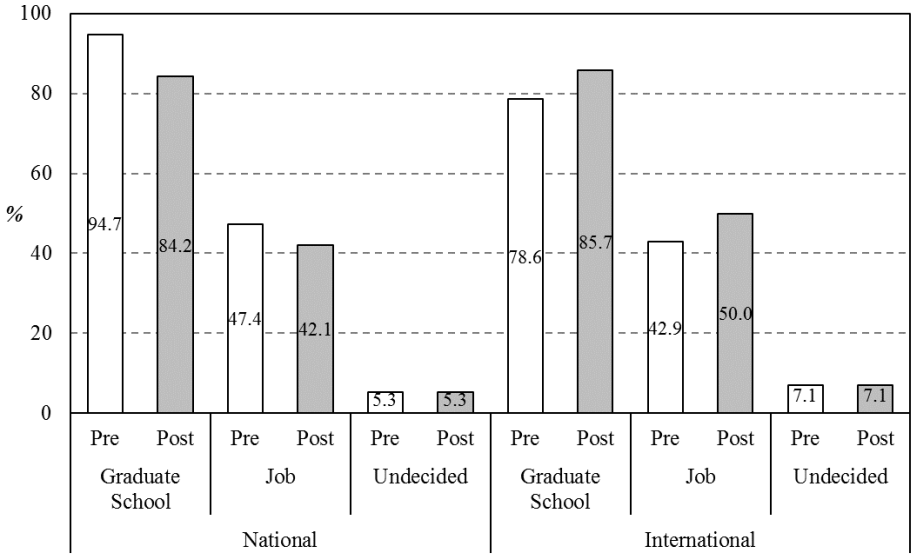

Figure 4. Changes in student career goals after college by national (*n* = 19) and international students (*n* = 14)

B. Self-efficacy about Graduate School

In terms of self-efficacy as a whole, Wilcoxon signed rank *T*-tests revealed that there were no significant changes in participants' decision-making toward graduate school and success in graduate school before and after the programs. Separating the data by program, the changes in both self-efficacy scores were not statistically significant either.

Table 2. *Pre-post Changes in Participants' Self-efficacy and Perceptions of Entrepreneurship*

Self-efficacy	Pre			Post		Wilcoxon signed rank *T*-test			
	n	*M*	*SD*	*M*	*SD*	*T*	*Z*	*p*	*r*
Both Programs as a Whole									
Decision making toward graduate school	33	5.91	0.78	5.79	1.10	201.0	-0.358	.720	0.04
Success in graduate school	33	5.68	0.87	5.66	1.10	236.0	-0.401	.688	0.05
National Program									
Decision making toward graduate school	19	6.02	0.78	6.09	0.75	70.5	0.130	.896	0.02
Success in graduate school	19	5.58	0.78	5.81	0.76	87.0	0.986	.324	0.15
International Program									
Decision making toward graduate school	14	5.76	0.78	5.38	1.35	38.0	-0.525	.600	0.09
Success in graduate school	14	5.81	1.00	5.45	1.44	41.0	-0.315	.753	0.05

C. Perceptions of Research Knowledge, Skills, and Engineering Career Path

After the programs, both national and international students' perceptions of research knowledge, skills, and engineering career path significantly increased as shown in Table 3. The effect sizes (*r*) indicate that the magnitudes of the changes in perceptions were large.

Table 3. *Pre-post Changes in Student Perceptions of Research Knowledge, Skills, and Engineering Career Path*

Perception	Pre			Post		Wilcoxon signed rank *T*-test			
	n	*M*	*SD*	*M*	*SD*	*T*	*Z*	*p*	*r*
Both Programs as a Whole									
Research Knowledge	31	4.99	0.84	5.78	1.05	371.0	3.828	< 0.001	0.486
Research Skills	31	5.05	0.92	5.73	1.06	347.5	3.818	< 0.001	0.485
Engineering Career Path	31	5.13	1.02	5.80	1.00	357.5	3.521	< 0.001	0.447
National Program									
Research Knowledge	18	4.71	0.88	5.52	1.23	119.0	2.643	0.008	0.763
Research Skills	18	4.88	1.07	5.52	1.25	120.0	2.695	0.007	0.778
Engineering Career Path	18	4.79	1.04	5.53	1.15	132.0	2.637	0.008	0.761
International Program									
Research Knowledge	13	5.36	0.63	6.13	0.63	73.0	2.670	0.008	0.771
Research Skills	13	5.29	0.63	6.02	0.68	64.0	2.763	0.006	0.798
Engineering Career Path	13	5.60	0.82	6.17	0.60	60.0	2.413	0.016	0.697

D. Expectations of Research Skills and Acquisitions of Research Skills

Two common themes emerged from open-ended questions on the surveys: hard and soft skills, including several subthemes. Hard skills that students mentioned were fundamental knowledge acquisition, practice of techniques/skills, and how to do research. Soft skills that students addressed were higher-order thinking skills, communication, teamwork, professionalism, and networking. Higher-order thinking skills that students addressed include analytical, critical, problem solving skills, and creativity. Communication includes communication skills with peers, research teams, and people from different disciplines of research, presentation of the research through posters, and writing skills. Professionalism includes persistence, patience, confidence, independence or autonomy, and time management.

As shown in Figure 5, before starting the programs, 43% of students valued acquiring knowledge but it dropped tremendously on the post-survey to 20%. However, practice of techniques/skills was the area students expressed more on the post-survey (60%) than on the pre-survey (40%). Students did not show any change of views on how to do research between pre-post. Regarding soft-skills, professionalism was the area that students expressed as the most gained (70%) but the decrease in high-order thinking skills (15%) showed that it did not meet student expectation for acquisition.

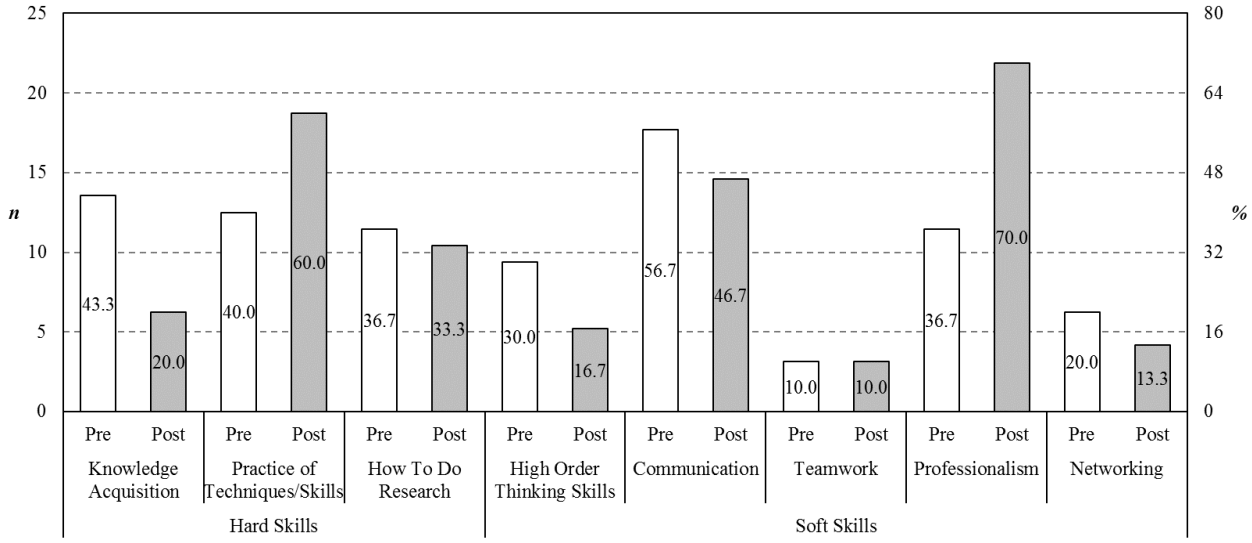

Figure 5. Research skills that students wanted to acquire before the programs and acquired after the programs

According to Figures 6 and 7, there were apparent distinctions on the pre-post changes on the common themes between national and international students. Although students of both programs showed decreases in knowledge acquisition on the post-survey compared to their expectations on the pre-survey, the decrease was smaller for international students (7.7%) than national students (35.6%). National students cited acquisition of practice of techniques/skills higher on the post-survey (65.7%) than on the pre-survey (35.3%). Regarding learning of how to do research, international students mentioned it more than national students (29.4% to 46.2%) on the pre-survey, and the trend continued onto the post-survey (23.5% to 46.2%).

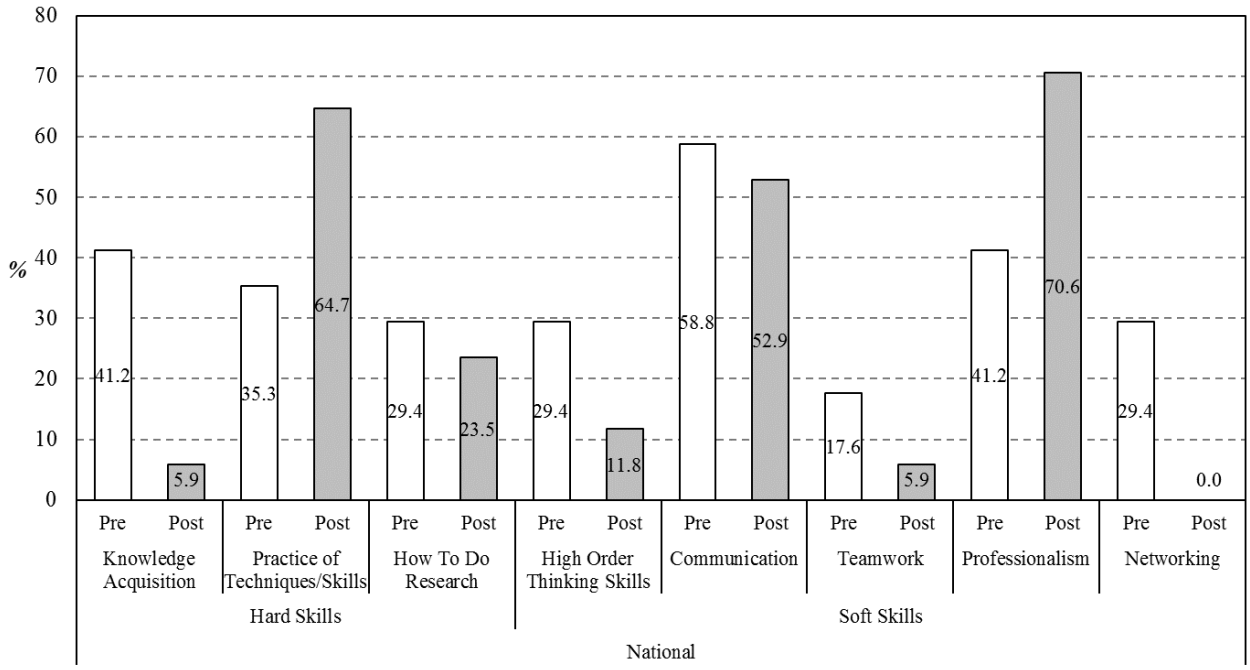

Figure 6. The national students view of specific research skills before and after the program

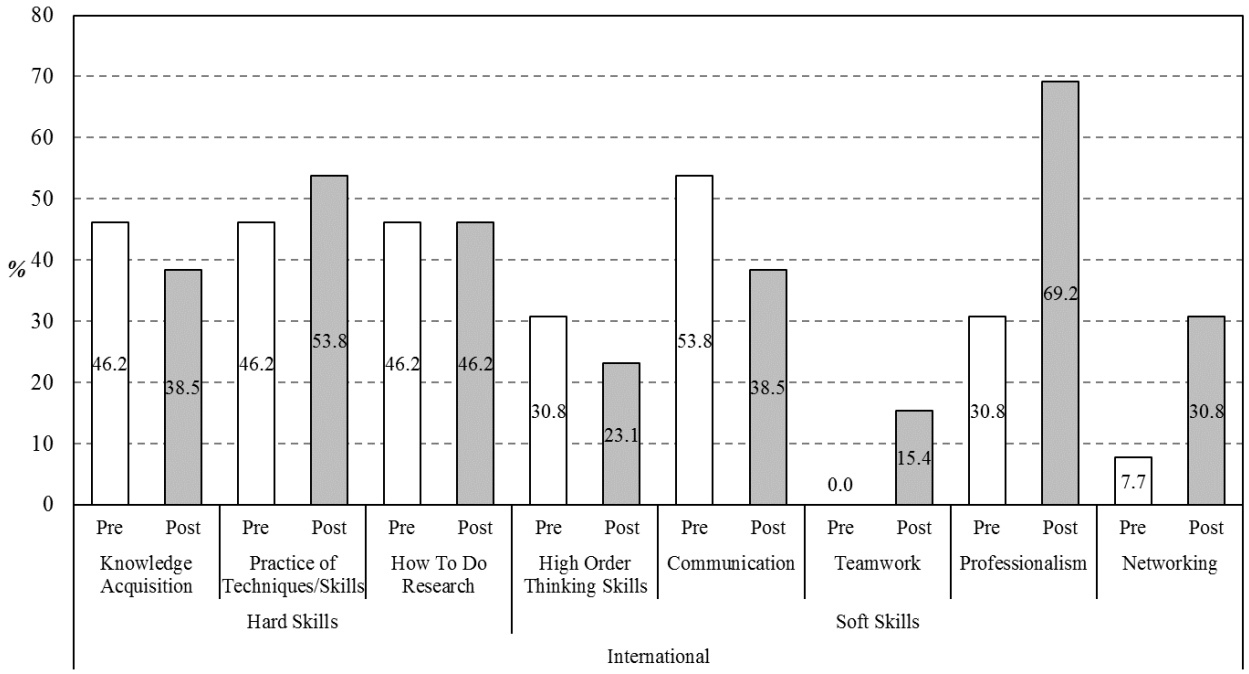

Figure 7. The international students view of specific research skills before and after the program

Among the five soft skills, communication was the one that both national and international students had the highest expectation to learn (58.8% and 53.8%, respectively). National students showed a big drop (17.6%) in higher-order thinking skills on the post-survey. International students showed a big drop (15.3%) in communication. No international students mentioned expecting to learn teamwork on the pre-survey, but 15.4% of them mentioned it on the post-

survey. Eighteen percent of national students mentioned teamwork on the pre-survey, but it decreased to 6% on the post-survey. About 70% of students from both programs mentioned professionalism on the post-survey as a skill they acquired through the programs. Although 29% of national students mentioned that networking was a skill to learn, none indicated it at all on the post-survey. In contrast, 7.7% international students mentioned networking for acquisition on the pre-survey and 30.8% of them mentioned that it was acquired on the post-survey.

IV. Discussion

While 33 national and international undergraduate students participated in 10-week summer REU programs at the same university with similar research environments and social activities, their expectations and experiences were not the same. The findings from the two-years data on career goals, self-efficacy, and perceptions showed similar patterns from the one-year data [40]. To supplement quantitative results for discussion, we sampled quotes from the students' responses to the open-ended questions on career goals and research expectations and experiences and their comments on the programs.

A. Career Goals toward Graduate School and Engineering Career Path

There were no apparent differences in aspirations toward graduate school and career goals from before to after the program for national students. International students started with less interest in graduate school, but had a slight increase in favoring the graduate school option. The research programs did help students learn more about the engineering disciplines and focus their career goals, as one national student stated below on the post-survey:

> "*This REU challenged me to find my passion in specific fields of engineering. Yes, I knew I loved Aerospace Engineering. But it wasn't until this REU where I was able to sample all the different sub-fields and determine which I wanted to specialize in*."

Students' responses indicate a better understanding of graduate education and research options. Another national student found the value of graduate school as:

> *"I learned that I do not know anything yet. Real, hands-on education seems to come during graduate school, and it seems that undergraduate research simply prepares for that."*

One international student stated that:

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

Regarding the decision-making toward graduate school, there were no significant changes for either groups of students. However, the open-ended responses by two international students below revealed their preference of job experiences over graduate school as revealed in the literature [33] – [35]:

> *"I will try to get in an industry for some exposure and then will get into Graduate Studies.*
>
> "*I want to have a job experience before go to higher studies. I may go in to financial field as well*."

Students seemed to tie their experiences to job interests, whether before or after graduate school, and types of job (e.g., *research, design, innovative, and start-up*). For example, one national student said: "*This [program] challenged me to find my passion in specific fields of*

engineering." Another international student mentioned his long term career goals as "*Engaging in research and entrepreneurship*."

The results support previous findings about the effectiveness of REUs in increasing interest in graduate school [2] – [7], [16] – [18]. The findings for international students that showed an increase means that an REU can also be as effective in increasing their interest in graduate school, reversing previously observed trends [33] – [35].

B. Research Expectations and Experiences

Hard Skills. Students were more specific about the research skills acquired during the programs on the post-survey than on the pre-survey, where they did not specify which skills they wanted to learn [14]. For example, a student mentioned coding on the pre-survey, but on the post-survey, the student specified learning of coding in a language (e.g., C++).

Soft Skills. Regarding professionalism, students of both programs found that they improved their competence and confidence in a research area, attitude toward research, patience, and persistence (e.g., "*being wrong and still moving on*", "*I learned how to deal with setbacks*"). Students also mentioned being more independent researchers, yet still mentioned knowing "… *when to ask around.*" Through the REU, students indicated learning how to discover and best utilize human and infrastructure resources. Several students noted several ways to disseminate their research findings, such as poster presentations, exhibitions, conference presentations, and publications, even after leaving the summer research institution. Some students elaborated on how much they learned about presenting their research and writing reports [7], [12]. Distinctions in the soft skills between the two groups may be due to cultural differences in research environment. For example, the changes in the views on teamwork and networking by national and international students might be due to learning about what is important in conducting research or adopting a view of what is important in a different research culture. Further research can explore the different viewpoints on the importance of soft skills between national and international students.

One important lesson from the findings on hard and soft skills is that an REU can be more intentional in designing to build these skills as they are also addressed as important according to the ABET Student Outcomes. Even though the REU programs at the Southwestern public research university have already incorporated workshops for communication skills, the findings of this study identified other skills that warrant more proactive workshops, such as professionalism and networking. Then, the REU programs can strengthen soft skills too, even though students come to do research expecting to build associated hard skills.

C. Limitations of the Study and Suggestions for Future Research

As the limitations of this study, first the small sample size and the unique learning and research environment at the university limit the generalizability of the findings beyond the scope of this study. Therefore, there is a need to increase the sample size to increase statistical power for future research. Second, the Likert scales used to assess student self-efficacy on graduate school and perceptions of research knowledge, skills, and engineering career path were not validated yet due to the small sample size. Further research is necessary to validate those scales with a larger

sample size. Third, this study only explored cross-sectional effects of the programs on student career goals and research outcomes. Therefore, there is a need of a longitudinal study, tracking participants' career changes after undergraduate graduation, such as graduate enrollment in engineering, and research activities, such as presentations at a conference and publications in a journal. Fourth, while both national and international students had similar favorable perceptions of the graduate schools before and after programs, this does not mean that international students did change their preferences of lucrative positions in the work-force after graduation, despite their positive statements about their summer research experience. Further research is necessary to explore other factors that may influence international students' decision-making toward graduate school at the US.

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