BOARD # 300: REU Site: Undergraduate Research Experiences on Resilient and Sustainable Infrastructure Systems in Smart Cities

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NSF REU Site: Undergraduate Research Experiences on Resilient and Sustainable Infrastructure Systems in Smart Cities

Abstract

The NSF Division of Engineering Education and Centers-funded REU Site was developed to bring a cohort of students to a large R-1 university to expose students to the critical role of civil and environmental engineers in serving society. Students participated in hands-on interdisciplinary research with faculty teams exploring innovations for Smart Cities. Associated cohort programming helped students to build basic research skills, to develop their career paths with emphasis on the preparation process for graduate studies, and to expose students to real-world applications of Smart City technologies. The program was designed and evaluated with a framework of social capital that posits that guided immersive research experiences are influential in converting student goals into actions. Students developed social capital related to career exploration and the research process through the relationships developed with their graduate student mentors, faculty advisors and the program leadership. Students also reported the significant opportunities to practice professional skills. Overall, student participants reported positive program experiences, pride in the work results they showcased in a closing college-wide poster session, and greater clarity in their future academic and career plans.

Introduction

As urban populations increase in the coming decades, the solution to providing safe and resilient infrastructure systems to city inhabitants will increasingly involve integration of advanced technologies, creating so-called “Smart Cities”. Growing populations [1,2] pose critical challenges to re-think urban infrastructure systems that are already stressed by aging materials and structures, growing energy and service demands, threats from climate-related hazards, and dwindling access to resources [3]. Increasingly, there is a need to consider interconnections between individual transportation, energy and power, water and wastewater and building systems. The combination of physical infrastructure assets and their operations are key to sustaining the public health and safety and economic viability of a Smart System.

We launched the Research for Experiences for Undergraduates (REU) Site to address the need for training a future workforce that can develop smart solutions to enhance the resilience and sustainability of urban systems to ensure a high quality of life for urban inhabitants [4]. To meet these workforce needs, we adopted an integrated approach to design the REU Site by integrating the evaluation framework for our project. We were intentional to consider how program participation would influence participants’ social capital related to graduate school. We were also interested to characterize the extent to which participants had the opportunity to practice professional skills identified as critical to the design of future infrastructure systems [4].

Social capital refers to the network of relationships that people can use to gain resources that help them to achieve a goal. This concept derives from Lin’s Network Theory of Social Capital which is concerned with the size of REU participants’ social networks and what types of resources the people in their network can provide [5]. Prior work has shown that engineering students’ academic and career decisions are influenced by social capital [5,6]. Important social capital resources relevant to this REU Site project fall into two categories. First, *expressive social*

capital includes empathy, emotional encouragement, and other expressions of caring that support well-being and satisfaction of a participant to achieve a goal. Second, *instrumental social capital* describes the specific information and tangible resources necessary to achieve a particular goal. We anticipated that faculty and graduate student mentors, and cohort peers during an REU would provide both these aspects of social capital.

This paper reports on the outcomes and evaluation of the REU Site, including continuous improvement strategies developed to attract more students to careers in civil and environmental engineering research to address the urban challenges of the coming decades.

Program Structure

The primary objectives of the REU Site project were threefold:

- Provide opportunities for undergraduates to conduct hands-on interdisciplinary research exploring new civil and environmental engineering innovations for Smart Cities, thereby exposing students to the critical roles of these engineers to serve society;
- Equip students to pursue graduate degrees in civil, environmental and geodetic engineering by preparing them for the application process and building their networks of social capital related to research careers; and
- Develop student skills in communicating engineering advances to technical and non-specialist audiences.

These objectives were achieved through an immersive experience with REU participants conducting research in Faculty Mentor labs, working in close association with Graduate Research Ambassadors. The REU Site program was arranged around a 10-week schedule with two bookend activities and four regular weekly professional development activities undertaken as a cohort (Table 1). Program dates were coordinated with other on-campus undergraduate research programs to leverage resources and create a larger undergraduate student cohort.

Table 1. Sequence of REU Site activities. Graduate Research Ambassadors (GRAs) served as day-to-day research mentors.

Wk		Mon	Tue	Wed	Thu	Fri	Weekend
1		Memorial Day	*Arrival Day*	*Research Bootcamp*			
2	***Research Immersion***	*Morning Journal Club & Networking with GRAs*		*Lunch workshop: Professional Development*	*Mentor Meeting*	*Guest Lecture*	
3						*Guest Lecture*	*Picnic*
4						*Field Trip: OSU*	
5						*Guest Lecture*	
6						*Guest Lecture*	
7						*Guest Lecture*	
8						*Field Trip: City*	
9						*Guest Lecture*	
10				*UG Research Symposium*	*UG Research Symposium*	*Farewell*	Close Site

Research Bootcamp: The REU Site program opened with a 3-day *Research Bootcamp* to prepare students for the research process. Students learned the 'why' of engineering research with presentations from the participating research labs to learn the importance of questions addressed in their research project. Participants worked together to learn common elements of research projects, including research ethics, replicates/reproducibility, control experiments,

validation, and lab safety.

Weekly Professional Development: On Mondays, the REU participants participated in a *Journal Club* to develop their skills in reading scientific literature using 'Quality Talk' as a structured framework to promote critical and reflective thinking [6]. Participants also shared concepts related to their individual projects in 20-minute presentations at least twice during the program.

Participants were introduced to advanced research and applications in the field of Smart Cities through the weekly *Guest Lectures* or *Field Trips*. These events provided students to networking opportunities with regional and academic and industry leaders. Field trips showcased operational implementation of smart energy, water, and transportation infrastructure systems.

On Wednesdays, the REU participants gathered for lunch time workshops on topics to demystify the graduate education and application process. This sequence of workshops was hosted through the on-campus academic conference alliance summer research program.

Undergraduate Research Symposium: In the last week of the REU Site program, participants presented their research findings with posters in a campus-wide symposium.

Recruitment

We utilized several networks to broaden our recruitment of participants to include students not traditionally involved in civil engineering research, including the College of Engineering open house, information sessions at minority-serving institutions, and online recruitment.

Outcomes

The REU Site was funded in March 2023 with the first cohort of students welcomed on campus two months later. We have since implemented the project fully in summer 2024. Across the two cohorts, the project engaged 20 undergraduate students (17 were not currently enrolled at our university) from a variety of majors to work on research questions in the fields of civil, environmental, and geodetic engineering. The student cohort diversity increased across the program years with the 2024 cohort having gender parity, one student from a Historically Black College and University, and two students from Puerto Rico.

The key activity of the REU Site was the 9-week immersive research experience in which participants worked in Faculty Mentor laboratories under the guidance of a Graduate Research Ambassador and with regular Faculty Mentor meetings. Participants were able to see relevance to Smart City innovations of their backgrounds in microbiology, biochemistry, physics, mechanical engineering, computer science, architecture and urban planning, and civil engineering. Participants used new image analysis tools, sustainable materials analysis, technologies for quantifying indoor air quality and remediating water pollution, decision analysis tools, and strategies for autonomous navigation. Example research topics were digital identification of hurricane-damaged utility poles damage after hurricanes, indoor mapping in smart environments, quantifying traveler experience of transit passengers, and characterizing fungi in the built environment.

The mentored research experiences of the REU program provided opportunities for students to develop and practice professional skills that are important to all career paths. Participant professional skill development was assessed through the Professional Skills Opportunities

survey. The survey was administered twice: once, before the program start, to benchmark opportunities for student professional skills development in their home undergraduate institutions. It was administered again in week 10 of the REU program to assess the extent to which students were able to practice had opportunities to practice professional skills during their research experience and the associated programming. Participants reported practicing professional skills most frequently in communication, a stated project objective, and with decreasing frequency of problem-solving, professional and ethical responsibilities, shared leadership, and business principles (Table 2).

Table 2. Participant rankings of opportunities to practice professional skills during the REU program. Values are reported as the averages across 4 to 6 specific scenarios for each skills category with a rank of 1 = 'not at all' to 7 = 'very frequently'

Skills Opportunities Reported by the 2023 Cohort *(listed in order from most opportunities to practice to least opportunities to practice)*	**Mean**	**SD**
Communication	6.10	0.08
Creative problem-solving	5.60	0.35
Professional and ethic responsibilities	5.24	1.23
Shared leadership	5.08	0.72
Business and management principles	4.49	0.75

The Undergraduate Student Support survey was used in week 10 to evaluate how social capital was gained by participants in the REU Program [8]. Participants were asked to name 5 people with whom they had close interactions and who provided instrumental social capital related to navigating a research career or expressive social capital in the form of support for personal well-being and growth. Results indicated that the REU program director and faculty mentors built the most instrumental and social capital with participants.

The most frequently cited forms of instrumental social capital were occurrences of checking participants' progress, discussing graduate school, helping participants to understand graduate school requirements, and introducing students to other researchers in the mentors' networks. Less cited were actions of encouraging students to take classes aligned with graduate school, and suggesting graduate school or job opportunities.

Trends in expressive social capital of participants showed the most frequent occurrences to be trying to learn about participants' career goals, asking how research was going, encouraging participants when they were struggling and initiating conversations. Participants cited less frequent forms of support to be talking about their mental, emotional, or physical health.

Overall, similar trends in student outcomes were observed between the Year 1 and Year 2 cohorts. Participants in the REU program had opportunities to practice important non-technical professional skills while developing research skills. A major strength of the program was the development of the participant's social capital related to graduate school and research careers.

Evaluation and Continuous Improvement

The quantitative survey tools were complemented with qualitative data collection through one-

on-one semi-structured interviews [8,9] in the last week of the REU program. These interviews followed up on the Undergraduate Student Support Survey; they were also used to gather feedback about program improvements. Broad trends from the participants' experiences were beneficial to guide continuous improvement over the REU program three-year duration.

Feedback from the Year 1 evaluation identified the need for participants to have more flexibility in the timeline of deliverables as they worked toward their final project presentation at the Undergraduate Research Symposium. Some benefit was gained by restructuring the weekly *Journal Club* meetings in Year 2 to allow for the nonlinear progress of research projects. Greater clarity was provided to Faculty Mentors in Year 2 about expectations for planning the project scopes, their own availability, and graduate student mentoring to ensure the participants would receive continuous support for successful research outcomes in the ten-week program.

Feedback from Year 2 highlighted additional adjustments needed for cohort activities to build more community in the Year 3 (2025). The *Journal Club* will benefit from the integration of informal roundtable sessions to replace more formal presentations. We also plan to integrate more professional development for giving and receiving feedback with a constructive lens.

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