ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE
Paper ID #38311

Impacts of a Sustainability-Focused REU Site on Student Products and Career Trajectory for Underrepresented Groups in Engineering

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Abstract

This paper summarizes the overall approach and assessment of a National Science Foundation Research Experience for Undergraduates Site focused on sustainable civil and environmental infrastructure in rural areas. This site has hosted over 60 students over 5 years, including 1 year of virtual participation due to travel restrictions associated with the COVID-19 pandemic. Detailed discussion and results are provided with respect to the recruitment approach, including particular attention to first-generation college students, and the potential negative impacts of the COVID-19 pandemic on first-generation applicants. This site also incorporates targeted instruction on technical writing, which occurs over several weeks throughout the first half of the summer and culminates with a final conference paper deliverable. This approach has yielded over 20 peer-reviewed journal articles, conference papers, or national conference presentations, which have been co-authored by the undergraduate student participants. External evaluation of this site has included both formative and summative assessments, including pre-program, mid-program, and post-program surveys and focus groups, which has enabled a successful continuous improvement cycle, in which cohort-building activities, technical writing deliverables, and mentor training have been gradually incorporated or enhanced. Results of this assessment have also been used to quantify the site's success with respect to student exposure and interest in research and graduate education. In addition to most participants persisting in STEM fields, many have gone on to pursue graduate school in civil and environmental engineering and win national fellowships.

Introduction

Although rural areas comprise the majority of land area throughout the United States and are crucial to the fabric of life with their unique resources and food production capability, they are habitually underfunded from a research perspective. Rural areas, which contain approximately 20% of the US population (60 million people) and over 90% of the land area in the United States [1], are fundamental to human well-being in both rural and urban areas. Within the United States, low density rural areas, defined as regions with less than 25 people per square mile, provide resources such as the infrastructure for U.S. food and bioenergy production as well as the transportation infrastructure from inland urban centers to ports. Despite differences in the nature of civil infrastructure networks between rural and urban regions, little attention is paid to the unique challenges and opportunities for sustainability in rural areas.

In response to this broad research need, a National Science Foundation Research Experience for Undergraduates (REU) Site was established in 2017 focused on sustainability of rural horizontal civil infrastructure networks to provide 10-week summer research and professional development opportunities to undergraduate students. This REU site has three objectives: 1) Provide research experiences to undergraduate students with at least 60% of the program participants coming from colleges and universities with limited research opportunities, at least 50% coming from underrepresented groups in engineering (female and underrepresented minorities), and at least

40% first-generation college students; 2) Provide participants with first-hand exposure to the engineering and infrastructure challenges facing the rural United States through research and professional development opportunities in both academia and the civil engineering profession; and 3) Through undergraduate research experiences and sustained mentoring, promote and sustain the interest of undergraduate students in persisting in a STEM field and pursuing graduate education.

The 10-week summer program places 10 undergraduate students per year in faculty research groups for an independent research project. The primary focus of individual research projects is on sustainable rural infrastructure with emphasis in either: 1) environmental and water resources in rural and/or agricultural areas, or 2) structural, transportation, and geotechnical engineering research for sustainable rural infrastructure. Each student project is based on on-going fundamental research in faculty labs, but the student project is driven based on its own research question or objective to ensure an independent and fundamental research experience. The REU students are integrated into the research groups using a multi-mentor model [2], and with laddered layers of mentors including graduate students, postdoctoral research associates, and participating faculty to maximize student success. Strong integration into the research groups and a feeling of belonging have been shown to lead to strong levels of persistence in undergraduate research experiences [3]. In addition to being housed within individual faculty research labs, students receive weekly professional development to complement their experience and meet program objectives. Professional development focuses on student goal-setting, rural sustainability technical topics, and communication skills, including both written and oral skills for various types of audiences. This includes the development of individual development plans (IDPs), which assist each student in setting short-, intermediate- and long-term professional goals, defining the skills necessary to meet the goals, identifying opportunities for professional development as well as any gaps in skills [4]. IDPs are especially useful for minoritized students in STEM and first-generation students [5].

This paper describes the overall approach and lessons learned over five consecutive years of the summer research program. First, the approach to recruitment is described and assessed with respect to applicant pool and selected cohort demographics to evaluate success with respect to achieving the REU site objectives with respect to cohort diversity. This is followed by a detailed discussion on technical writing training, which has been incorporated into the professional development programmatic activities and has yielded broad success with respect to student-led publications and student satisfaction. Then, the approach to both formative and summative assessments is described, which has led to a cycle of continuous improvement of the program and key lessons learned. These assessments have also been used to quantify the success of the second and third site objectives focused on student exposure and interest in graduate STEM research – the results of which are summarized in the subsequent section.

Recruitment Approach and Cohort Demographics

Recruitment efforts for the REU site were led by the site organizers as well as the Office of Graduate Studies at the University of Nebraska-Lincoln. The Office of Graduate Studies oversees an umbrella summer research program, the Nebraska Summer Research Program, or SRP, encompassing most externally-funded summer research opportunities at the university.

Recruitment efforts led by the Office of Graduate Studies include sending SRP representatives to the following annual conferences: the Society for the Advancement of Chicanos/Hispanics and Native Americans in Science (SACNAS) annual conference; the Annual Biomedical Research Conference for Minority Student (ABRCMS), the Out in Science, Engineering, Technology and Mathematics (oSTEM) annual conference, and the California Forum for Diversity. Additionally, the Office of Graduate Studies conducts a direct email campaign to all faculty who serve as recommenders for past applicants to the SRP as well as to TRiO and McNair programs across the country. The REU site recruitment activities include sending program announcements through the American Society for Civil Engineers (ASCE) and Big10+ department chair listservs, advertising through professional organizations such as the Association of Environmental Engineering and Science Professors (AEESP) and by e-mail from each faculty mentor to their professional contacts. The REU site leaders also send a directed e-mail to the department of any former participants, encouraging additional students from that department to apply. The success of these recruitment strategies is provided in Figure 1, which indicates that the top three recruitment strategies are (1) learning about the program from a faculty member or advisor at the student's home institution; (2) web search; and (3) the National Science Foundation REU website. These data indicate the importance of faculty-student networking and a robust web presence in developing recruiting pathways for REU sites.

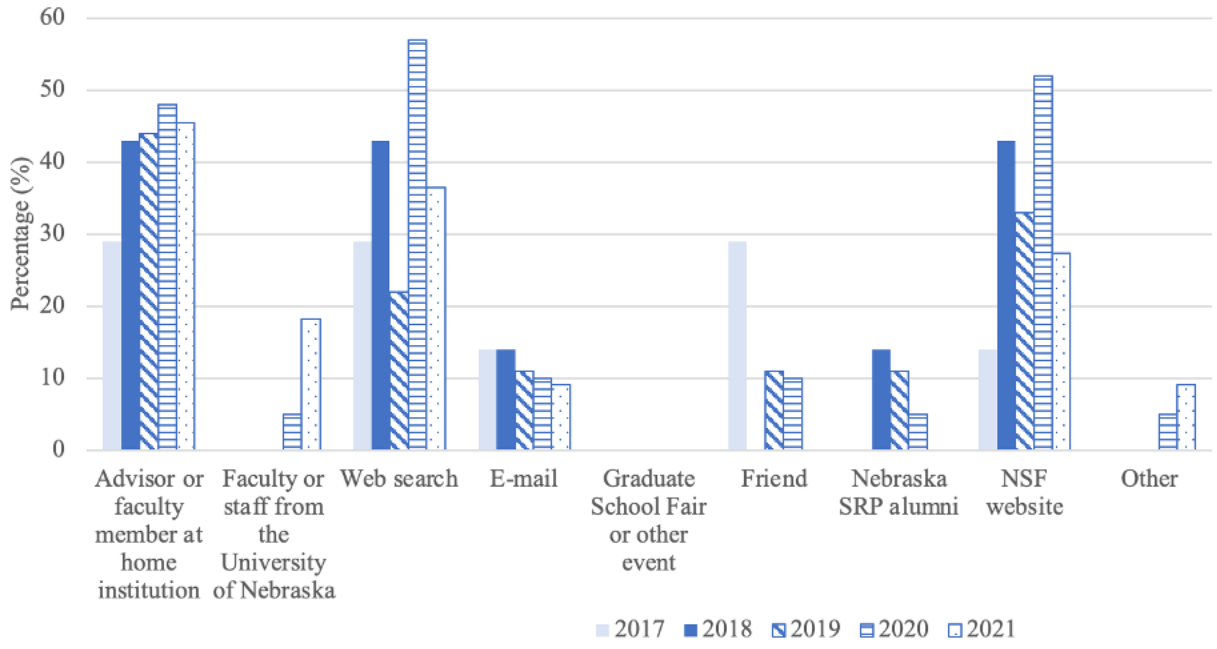

Figure 1. How REU Site participants learned about the program.

The REU Site applicant and admitted cohort demographics are provided in Table 1. The REU site has been selective with typically greater than 100 applicants per year applying for ten available positions (Table 1). Across the five years the site has been active, 555 students have applied for 63 available positions for an 11% acceptance rate.

The REU Site has largely met its goals for broadening participation of groups underrepresented in engineering, which include at least 60% of the program participants coming from colleges and

universities with limited research opportunities (defined as institutions without Ph.D. programs in Civil or Environmental Engineering), at least 50% coming from underrepresented groups in engineering (female and students underrepresented in STEM in terms of race and ethnicity), and at least 40% first-generation college students. Across the first five years of the REU site, 67% of participants are female, 38% identify as students underrepresented in STEM, 59% come from institutions with limited research opportunities and 27% are first generation students. One note with respect to applicant demographics is the potential impact of the COVID-19 pandemic on first-generation student applications. In the first three years of the in person REU Site, the percentage of applicants that were first-generation students ranted from 27.5% to 29.8%. In 2021, when we held a in person program, the percentage of applications from first-generation students dropped to 21.4%. We will continue to monitor the number of first-generation students applying to the program to determine if this drop in applications persists.

Table 1. Applicant and Admitted Cohort Demographics by Year

	2017		2018		2019		2020[1]		2021	
Demographics	Applied	Admitted	Applied	Admitted	Applied	Admitted	Applied	Admitted	Applied	Admitted
Total	109	9	114	10	133	12	59	21	140	11
Female	57	6	61	6	74	7	27	16	82	7
Male	52	3	53	4	61	5	31	5	55	4
Unspecified Gender	0	0	0	0	1	0	1	0	3	0
Asian	9	1	12	1	13	1	2	3	13	0
Black and African-American	13	1	10	1	24	1	8	2	15	1
Native American or Alaskan Native	0	0	0	0	8	1	1	1	5	0
Hispanic/Latino	22	2	3	3	20	4	17	2	30	4
Native Hawaiian or other Pacific Islander	0	0	0	0	2	0	1	1	0	0
Underrepresented Minority (URM)[2]	35	3	13	4	54	6	27	6	50	5
Multiracial	4	0	22	0	0	0	5	2	16	0
White	61	5	67	5	98	6	44	18	91	8
Limited Research Institution	44	5	43	5	61	9	32	9	45	9
First-generation student	30	3	34	5	38	3	42	42	30	2

[1]The 2020 REU Site was operated virtually due to the COVID-19 pandemic. [2]Underrepresented Minority (URM) includes students who identify as Black or African-American, Native American or Alaska Native, Hispanic/Latino and Native Hawaiian or other Pacific Islander.

Technical Writing Training

A key student outcome of the 10-week program is a development of a conference paper. The motivation for this student outcome is multi-faceted: 1) to introduce student participants to the scientific writing aspects of graduate-level research, 2) to provide student participants with a

tangible outcome of their research, 3) to motivate student participants for research excellence, and 4) to enable sustained mentorship of student participants after the conclusion of the 10-week program. To meet this outcome, a structured approach to technical writing training has been incorporated into weekly professional development meetings, as presented in Table 2. The training consists of both workshops, in which the program coordinators and faculty mentors introduce different sections of a scientific article and describe best practices to technical writing. This training begins with an introduction to scientific writing and authorship, in which students learn the overall structure of scientific article, norms of authorship, and the need for research dissemination. This is followed by weekly discussions on the different sections of an article, which are primarily front-loaded in the 10-week program to accommodate student projects at various stages.

Table 2. Typical timetable for technical writing training

	Workshop	**Deliverable**
Week 1	Intro to Scientific Writing & Authorship	
Week 2	Introduction & Literature Review	One-Page Summary
Week 4	Methodology	Introduction and Literature Review
Week 5	Analyzing Data and Writing Results	Methodology
Week 6		
Week 7	Summarizing Findings	Results
Week 8		Analysis and Discussion
Week 9		Conclusions and Draft Paper
Week 10		Final Paper

Student participants prepare different sections of their conference paper in a staggered approach throughout the course of the summer, both to distribute the workload and to align with the actual conduct of their research. The first deliverable is due by the end of the second week, which is a one-page summary of the research to allow the students to articulate the background, motivation, and approach to their project. This provides an opportunity for students to practice describing research in their own words and to identify if they are not able to see the bigger picture. In addition, faculty and graduate student mentors can begin providing feedback to student participants in terms of their technical writing style. In later weeks, students prepare draft introduction (literature review), methods, results, analysis/discussion, and conclusions sections. Within one week, students should receive feedback on their writing from their mentor team so that they can revise in preparation for the full draft paper (due by the end of the ninth week of the program). Since students have largely concluded their projects by the tenth week of the program, students also peer-review each other's draft papers in addition to gaining feedback from their mentor team. This enables each student to complete a "final" paper by the last day of the program incorporating detailed discipline-specific feedback from their mentors and general writing and clarity feedback from their peers.

While each student departs the program with a "final" conference paper, conference submissions do not necessarily line up with the summer program. This enables an opportunity for sustained mentorship of students as abstracts and/or papers are oftentimes revised again to fit conference-specific guidelines. To encourage this, each student participant is guaranteed up to $500 to

partially cover conference participation costs should a student participant be the presenting author. The remainder of costs are typically offset by individual research projects, other student scholarships, and/or the student's home institution. This approach has been highly successful resulting in 3 journal articles or book chapters [6 - 8], 6 peer-reviewed conference proceedings [9 - 14], and 9 conference presentations [15 - 23] which have been co-authored by student participants since 2017.

Evaluation Approach and Continuous Improvement

Program evaluation was conducted by an external evaluator with the Methodology and Evaluation Research Core Facility at the University of Nebraska. Program evaluation was designed to monitor success of the program through formative and summative evaluation. Participating students completed an online baseline survey prior to beginning the summer program to measure their current level of understanding, confidence, and interest in research. At the conclusion of the summer program, participants completed the survey again to measure change. One year later, participants completed a follow-up survey to assess longer-term outcomes, including updates on publications and graduate school/career plans. The results of these surveys are presented in the following section focused on program outcomes.

In addition to gathering quantitative data from participating students, focus groups provided supplemental qualitative data. A mid-point focus group was conducted at the end of the third week each summer. An exit focus group was also conducted at the end of final week of the program. Faculty mentors were also interviewed to assess their perception of the program, including input on the student selection process, the program's day-to-day practices, administrative support for their efforts, interactions with their mentee, contributions made by their student, perceived utility of the program in meeting their goals, and to identify processes for improvement. These focus groups and interviews provided meaningful insight for continuous improvement of the program.

The mid-point (third week) focus groups allowed for improvements to the program while students were still present and to maximize student outcomes and experience. During these focus groups, students were queried regarding their likes and dislikes of the program, preparation for success, and experiences with their mentors. While large programmatic changes are not feasible based on the results, this routinely presented an opportunity to identify if there were any mentor-mentee issues arising that could be addressed. These issues typically arose due to miscommunications. Prompt attention during the first half of the program was able to lead to increased student satisfaction, as evaluated by comparison with exit focus group comments. Specific actions that were taken included encouraging faculty to hold at least a regular, weekly meeting with students so that they knew when to anticipate feedback. In addition, students and faculty were both encouraged to set expectations for communication.

While these actions were able to be implemented during the summer in which an issue arose, actions were also able to implemented for subsequent summers. For example, all faculty mentors were required to reach out to REU students 3-4 weeks before the program began. The intention was to set expectations for both faculty and students as well as to establish rapport. In this communication, faculty mentors include details on the student project, including a rough outline

of research tasks for the summer, and a handful of articles that can orient the students within the research area. Other pertinent information to help with student preparation were also included, such as recommended clothing to pack for field work and any online laboratory safety/training modules that would need to be completed right when they arrive. This initial communication is now routinely described during mid-point and exit focus groups as a major asset to helping them feel more prepared.

Impact of Program on Student Development

In the program's pre-program survey, student participants are asked about their expectations for what they will gain from participating in the REU site. In 2017 through 2019, the participants were unanimous (100%) agreement in their expectation to gain the following: ability to integrate theory into practice, friendships with peers, relationship with graduate students in the lab, skill in using laboratory equipment and tolerance for obstacles faced in the research process. In 2020, there was 100% agreement from participants in their expectation to gain skills in interpreting research results, presenting research to others, contributing to a research team, confidence as a researcher and tolerance for obstacles faced in the research process. In 2021, participants were unanimous in expecting to gain friendship with peers, ability to complete research independently, skill in contributing to a research team and skill in using laboratory equipment. These results indicate that REU participants expect to have both social (friendships with peers) and technical (teamwork, laboratory equipment, research skills) benefits from an REU site.

Results from the program assessment demonstrate positive impacts on participants skills as a scientist and familiarity with and plans to pursue graduate education. Participants were asked to raise their confidence with specific scientific skills on a five-point likert scale (5 = very confident, 1 = not at all confident). Results from the pre- and post-assessment from 2019 through 2021 indicate gains in a number of scientific skills (Figure 2). Results in 2017 and 2018 were not included in this analysis due to changes in the pre- and post-assessment surveys. In all three years, positive gains were found in participants' skills in writing an abstract, using the library and scientific databases, understanding research ethics, and preparing a paper for publication. The greatest gains across all three years were in preparing a paper for publication, which is one of the direct outcomes of the REU site. It is interesting to note that gains were observed at similar levels from both an in-person experience (2019 and 2021) and a virtual experience (2020).

Figure 3 presents the percentage of REU participants' plans for graduate study. Across all years, >48% of students report planning to pursue a masters degree. With the exception of 2020, between 60-80% of participants report planning to pursue a MS degree upon completion of the REU program. With the exception of 2017 when 0% of REU participants reported planning to pursue a doctoral degree, between 25 and 50% of REU participants plan to pursue a doctoral degree. In 2018 and 2019, more participants reported planning to pursue graduate study in the same discipline in which they conducted their summer research, while in 2017 and 2021, similar percentages reported planning to pursue graduate study in the same or different disciplines in which they conducted their summer research.

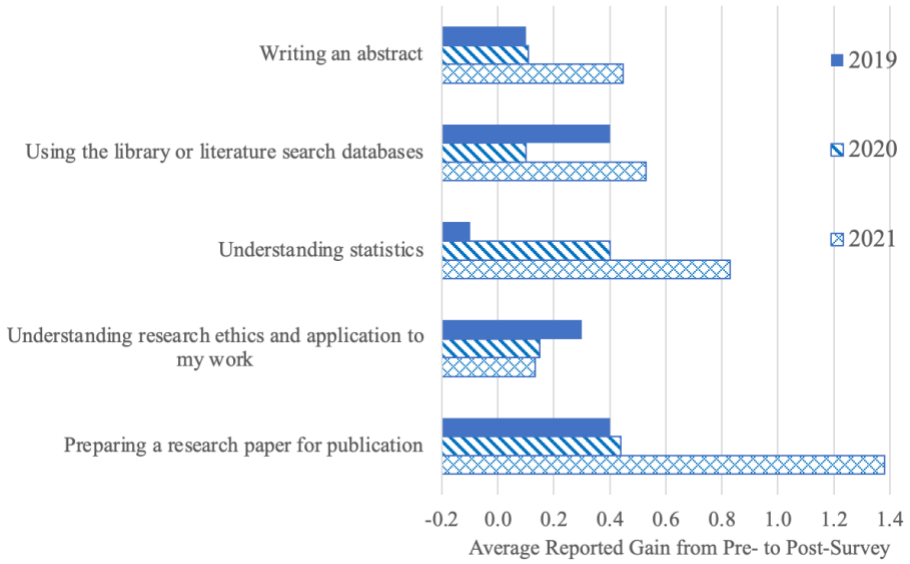

Figure 2. Gains in self-reported skills as a scientist.

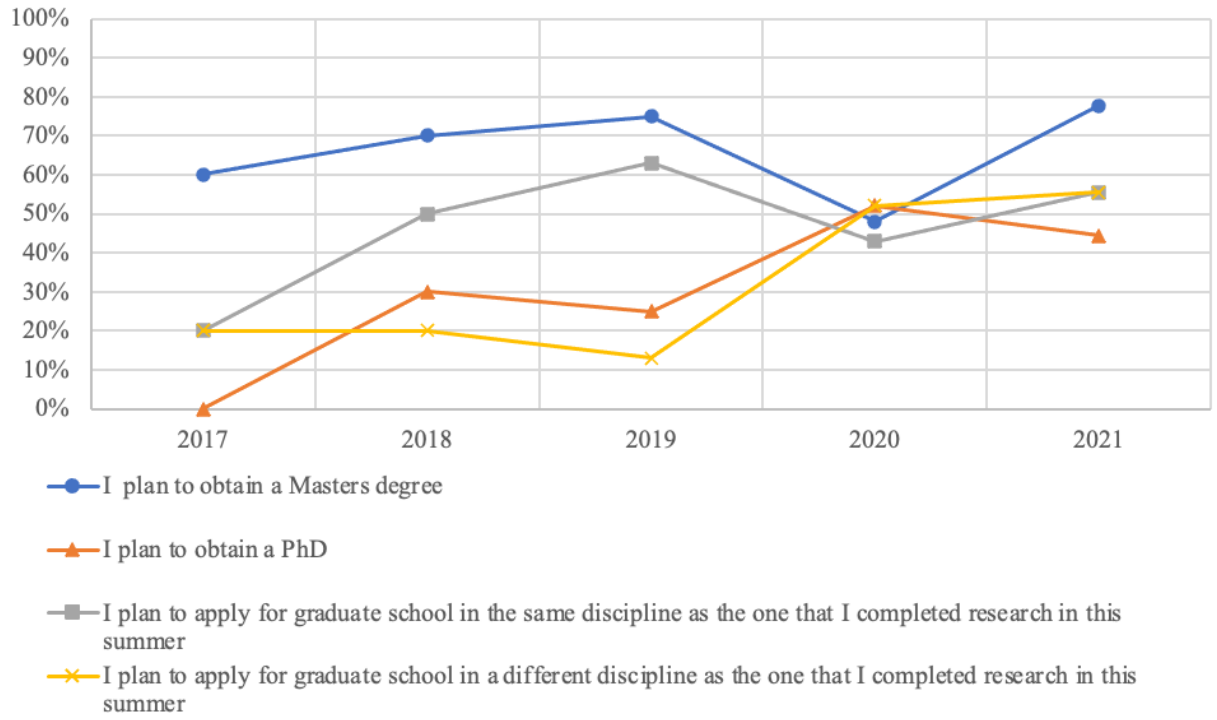

Figure 3. REU Participants reported plans for graduate study.

Conclusions

The REU site focused on sustainable rural infrastructure at the University of Nebraska has provided research training undergraduate student cohorts since 2017. The REU site is selective, with a recruitment strategy focusing primarily on faculty networks, outreach to faculty at prior applicant's home institutions as well as maintaining a strong web presence. Results from the participants self-reported gains in their skills as a scientist indicate that the professional development support provided for a major program deliverable, development of a conference paper, results in the largest gains from the pre- to post-survey in participants ability to produce a written research paper. This program outcome has also led to high levels of REU participants serving as co-authors and presenting authors for peer-reviewed journal papers and conference presentations.

Acknowledgments

The undergraduate research program described in this paper was supported by the National Science Foundation under award numbers EEC-1659601 and EEC-1950587 through the Research Experience for Undergraduates (REU) program. In addition, the authors would like to thank the faculty mentors, graduate student mentors, and student participants of this program for making it a success as well as the support of the University of Nebraska-Lincoln Office of Graduate Studies.

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