The Impact Of Undergraduate Research Experiences On Participants' Career Decisions

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Abstract

The benefits of undergraduate research include gains in research and communication skills, increased interest in graduate studies, and improvement in student persistence. Undergraduate research can promote career pathways into engineering by increasing enrollment and retention rates. Research Experience for Undergraduates (REU) programs funded by the National Science Foundation (NSF) offer undergraduate students the opportunity to participate in graduate level research during the summer for 6-9 weeks. The REU program at the NSF Nanosystems Engineering Research Center (ERC) for Nanomanufacturing Systems for Mobile Computing and Mobile Energy Technologies (NASCENT) at University of Texas, Austin, described and evaluated in this paper aims to achieve the following goals: providing students with basic research and professional skills to succeed in graduate school and beyond and increasing students' awareness of career opportunities in science and engineering fields. These goals are fulfilled by engaging undergraduate science and engineering majors in cutting-edge nanotechnology and engineering research projects, allowing participants to experience graduate level research. Moreover, the program offers research opportunities to students from backgrounds traditionally underrepresented in STEM (women and minorities), and students who might not otherwise have similar research opportunities. In the seven years from 2013 to 2019 that NASCENT has ran the program, it welcomed 62 students, 46% women, and 29% students from minoritized groups.

Program evaluation has been performed by analyzing responses from pre- and post-surveys of the 2016 to 2019 cohorts. The main focus of this analysis is investigating the impact of the program in increasing participants' confidence and awareness of opportunities in STEM careers and graduate studies. The analysis of qualitative and quantitative data shows gains in scientific self-reported skills and a positive impact on promoting graduate school and STEM careers.

1. Introduction

There are several benefits connected to undergraduate research widely recognized in the literature (Bauer & Bennett, 2003; Lopatto, 2003). Participants in Research Experience for Undergraduates (REU) programs have shown gains in research and communication skills (Lopatto, 2006; Seymour et al., 2004), increased interest in graduate studies, and improvement in student persistence (Hathaway et al., 2002). Studies of the impact of undergraduate research experience on students' career trajectory have shown that undergraduate research can help promote career pathways into engineering by increasing the enrollment and retention rate in graduate education (Gregerman et al., 1998; Hathaway et al., 2002).

The REU program described in this paper aims to achieve the following goals: providing students with basic research and professional skills to succeed in graduate school and beyond and increasing students' awareness of career opportunities in science and engineering fields. These goals are fulfilled by engaging undergraduate science and engineering majors in cutting-edge nanotechnology and engineering research projects, allowing them to experience graduate level research. Through this program, the NSF Nanosystems Engineering Research Center (ERC) for Nanomanufacturing Systems for Mobile Computing and Mobile Energy Technologies (NASCENT) at University of Texas aims to teach and demonstrate ethical decision making and professional responsibility, create a collaborative, welcoming environment in which participants are exposed to a diverse peer group, and offer research opportunities to students from backgrounds traditionally underrepresented in STEM, and students who might not otherwise have similar research opportunities. Over seven years, the 62 participants were 46% female-identifying and 29% students from underrepresented racial/ethnic minority backgrounds.

The results presented in this paper are based on analyzing responses from pre- and post-surveys of the 2016 to 2019 cohorts (no collected data prior to 2016 available). This paper provides an overview of the program, highlighting key components. The main focus of this analysis is investigating the impact of the program on increasing participants' confidence in their research skills and awareness of opportunities graduate studies and STEM careers.

2. Literature Review

There are benefits connected to the participation in undergraduate research and in REU programs (Sadler & McKinney, 2010), including improvements related to students' various skill sets. One of the goals of this paper is to report on the influence that the REU program has on participants' self-reported research-related skills.

Lopatto (2006) found that REU participants gained experience in scientific methods, such as laboratory work, data collection and analysis, understanding scientific literature, writing and learning ethical conduct. According to Brownell et al. (2015), undergraduate students who participated in a research experience reported a better understanding of "what it means to be a scientist" and showed an improvement in their ability to analyze and interpret data. Haave & Audet (2013) reported an increase in academic performance, especially among students with lower than average GPAs. Fakayode at al. (2014) found that REU programs could promote critical thinking, teamwork, and leadership as well as excitement towards STEM careers.

Evidence of gains in communication skills, through posters and presentations, have also been reported for undergraduates involved in research activities (Gilmore et al., 2015; Laursen et al., 2010; Seymour et al., 2004). Ing et al. (2013) found a significant improvement in communication skills for undergraduates who received both mentoring on research activities and the opportunity to share their thinking for a period of time longer than a single week, supporting the benefits connected to active participation and mentoring support.

The hands-on approach that characterizes REU programs is based on situated learning and apprenticeship theories where apprentices learn the tools and skills related to their discipline through direct participation (Clancey, 1995; Greeno, 2005; Lave & Wenger, 1991). Building upon the growing body of literature concerning the influence of undergraduate research on pursuing engineering pathways for graduate school, this paper aims to understand the influence of the program on participants' decision to pursue graduate studies.

The impact of REU programs on the students' willingness to pursue a scientific career has been widely studied.

Research has shown that participants increased engagement in their discipline, positively influencing the direction of their career paths (Lopatto, 2004). According to Hunter et al. (2007), REU participants valued the opportunity to assess how well the work of a researcher fits with their aptitudes, temperament, and life choices. Research experience during undergraduate studies can be effective in clarifying, refining or confirming students' pre-existing choice of career directions or in encouraging long term interests in research and academic work. Eagan et al. (2013) reported that these programs contribute to the intention to enroll in STEM graduate programs while Hathaway and colleagues (2002) found that participants involved in undergraduate research were more likely than students who did not participate in undergraduate research to pursue graduate education, continue in post-undergraduate scientific research, and network with faculty. Research has shown that students who participated in REU programs have clearer intentions towards career paths in science and a more positive attitude towards research (Junge et al., 2010; Yaffe et al., 2014).

Furthermore, REU programs provide an additional path to graduate school for students from traditionally underrepresented backgrounds (Graham et al., 2013; Linn et al., 2015; National Academies of Sciences & Medicine, 2017; Russell et al., 2007). According to Hathaway et al. (2002), students from minoritized groups who participated in undergraduate research were more likely to pursue graduate education and to participate in further research activity than their non-research counterparts. According to Carpi at al. (2017), participation in REU programs positively affects students' career ambitions. The program described in this paper provides students who have been traditionally underserved and/or had fewer opportunities to access undergraduate research experiences to experience graduate-level research and seminars and make informed decisions about their future careers.

Since professional identity is a key component for retention and persistence (Meyers et al., 2012), the authors believe that it is important to include measures of engineering identity to the analysis by introducing and adapting published scales. Studies of engineering identity have demonstrated a positive correlation between engineering identity and retention in engineering at the undergraduate level (Patrick et al., 2018; Tendhar et al., 2018) and a relationship between science and engineering identity and decisions to pursue graduate study (Borrego et al., 2018). Studies of identity in engineering PhD and master's students have identified separate engineer and researcher identities, which are each comprised of interest, performance/competence, and recognition components (Choe & Borrego, 2020; Perkins et al., 2018). According to Benson et al. (2020), students develop research identity by comparing their pre-conception about the job of a researcher with their personal experience doing research. Also, students' perception of their research identity is impacted by their other multiple identities, including the role within their family, identity as student, or professional identity such as engineer or scientist identity. In the program described here, questions from published engineering and research identity scales (Borrego et al., 2018; Choe & Borrego, 2019, 2020) have been piloted on the most recent cohort to begin to understand the development of engineering and research identity by REU students.

3. Methods:

3.1 Overview

This paper describes the REU program at the NSF Nanosystems Engineering Research Center (ERC) for Nanomanufacturing Systems for Mobile Computing and Mobile Energy Technologies (NASCENT) at University of Texas, Austin. This is a nine-week summer research experience program designed for undergraduate engineering students, ranging from sophomore to senior year. Each summer, undergraduate students take part on ongoing research projects in the fields of nanotechnologies and nanofabrication under the supervision of a trained graduate student mentor and a faculty member. Each participant is assigned to one mentor and becomes a member of the mentor's research group. To provide some examples of research topics that REU participants have the opportunity to work on during the summer, Table 1 reports abstract's titles of projects developed by the 2019 REU cohort.

Participants conduct daily laboratory research and contribute to ongoing research projects. Students are also involved in extracurricular activities, including seminars, team-building, social activities and bi-weekly meetings to receive full support from the program director and staff and are exposed to life in graduate school, potentially influencing their future careers.

The research questions addressed in this paper are:

1. How, if at all, did students' self-confidence in their research-related skills change from the beginning to the end of the REU?
2. In what ways did the REU influence students' attitudes towards graduate school?
3. How strong are the students' engineering and research identity by the end of the REU, and how do these identities compare to published values?

3.2 Recruitment and Demographics

The recruitment process starts in the fall, with emails sent to introduce the program to deans and department directors of a variety of local universities with direct ties to NASCENT. Many institutions in the geographic area are Minority Serving Institutions (MSI), specifically Hispanic Serving Institutions (HSI) (U.S. Department of Education, 2007, 2016). The connection with local higher education institutions gives students who are unable to move across the country for the summer the opportunity to experience graduate research close to their home. Additionally, students become familiar with the institution if they decide to apply to its graduate school. NASCENT faculty also host recruitment sessions at the targeted institutions, and other connections, such as research collaborations between faculty members, also augment recruiting. This program gives priority to first generation, Latinx, and African American students.

Applicants submit transcripts, a recommendation letter and a statement of purpose. The criteria taken into consideration when evaluating a student's application include demographics, the ability of the student to move for the summer, the amount of research experience previously acquired (the ideal candidate has little to no research experience), GPA showing that the student has been putting sufficient effort in schoolwork, and the type of coursework taken (for example, having some lab experience is important). The number of students selected from a particular discipline depends on capacity in particular labs, which in this program are distributed across mechanical, chemical and electrical engineering.

NASCENT has been successful in recruiting a diverse student population for the summer research programs, including female, Latinx, and African American students, with the goals of broadening participation and increasing diversity of contributions both within NASCENT specifically, and in the field of nanomanufacturing in general. In the seven years from 2013 to 2019 that NASCENT has ran the program, it welcomed 62 students, 46% women, and 29% students from minoritized groups. Except for demographics, there are no available survey data prior to 2016.

3.3 Orientation

During the first day of the program, undergraduates attend a full day orientation, where they learn details

Project Titles
Fabrication and Metrology of Nanophotonic Structures
Synthesis & Characterization of foam-like Hexagonal Boron Nitride
The Characterization of Thermal Conductivity of Metal Nanoparticles
Atomic Layer Deposition and Etching of Alumina
Growth Optimization of Transition Metal Disulfides
Local Photoelastic Stress Mapping for Dynamic Roll-to-Roll Metrology
Directed Self-Assembly of nm-scale Gold Catalyst Using Block
Modeling and Simulation of Roll-To-Roll Nanoimprint Lithography Tool

Table 1. Titles of 2019 REU projects

about the schedule, organization and expectations of the summer program. Mentors introduce the research projects; participants conduct lab safety training, tools and cleanroom training. Students participate in icebreaker and teambuilding activities to model some of the skills that might be useful in the research labs, such as communication and collaboration. Lastly, students take a short tour of the campus and pick up their ID cards.

3.4 Programmatic Experience

REU participants are expected to work on their projects in the lab daily, performing original research under the supervision of their graduate mentor, reading reference material and maintaining a laboratory notebook. They also participate in seminars, bi-weekly meetings and presentations. Seminar topics include design of experiments, research modeling, simulation and data collection, entrepreneurship, and navigating graduate school opportunities and applications.

Bi-weekly check-in meetings with program staff are formal meetings to discuss participants' experiences and their progress. During the check-in meeting, participants share problems encountered during their research, and technical or personal challenges experienced. The goal is to support REU participants and help them get the best possible experience, improving their research knowledge, skills and confidence, developing their presentation skills and encouraging their future career development. In particular, the first check-in meetings are very useful to identify the synergy of the group and how integrated or isolated an individual student feels, allowing intervention when necessary. REU participants also hold bi-weekly presentations in front of faculty members and other REU participants. During the presentation, the audience asks questions to challenge and engage students.

REU students participate in two poster symposia and one final presentation on the last day of the program to present the final results of their project. Throughout the summer, social activities are organized to help create a sense of community among the cohort's members.

3.5 Data Collection

Pre- and post- surveys were administered to each cohort. The surveys have been modified from the Berkeley Engineering Research Experiences for Teachers (BERET) Program (2015) and identity scales previously tested on engineering students (Choe & Borrego, 2020; Patrick et al., 2018) were added in 2019.

Surveys were sent and submitted through Qualtrics™. Responses from pre- and post-surveys of the 2016 to 2019 cohorts were analyzed. The surveys were kept fairly consistent over time, containing between 15 and 57 questions in various formats including:

- 3-, 4- and 5-point agreement and satisfaction Likert-type scales.
- Side-by-side and multiple-choice questions.
- Open-ended text entry.

An IRB protocol allows for data analysis and publication.

3.6 Instruments and Data Analysis

The analysis of the surveys included both quantitative and qualitative data and methods. Due to small numbers in each cohort, we intentionally did not analyze results based on gender or race/ethnicity, to protect the identities of participants.

To answer research question 1, how, if at all, students' self-confidence in their research-related skills changed from the beginning to the end of the REU, respondents were asked to self-report their confidence on a 5-point Likert-type scale ranging from 1=Extremely Unconfident to 5=Extremely Confident. Occasionally, between survey years, the anchors for scales measuring the same construct varied. During data cleaning, all variables were rescaled to a 5-point Likert-type scale.

The mean of pre- and post- surveys responses have been compared using a nonparametric unpaired t-test, the Mann-Whitney test, on Stata (Yatani, 2018). The Mann-Whitney test has been chosen because of the small sample size and the need to treat pre- and post-survey responses as two separate samples, in order to account for the sample's variation. Statistical significance has been reported, including the Bonferroni adjustment's correction of the p-value, to account for increased Type I error in multiple comparisons. In this study, the Bonferroni critical value is 0.0027, calculated by dividing $p=0.05$ by the number of tests (18). Answers from open-ended questions provided an additional layer of qualitative data, confirming the findings from our statistical analysis.

To answer research question 2, in what ways the REU influenced students' attitudes towards graduate school, the analysis and summary of open-ended questions have been reported. To measure changes in the number of respondents who are interested in graduate school, only participants who mentioned graduate school in their open responses were reported. Additionally, post-survey text entries have been analyzed and coded in four categories concerning the impact of the program on their decision to attend graduate school. Some participants were included in multiple categories. There were qualitative survey items only about graduate school intention.

In February 2020, a follow up survey was sent to all REU participants to update their current school or employment status. Because of low response rate, the survey responses were complemented with an Internet search of former REU participants' LinkedIn profiles.

To answer research question 3, concerning the strength of the students' engineering and research identities by the end of the REU, and how they compare to published values, existing and adapted measures were used. For engineering identity, the authors used a scale developed by Borrego and colleagues (2018). Participants were asked to report their answers on a scale of 1=Far Apart to 8=Complete Overlap between their identity and that of an engineer. The mean and standard deviation have been reported. The mean of pre- and post- surveys were compared using the Mann-Whitney test and effect size has been reported (Cohen, 1992; Fritz et al., 2012; Yatani, 2018).

Measures of research identity, including the components of performance/competence, interest and recognition/identification were adapted from surveys developed and tested on engineering graduate students in three engineering disciplines (Choe & Borrego, 2020). Adaptation was informed by interviews conducted with the 2019 cohort. In the post-survey of the most recent cohort, participants were asked to rate their competence and agreement on a 5-point Likert-type scale ranging from 1=Strongly Disagree/ Not Capable to 5=Strongly Agree/ Highly Capable. Since we only report post-REU data for our participants, we provide comparison values from published data when available to provide context.

4. Results

4.1 Research Question 1: How, if at all, did students' self-confidence in their research-related skills change from the beginning to the end of the REU?

Table 2 presents pre- and post- survey results concerning self-reported research skills. The data show an overall improvement in most measures of students' self-confidence in their lab skills with statistically significant gains (based on the Bonferroni adjusted p-value). "Designing my own research" ($p \leq 0.0027$) and "Using tools in the lab" ($p \leq 0.0027$) show statistically significant improvements, reflecting the emphasis placed on providing a daily laboratory practice to the undergraduate students. "Understanding the theory/concepts guiding my summer research" ($p \leq 0.0027$) and "Understanding the relevance of my research to real world applications" ($p \leq 0.0027$) significantly increased, suggesting that the program successfully exposed students to the various opportunities that STEM has to offer and to connect the research projects to real world application, in order to give participants a greater sense of the relevance of these skills.

When asked to list two accomplishments achieved during the summer, participants mentioned increased confidence and deeper appreciation for scientific research. One participant said, "I expect research to continue to be a part of my life/career long term" (2019); and another reported, "I gained a better understanding of what it is like to troubleshoot a system. I gained a better understanding of how to deal with unexpected problems in research" (2019).

When asked about accomplishments, one REU student summarized the research-related skills and content

Rate your skill level for the following activities	All Cohorts (2016-2019)	
	Pre (n=23)	Post (n=24)
Observing research in the lab	3.63	4.34*
Understanding guest lecturers' content	3.72	4.18
Working as a member of a research team	3.78	4.45*
Designing my own research	2.70	3.91***
Using tools in the lab	2.92	4.21***
Collecting data	3.74	4.51*
Analyzing data	3.78	4.03
Presenting results of my data	3.70	4.29
Understanding the theory/concepts guiding my summer research	3.15	4.32***
Understanding the relevance of my research to real world applications	3.45	4.57***
Writing scientific reports	3.57	3.54
Preparing a scientific poster	3.37	4.33**
Using statistics to analyze data	3.56	3.86
Understanding scientific journal articles	3.74	4.13
Speaking to/with professors	3.95	4.01
Your knowledge of research/engineering/careers	3.55	4.22*
Managing my time	4.25	4.44
Problem solving in the lab	3.87	4.00

*$p \leq 0.05$
** $p \leq 0.01$
*** Bonferroni adjusted $p=0.05/18 \leq 0.0027$

Table 2. REU survey, skills confidence

knowledge gained as well as the impact of the program on their achievements and understanding/appreciation for the unanticipated difficulties that scientific research comprise by saying,

> "I was able to use tools inside and outside the clean room by myself. I am coming out knowing much more of the concepts and applications behind metasurfaces in general (I also now appreciate optics whereas I had rather disliked it before). This was my first time doing research in a laboratory or clean room, and I now have a grasp of what it is like to participate in experimental research. There were difficulties and maintenance issues that were not anticipated, and one had to troubleshoot and hope for the best as he went along" (2017).

4.2 Research Question 2: In what ways did the REU influence students' attitudes towards graduate school?

In the pre-surveys, participants were asked to answer the open-ended question "How may the summer experience impact your decision to attend graduate school?" In the post-surveys, participants answered the open-ended question "How did the summer experience impact your decision about graduate school?" Respondents were at various stages of their undergraduate degree, ranging from sophomores to seniors.

Among the participants who explicitly mentioned graduate school in their pre-survey response, 12 respondents described their intention to apply to graduate school while three said that they are considering it. In the post-surveys, 20 respondents answered that they will apply to graduate school and one respondent mentioned that they are considering it.

Table 3 reports the analysis of the post-survey responses to the open-ended question "How did the summer experience impact your decision about graduate school?" for all four cohorts. Four categories were coded and entries for each category were counted; multiple preferences have been reported for some participants. The majority of respondents reported that the summer experience reaffirmed the decision to attend graduate school by increasing awareness of research opportunities, comfort and confidence in research skills, as stated by one of the participants in the quote below,

> "This experience made me a lot more comfortable with the idea of graduate school. It made me confident that I can do research on my own if I were to have to. I also really liked what I was doing research in this summer and hope to continue working in the field in the future" (2017).

Participants reported that the REU program broadened their view in terms of the major that they are considering or the kind of degree (master's or PhD) they would like to pursue. For example, one student stated, "I was already planning on applying to graduate school, but this summer experience has somewhat tailored what I plan on studying. At first, I was only planning on polymer/computational science fields, but now I am also interested in nanomaterials and their applications" (2016). Another student reported, "Before the program, I was unsure if I wanted to get a master's degree or a Ph.D. I am now confident that I want to get a Ph.D. in Computer Engineering" (2017). These data seem to indicate that the REU program broadened awareness among participants about the various opportunities available both in terms of degrees and majors.

Also, reported in Table 3, two participants felt that the program allowed them to experience what they termed "graduate life," and three students reported that the experience was important in convincing them to attend graduate school. Three participants, undecided about graduate school, reported that the program was among the factors to convince them to move forward towards a graduate degree. This analysis suggests that the REU program and the experience that students acquired working with graduates and faculty members contributed in finalizing their decision to attend graduate school.

Among 27 REU participants from all cohorts (2013-2019) who responded to our follow-up survey or who had a public LinkedIn profile, 14 are working toward a graduate degree, 9 work in industry, and 4 are still enrolled in an undergraduate program.

4.3 Research Question 3: How strong are the students' engineering and research identity by the end of the REU, and how do these identities compare to published values?

In 2019, identity scales were piloted on the REU surveys. In terms of overall engineering identity, the participants' means went from 5.10 (n=5 in the pre-survey) to 6.07 (n=9 in the post-survey) on an 8-point scale (Borrego, Patrick, et al., 2018). Although the values suggest an overall improvement, comparisons between pre- and post-surveys were not statistically significant. The p-value was 0.3173 and the effect size was calculated as 0.19 (i.e., small, Yatani, 2108). For comparison, using the same scale, mechanical engineering undergraduate students at an HSI had a mean engineering identity of 5.74 (Kendall et al., 2019), and students in four engineering majors at two institutions had a mean engineering identity of 5.21

Impact of the summer experience on the participants' decision to attend graduate school	All Cohorts (2016-2019) Post surveys (21)
More confident/ reinforce decision about graduate school	10
Broadening view/clarifying major or degree	7
Introduce to graduate life	2
Convinced to apply to graduate school	3

Multiple preferences have been reported for some participants

Table 3. Impact of the summer experience on the decision to apply to graduate school

(Choe et al., 2019).

Research identity scales were also piloted in 2019. Items were adapted from surveys developed and tested on engineering graduate students (Choe & Borrego, 2020).

Table 4 lists the items and reports mean and standard deviation of responses concerning research identity as well as its three components research performance/competence, research interest, and research recognition. The mean values ranging from 3.90 to 4.39 correspond to agree or strongly agree with the statements. Using different items, the corresponding mean values for engineering graduate students are research identity (Mean=3.78, SD=0.92) (Choe et al., 2017), research performance/competence (Mean=3.88 SD=0.69) (Choe & Borrego, 2020), research interest (Mean=3.91 SD=0.89) (Choe et al., 2017), research interest (Mean=4.16 SD=0.81) (Choe & Borrego, 2020), and research recognition (Mean=4.05 SD=0.73) (Choe & Borrego, 2020). Although direct comparison between this study and published results is not possible due to item adaptation informed by interviews of the 2019 cohort, the results are promising in terms of these REU students developing research identities comparable in strength to those of current graduate students. Given that identity has been linked to retention in engineering degree programs, these identity results suggest that REU participants are developing attitudes toward engineering and research that will serve them well in graduate school. Cronbach's alpha was calculated for internal consistency as shown in Table 4. Cronbach's alphas ranged from 0.67 to 0.9, above the minimally acceptable range of Cronbach's alpha values (DeVellis, 2016).

Factor	Items	2019 Post-survey (n=9)		
		Mean	SD	Alpha
Research Identity (To what extent do you agree)	• I consider myself a researcher • Being a researcher is an important part of who I am • I am proud to be a researcher • I feel strong ties to other researchers in my discipline	4.00	0.50	0.70
Research Performance/Competence (To what extent do you feel capable of)	• Understand contemporary concepts in your field • Make use of primary scientific literature in your field (e.g., journal articles) • Identify a specific question for investigation based on the research in your field • Formulate a research hypothesis based on a specific question • Design an experiment or theoretical test of the hypothesis • Understand the importance of "controls" in research • Observe and collect data • Statistically analyze data • Interpret data by relating results to the original hypothesis • Reformulate your original research hypothesis (as appropriate) • Relate results to the "bigger picture" in your field • Orally communicate the results of the research projects • Write a research paper for publication	3.90	0.41	0.77
Research Interest (To what extent do you agree)	• I am interested in my research topic • My current research topic aligns with my research interest • I feel good when I am doing research • I think research is fun • I think research is interesting	4.39	0.40	0.67
Research Recognition (To what extent do you agree)	• Other students in my program see me as a researcher • My friends see me as a researcher • My peers see me as a researcher • My family sees me as a researcher • My mentor sees me as a researcher • My professor sees me as a researcher	3.96	0.21	0.91

1=Strongly disagree to 5=Strongly agree or 1=Not capable to 5=highly capable

Table 4. REU 2019 research interest/recognition

5. Discussion

This study provides answers to three research questions concerning the influence of the REU program on participants' self-reported research skills, interest in graduate school, and engineering and research identities. The analysis is based on longitudinal data across four cohorts, providing additional support to the existing literature in this field.

To answer research question 1, the analysis of pre- and post-survey responses to a set of statements concerning research-related skills was performed. The data show an improvement on the overall self-reported skills with statistical significance (Bonferroni adjusted p-value) for four items reported in Table 2. These items can be grouped as gains in laboratory skills and understanding project relevance. These findings are consistent with the main goals of the program. A substantial amount of time and effort was spent during the summer in promoting laboratory skills, through daily practice and support from graduate mentors and faculty. Mentor training was used to emphasize theory and relevance of the research projects, connecting them to real world applications, to help participants see the "big picture." The statistical significance of the improvements across these items suggests that the program has been overall successful in improving research-related self-reported skills among participants.

The REU program's findings related to research skills are in line with prior research (Lopatto, 2003; Seymour et al., 2004). Lopatto (2003) surveyed 384 science undergraduate students working on summer research programs at four liberal arts colleges. The results showed that "Learning laboratory techniques" and "Understanding the research process" were among the highest rated benefits together with personal development items, like "Readiness for more demanding research" and "Tolerance for obstacles." Seymour et al. (2004) found a similar pattern analyzing the results of 76 interviews with students participating in undergraduate research experiences at the same four sites examined by Lopatto (2003).

To address research question 2, the analysis of open-ended responses to a question about the impact of the summer program on the decision to apply to graduate school is reported. The analysis of post-survey responses showed that 20 participants declared plans to apply to graduate school, mentioning the impact that the program has had on this decision, either increasing self-confidence or reinforcing a decision already in place. This finding is consistent with the literature. For example, Lopatto (2004) found that out of 1,107 respondents almost 91% reported that the experience maintained or increased students' interest in pursuing a graduate degree. In open-ended survey items studied in this paper, five of the respondents also reported that the program played an important role in experiencing "graduate life" or in removing previous doubts about graduate school application.

To answer question 3, the authors reported pilot results for the 2019 cohort using an existing engineering identity scale and adapted research identity scales. The analysis suggests that the program may have improved students' engineering identity, although not in a statistically significant manner. Research identity items adapted from studies of engineering graduate students need to be tested and refined more thoroughly, but initial results indicate comparable research identity, research performance/competence, research interest, and research recognition to graduate students by the sophomores and juniors upon completion of this REU program. Since studies have shown a positive correlation between engineering identity and retention in engineering at the undergraduate level and between engineering and research identity and the decision to pursue graduate study, this is an important area that will be further investigated in the future. Importantly, this study pilots research identity items with an undergraduate sample.

This program offered opportunities to students from backgrounds traditionally underrepresented in STEM, fostered self-confidence in participants' ability to perform scientific research and to obtain a graduate degree, and increased awareness of engineering career opportunities. In the seven years from 2013 to 2019 that NASCENT has run the program, it welcomed 62 students, 46% women, and 29% students from minority groups. Moreover, it created recruitment channels and long-lasting relations between MSIs and the host institution.

6. Limitations

Survey items related to students' engineering/research identity were added in 2019 but were not present in previous years resulting in the sample size being too small for factor analysis. Longitudinal data around engineering/research identity could have provided additional support to answer the third research question.

A follow-up survey was sent annually to former REU participants to verify their career path, but a more thorough investigation of participants' career trajectory after the REU experience, including interviews and focus groups, could enlighten the long-term impact of such programs.

7. Conclusion

The strength of this program lies in its effectiveness in promoting graduate school opportunities by fully exposing undergraduates to "graduate life" and allowing them to play an important role in a research team. Moreover, the supporting activities, such as seminars, check-in meetings, social and team building events, contribute in making this an enriching experience, where participants learn scientific and other foundational skills applicable to their future careers. By prioritizing students from backgrounds traditionally underrepresented in STEM, this program has an impact on broadening participation. Furthermore, the program established a strong and long-lasting relationship between different types of institutions, most importantly those not offering PhD degrees in the target STEM disciplines.

As evidenced by the positive student feedback and by the career path that the majority has chosen, this program is a strong and successful model.

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