Building Research Self-efficacy in Undergraduate Students through Authentic Research Experiences

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The Natural Hazards Engineering Research Infrastructure (NHERI) - Research Experiences for Undergraduates (REU) Program, funded by the National Science Foundation (NSF), provides research experiences for a diverse group of college students interested in mitigating the effects of natural hazards. The program engages in targeted recruitment for underrepresented students in engineering including women, first-generation college students, students who may not have research opportunities at their home universities, and members of racial and ethnic minority groups. The program structure and activities are designed to prepare undergraduates for research work with the ultimate goal of retaining students in science, technology, engineering, and math fields as well as preparing them for graduate school. This evidence-based paper demonstrates an effective hybrid-model (virtual and in-person) research program for undergraduate students over a five-year period across a network of eleven (11) sites within the continental U.S. Through mixed methods research, a longitudinal case study shows evidence of 100% retention of the *105 REU alumni in the engineering and STEM field; 9% of the REU alumni are enrolled in an engineering PhD program; and diversity measures include participation from 53% females, and 25% first-generation college student participation as well as 30% Black and Hispanic students.

The NHERI-REU Program also collects qualitative and quantitative data on the progress of students' preparation of scholarly work including their self-efficacy and confidence levels throughout the program. This paper will include quantitative pre- and post-program data to show students' increased confidence and levels of self-efficacy.

An important element of the program is the multiple points of support for students. These supports include faculty, graduate students, peer, and program mentors. The structure of the support system and the community building activities throughout the REU program also include career development workshops, a NHERI faculty and professional panel, and a diversity, equity, and inclusion (DEI) reflective session. The peer support is extended at the end of the REU experience, as students come together at one of the network sites to present their research and posters via virtual and in-person means; they also tour the facilities to learn more about the various aspects of research outside of their assigned REU site. Overall, students show an increase in the research skills gained throughout the REU program. The students are monitored longitudinally to learn more about their career paths after they exit the REU program.

Background

There continues to be a great need to encourage and prepare a diverse group of undergraduate engineering students to persist in their degree programs and, ultimately, continue on pathways to academia. This is especially important due to the challenging societal issues requiring diverse perspectives [1]. Special groups that continue to be disproportionately included in engineering pathways include women and members of underrepresented racial and ethnic minority groups. Undergraduate research experiences increase the likelihood of engineering students attending graduate school. Through critical funding from the National Science Foundation (NSF), research opportunities can be offered to students, which can target engineering undergraduates from underrepresented backgrounds as well as those from universities with few research offerings.

The Research Experiences for Undergraduate (REU) is a mechanism to provide these opportunities to students.

To help better prepare students for work in the academy, self-efficacy [2] plays an important role in determining their confidence to carry out research. This means that students must have positive perceptions of their abilities and capabilities in order to achieve success within the REU program. Self-efficacy also includes recovering from challenges and perceived failure in order to learn and improve in their capabilities and confidence. Overcoming these challenges is key to helping students grow in their self-efficacy around research activities such as preparing and presenting research forums and poster sessions, working with experienced faculty to conduct research, and integrating as a member of the research community.

This paper presents research results of research growing self-efficacy of undergraduate students through authentic research experiences. The purpose of the work is to present innovative ways to incorporate educational best practices to help encourage and prepare more students as well as diverse groups of students to continue in engineering pathways that lead to academia with improved self-efficacy.

Self-Efficacy in Research

Building self-efficacy for students engaged in research is imperative to the success of the NHERI-REU program as it continues to support underrepresented groups pathways to STEM careers. Bandura [3] defines self-efficacy as an individual's confidence that their actions affect an outcome, and the perception that one is capable of reaching a desired outcome [4]. In the NHERI-REU program, self-efficacy in research underscores a student's ability to decipher journal articles, use research tools to better understand the topic and conduct experiments, explain their research to less experienced individuals, and effectively report on research. The literature suggests, however, that individuals develop varying levels of self-efficacy even within the same learning context [5]. According to several studies, research self-efficacy mediates participants research experience and commitment to a STEM career ([6] [7]). Other studies suggested that increased self-efficacy is critical to continued persistence in STEM ([8]; [9]). According to Hong and Page [1], mastery experiences (i.e., apprenticeships) are the most effective way to strengthen self-efficacy followed by vicarious experiences (i.e., modeling), social persuasion (i.e., verbal praise), and a relaxed state that supports individuals as they reconcile prior knowledge with new knowledge. Considering these conclusions, it is relevant to understand how the NHERI-REU experience impacted participant's self-efficacy in research to continue to improve the program and support diversity within STEM fields.

Literature analyzing REU experiences also provide suggestions for improving research self-efficacy that align with the suggestions from Bandura [2] including modeling, mentoring, persuasion of the importance of research, small research successes in context, working with a community to increase research knowledge and proficiency, and situated research experiences. Berkes and Hogrebe [10] found that self-efficacy in science is correlated with conducting research and providing content and experiences appropriate for undergraduates in personal mastery. In addition, [11] and [12], the use of both implicit and explicit methods results in increased participant self-efficacy compared to implicit instruction alone. Based on this

groundwork, the NHERI-REU program uses both implicit and explicit methods of apprenticeship (i.e., conducting research side by side with a mentor) and instruction (i.e., specific guided instruction on research and writing) to scaffold participant self-efficacy.

The Natural Hazards Engineering Research Infrastructure – Research Experiences for Undergraduates Program (NHERI-REU)

The NHERI-REU is a ten-week, full-time summer research experience for undergraduate students aimed at fostering research self-efficacy through mentoring, community building, and research skills development. The program is part of a broad network of natural hazards engineering and research sites and is organized by representatives from each of these sites. Students are recruited broadly and apply online to be considered for the program. Through a holistic review process, three students are selected to participate at each of the eleven NHERI sites which specialize in various natural hazards engineering and research fields including tsunami and coastal engineering, wind engineering, earthquake engineering, rapid reconnaissance, computational modeling and simulation, and social science research of natural hazards.

Across the eleven sites, NHERI-REU students receive an asynchronous virtual orientation to the summer program via Zoom and are presented with the support networks available to them throughout their research including an educational specialist, their peers at their site and at other sites, an experienced faculty mentor, and a graduate student mentor. Throughout the summer, students meet weekly with the educational specialist to discuss research topics and report their research progress and challenges. During this time, they practice "elevator speeches" that highlight their research work and help them learn how to dialogue about their research. Students also join interactive workshops to prepare their CVs and resumes, personal statements for graduate school, and cover letters for employment and graduate programs. A panel of natural hazards engineering professionals also answer students' questions about the preparation for graduate school and careers as well as orient students to the many pathways to academia and the profession of natural hazards engineering.

Students conduct research at their assigned sites throughout the ten weeks. At the end of the program, all students come together at one site to tour the NHERI facility, present their final research findings, and network with their peers and faculty mentors. Presentations are delivered in a hybrid format for virtually and in-person audience members and poster sessions are held for those who are able to attend in person.

Methodology

Throughout the NHERI-REU program, a case study research design [13] was employed to collect data. Given that students participated in a ten-week summer program, the case was bound by time. Additional longitudinal data were also collected to determine lasting outcomes of the research experience. These data were purposefully collected annually beginning one year after the students participated in the REU program. Because the data were collected to learn about the in-depth and evolving experiences and research self-confidence throughout the summer, it is

important to note that each type of data was purposefully collected to learn more about the case study.

TABLE I
DATA COLLECTED FOR CASE STUDY ANALYSIS

Data Collected (In order collected)	**Description**
Pre-assessment	Baseline for attitudes towards research, career goals, interest in PhD, experience and confidence conducting research activities.
*One-on-one Student Meetings	Informal meeting to identify student's personal summer goals, career goals, engineer & scientist identity, desired personal impact
Weekly Guided Reflections	***Qualitative information about experiences, guided by weekly events. Students' challenges and lessons learned identified.***
Student Engagement	Attendance of weekly meetings and workshops. Participation and observations of students' engagement.
Weekly Deliverables	Portions of the research paper, group lesson plan, peer review feedback, research poster, PowerPoint presentation, resume or curriculum vita, personal statement, and final paper
**Focus Group	All-inclusive group feedback about aspects of the program, including travel, site experience, mentor experience, presentation preparation, research meetings, and recommendations for improvement
Post-assessment	Comparison for post attitudes towards research, career goals, interest in PhD, experience and confidence conducting research activities
Longitudinal Survey	Assesses students' career trajectories, research activity, and future goals

*One-on-one student meetings were added after Year 2.

**The focus group data were collected in person while all other data were collected virtually via Zoom, Moodle, email, and Qualtrics.

After data collection, the quantitative data from pre- and post-assessments were compared for impact and gains or losses of important success indicators in students' targeted development, including students' self-efficacy in research tasks.

REU Participant Demographics

Students participating in the NHERI-REU summer program came from diverse backgrounds including race and ethnicity, gender identities, first-generation college status, and veteran status. As can be seen in Table II, the REU participant racial and ethnic demographics include 19% Hispanic, 13% Black, and 12% multiracial. In terms of gender, REU participants self-identify as 53% female and 47% male. Of the total participants, 25% have been the first in their family to attend a 4-year college.

TABLE II
REU PARTICIPANT DEMOGRAPHICS

Cohorts		2017 (n=17)	2018 (n=29)	2019 (n = 31)	2021 (n=28)	Total (N=105)
Race	American Indian or Alaskan Native	0%	3%	0%	0%	1%
	Asian	29%	10%	13%	7%	12%
	Black	18%	13%	7%	11%	13%
	Hispanic	12%	3%	29%	29%	19%
	Multiracial	6%	16%	6%	21%	12%
	Native Hawaiian or Pacific Islander	0%	3%	0%	0%	1%
	White	24%	52%	45%	32%	40%
	Not reported	11%	-	-	-	2%
Gender	Female	47%	52%	39%	50%	53%
	Male	53%	48%	61%	50%	47%
First-Generation Status	First-Generation	41%	19%	19%	29%	25%
	Not first-generation	47%	81%	78%	71%	73%
	Not reported	12%	0%	3%	0%	2%
Veteran Status	Veteran	5.9%	3%	0%	4%	~3%

Quantitative Pre- and Post-assessment Results

In order to understand the development of research self-efficacy in NHERI-REU participants, a pre- and post- assessment was administered. A paired-samples t-test was used to determine whether there was a statistically significant mean difference between the pre and post research self-efficacy of REU participants. While outliers were detected (question pairs 1,5, 11, 13, and 20) that were more than 1.5 box-lengths from the edge of the box in a boxplot, inspection of their values did not reveal them to be extreme, and they were kept in the analysis. Since there were more than 50 participants, the Normal Q-Q lot method was used to analyze and demonstrate that the difference score between question pairs was approximately normally distributed for all questions. Further, paired samples t-test have been found to be robust to normality violations [14]. Based on the pre-post data as seen in Table III, undergraduates who participated in the NHERI REU program demonstrated a statistically significant increase in difference of research self-efficacy from their pre- to post-assessment with a large effect size for all but Q4 and Q22 which were medium effect size [15]. The effect size (Cohens *d*) can be interpreted on a range: small ($d = 0.2$), medium ($d = 0.5$), and large ($d = 0.8$) [15].

TABLE III
RESEARCH SELF-EFFICACY QUESTIONS AND RESULTS

Question	Mean	Standard Deviation	t	df	Sig.	Cohens d
Q1:How much experience do you have engaging in real-world, hands-on engineering research?	1.515	1.289	11.699	98	.000	1.18
Q3:How much experience do you have understanding the theory and concepts guiding a research project?	1.131	1.131	9.955	98	.000	1.00
Q4:How much experience do you have understanding the relevance of research to your coursework?	.899	1.298	6.894	98	.000	.69
Q5: How much experience do you have understanding what everyday research work is like?	1.606	1.300	12.292	98	.000	1.24
Q7: How much experience do you have understanding research journal articles?	1.051	1.128	9.264	98	.000	.93
Q9: How much experience do you have understanding professional data and research presentations?	1.010	1.153	8.672	97	.000	.88
Q10: How much experience do you have writing scientific reports and publishable papers?	1.194	1.265	9.340	97	.000	.94
Q11: How much experience do you have preparing a scientific poster?	1.561	1.385	11.157	97	.000	1.13
Q13: How much experience do you have explaining a research project to people outside the field?	1.340	1.189	11.099	96	.000	1.13
Q20: How much experience do you have collaborating on a research project with an experienced faculty mentor?	1.551	1.465	10.479	97	.000	1.01
Q22: How much experience do you have engaging in quality mentorship?	.990	1.556	6.295	97	.000	.64

Concluding Remarks

The goal of this research study was to present a case that exemplified positive gains towards self-efficacy development within research tasks for young engineering scholars, many of which were first-time undergraduate researchers.

Results point to the convergence of high levels of self-efficacy toward producing and presenting scholarly products as well as increased confidence levels in conducting research which were gained through the challenges and successes of authentic research experiences and supported at various levels throughout the duration of the ten-week program.

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