[Work in Progress] Broadening Participation and Building Students' Self-Efficacy Through Experiential Learning Undergraduate Research Experiences focused on STEM Research for Social Change

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Introduction

Three mission-aligned universities in different U.S locations collaborated to launch the inaugural year (2024) of the STEM Research for Social Change Research Experience for Undergraduates (REU) program (National Science Foundation REU) to provide transformative, interdisciplinary experiential learning to undergraduates through 10-week, faculty-mentored summer research with social change partners designed to advance UN Sustainable Development Goals achievement. This program is a model for broadening participation in STEM by providing underrepresented first through third year science and engineering students with a structured research experience that builds their self-efficacy related to STEM research, career development, and future sense of self. This REU also demonstrates effective co-mentorship of undergraduate research utilizing in-person and remote strategies. Discussed herein are the REU's theme, structure, and mentorship approaches that resulted in successful outcomes aligned with the Cooperative and Experiential Education Division's objectives to broaden participation, increase student self-efficacy, and promote student retention through experiential education.

Literature Review

Several studies suggest that participating in research is a key element for undergraduates to build a foundation in critical thinking and professional development. Mathews et al. (2019) highlighted how alumni from undergraduate research programs felt that these programs aided them throughout their careers by fostering their problem solving, communication, and the ability to work independently.

Undergraduate research also serves as an instrument for social change. When STEM education intersects with social issues, a unique connection to individual's communities and greater societal concerns develops. For students, they become catalysts for social change by being empowered to bridge physical and social sciences (Weinberg et al, 2018). For teachers and mentors, integrating social change into education combines inquiry with collaborative-based learning, experiment-based learning, and real-world based learning to enhance students' knowledge and creativity (Nguyen et al, 2020).

National Science Foundation Research Experience for Undergraduates (REUs) is one model of such programs. REUs provide undergraduate students with intensive research projects over the course of a 10-week summer immersion. These projects are experiential by nature to retain students in STEM and prepare them for careers in that field. Borrego et al. (2021) emphasizes that students who participate in REUs gain confidence in their lab skills and experience a deeper understanding of how their research is applicable to the real world. Furthermore, Borrego also proposes that REUs have an initial impact on a students' sense of belonging in engineering by improving their engineering identity. REU programs have also been shown to reinforce the idea of graduate schools to students by affirming their abilities (Borrego et al, 2021).

Studies have shown that REUs have an impact on undergraduates' interest in STEM, can improve diversity in the US workforce, may increase interest in graduate schools, and enhance educational outcomes (Jin 2022). A 10-year post-REU survey conducted on 26 REU trainees that completed a NSF REU program between 2007-2010 revealed that all the trainees completed their bachelor's degree and 42.3% of them earned an advanced degree. Half of the trainees were Latino and 15% were African American, 50% were first-generation college students, while only 3 (11.5%) were female. Comparing these 26 REU trainees to a control group in the Electrical and Computer Engineering Department from the home institute of the REU, while demographics between the groups were similar, the REU group had a greater percentage of students that went on to earn a MS degree but the control group had a higher percentage of students that earned a PhD. A REU site established in 2017 with the goal of broadening participation of URM groups in engineering had a target of 60% of students coming from limited research

opportunity institutions, 50% coming from URM groups in engineering (based on gender, ethnicity and race), and at least 40% first-generation students. During the first 5 years of the program, 67% of participants were female, 38% were a URM in STEM, 59% were from limited research opportunities institutions, and 27% were first-generation students (Wittich and Bartlet-Hunt 2022). In general, URM and lowerclassmen students (i.e., freshmen and sophomores) are not often well represented in REU engineering programs across the nation (Nyarko 2021). However, early intervention and exposure to research and faculty mentoring experiences has been shown to improve retention and persistence, particularly for these lower classes.

Overall, undergraduate research, particularly REUs, is a key contributor to students undergoing transformative learning that cultivates them personally and professionally. The integration of social change within REU programs connects participants to their broader communities and empowers them to look beyond the traditional engineering curriculum (Weinberg et al, 2018). These programs benefit students not only during their undergraduate years - but also into their careers by providing insight that might be otherwise overlooked (Miller et al, 2022).

STEM Research for Social Change Theme and Structure

Researchers determined that the alignment of students' and STEM cultural values increases student persistence in STEM (Jackson et al, 2017). The NSF STEM Research for Social Change REU builds upon the key principles and successful methods of REUs and other undergraduate research programs by integrating social change with STEM research, thereby providing opportunities for students to link their cultural values to their STEM interests while participating in high-impact experiential learning. The three collaborating institutions offering the STEM Research for Social Change REU program each have missions and identities centered on using education for knowledge creation to advance social change for the common good, and the REU's theme reflects the collaborating institutions' connected educational missions. The four programmatic objectives of the REU are to:

- improve understanding of science and engineering research that promotes social change;
- increase interest in and awareness of graduate school opportunities;
- increase personal networks and collaboration; and
- increase competence in STEM research

In compliance with the 2023 Supreme Court affirmative action ruling, the collaborating institutions implemented successful recruitment and cohort selection strategies resulting in broadened REU participation. Recruitment leveraged the institutions' faith-based, land-grant, historically Black university (HBCU), Hispanic-serving (HSI) missions and identities and social capital with other mission-aligned institutions, HBCUs, HSIs, and STEM professional societies. Additionally, the REU's application, selection criteria, and rolling admission structure emphasized student experiences with sense of belonging, identity formation, and STEM career goals. Prior to review, applicant materials were de-identified and no demographic information was included in the applicant materials reviewed.

During the first year of the REU program (Summer 2024), five social change research projects were offered that contributed to at least eight different United Nations Sustainable Development Goals. Additionally, local social change governmental and non-profit organizations were collaborators on the research projects, and as collaborators they participated in research project discussions, co-mentorship, and provided opportunities for community outreach and engagement.

The REU was a 10-week summer research experience, and participants conducted research on one of four research projects at the collaborating institution designated to host the REU in Year 1. The research

projects were connected to at least one UN Sustainable Development Goal (SDG) and contributed to social change areas such as industry innovation, clean energy, sustainability, responsible consumption and production, food access, clean water, reducing inequality, and decent work and economic growth. One of the four research projects was further scaffolded such that there were five topics total as follows:

- Waste Collection Route Optimization to Reduce Greenhouse Gas Footprint
- Porous Carbon Sorbent Regeneration for Dye Absorption Optimization
- Bioenergetic Evaluation and Modeling of Microbial Biodegradation
- Citizen Reentry Utilizing a Foodbank Approach
- Sensor Development for Aquaponics

Depending on the project, level of research lab experience, and alignment of the major, participants spent between 10-40 hours each week working directly with their primary mentor, with an average of 27 hours per week. Participants also worked in the lab with other collaborating faculty mentors, graduate researchers, undergraduate researchers, community partners, and other REU participants. Weekly professional development, local excursions and social activities, and engagement with other summer research programs and campus REU participants also occurred during the program.

STEM Research for Social Change REU Evaluation

The Context Input Process and Product (CIPP) evaluation approach (Stufflebeam & Shinkfield,2007) was appropriate in that project team decisions were required throughout the implementation and evaluation of the project activities; the evaluator continually reviewed the project activities as related to proposed project goals, objectives, timelines, proposed theories, analyses and interpretations thereof. The evaluation plan was developed using the Joint Committee on Standards for Educational Evaluation (Yarbrough, Shula, Hopson, & Caruthers, 2010). An Institutional Review Board application was accepted and approved at Site 1. The evaluation plan addresses the Process and Product sections of the CIPP model.

A convergent parallel mixed method evaluation design (Creswell & Plano, 2007) was the research design of choice for the evaluation. Qualitative and quantitative data were collected during Year 1 and weighted equally. The two types of data were collected to document and assess successes and challenges for the Year 1 cohort. Trustworthiness strategies (Shenton, 2004) were implemented to minimize any biases in the qualitative data analyses associated with the evaluator's pragmatic worldview.

Evaluation Instruments. During year 1, site observations, one mentor survey, one participant survey, and individual one-on-one interviews provided evaluation data. Observation at the final program symposium captured details of the level of rigor and learning for participants over the entire program. Mentors were surveyed to check on participant progress and the Teaching to Increase Diversity and Equity in STEM (TIDES) survey was modified based on relevant questions and from a pre/post to full experience. Interviews with individual participants allowed a deeper investigation into the outcomes of the summer and revealed potential issues. Student participants were interviewed via online session with 10 questions (Table 1), and a modified (TIDES) survey that aligned with this REU's assessment needs was distributed via Qualtrics to all participants at the end of the 10-week REU experience. Faculty research mentors were surveyed with qualitative, open-ended questions to document progress on student participants.

Table 1. Participant Interview Protocol

1. Describe any new knowledge you have regarding engineering, chemistry and physics research that has a meaningful and positive impact on society and that promotes social change for equitable communities as defined by the United Nations' Sustainable Development Goals

2. Describe the research you worked on this summer.
3. How do you see that research impacting society?
4. Had you heard of the UN SDGs before this summer program?
5. Describe any new knowledge you have regarding research, lab safety, lab equipment, and research communications as a result of this program.
6. Do you plan to apply to graduate school? If yes, where?
7. Have you prepared a resume or CV? If not, why?
8. Do you plan to apply for any fellowships? If yes, which?
9. Describe any new connections you have as a result of this program.
10. Describe your future career plans.

STEM Research for Social Change REU Evaluation Outcomes

REU Participants' Experiences. Based on the evaluation observations, surveys, and interviews, students reported or demonstrated several outcomes related to their research, mentorship, networking, and professional formation experiences during the program.l For half of the students, this experience was their first time participating in academic research and for all students, the REU experience improved their ability to explain the impacts of their research project on society, as measured by the UN SDGs. Additionally, most students reported that working in a research lab was a new experience and that they felt comfortable asking their lab members or research mentor for help when needed. Following this 10-week REU program, the participants reported staying connected with their mentors and cohort members and 63% reported developing personal relationships with their cohort. This overall increased competence in STEM research led to students reporting increased self-confidence and a new or renewed interest in pursuing graduate school after completing the REU program experience.

Broadening Participation Outcomes- REU Applicant and Participant Demographics. A total of 43 applications were received for year 1 of this REU Research for Social Change program, with the majority (79%) self-reporting as an underrepresented race/ethnicity and the majority (65%) self-reporting as women. The 8 participants selected for this program were majority white females, not Hispanic or Latinx, and juniors at Primarily White Institutions (PWI) (Table 2). Their majors included computer science (50%), materials engineering (12.5%), physics (12.5%), electrical engineering (12.5%), and mechanical engineering (12.5%).

Table 2. Participant Demographics

Demographic Information	**Responses (%)**
Gender	
Male	25
Female	75
Race	
White	37.5
Black or African American	25
Asian	12.5
2 or more races	25
Ethnicity	

Hispanic or Latinx	29
Not Hispanic or Latinx	71
University Affiliation	
Hispanic-Serving Institution	25
Primarily White Institution (PWI)	75
Year in College (Fall 2024)	
Sophomore	25
Junior	50
Senior	25

The demographics of participants in this REU Research for Social Change were similar to demographics reported in the literature for other REUs in terms of percentage of females participating, but lower in terms of ethnicity, with more students self-reporting as not Hispanic or Latinx. More participants were also from PWI institutions rather than HSI, MSI or HBCU schools in this year 1 cohort.

Students' Self-Efficacy Outcomes. The impact of this REU program on students' self-efficacy and feeling more confident in STEM was also measured in the anonymous online survey based on the modified TIDES questions. Three-quarters of the students reported increased confidence in overcoming problems with teachers, understanding articles with STEM content, pursuing a career in STEM, and performing well in a STEM career.

Retention in STEM and Future Career Aspirations Outcomes. While only year 1 results are available, literature from REU experiences consistently demonstrate gains in research skills, academic preparation, confidence in research skills, and an interest in pursuing a graduate degree by students engaging in these activities (Nyarko 2021). The participants in the REU Research for Social Change program expressed appreciation for the Professional Development sessions that were incorporated into the 10-week experience. In particular, the sessions dedicated to resume preparation and finding/applying to fellowships and graduate school were most helpful.

Lessons Learned for Future Work

During year 2, strategic changes to the recruitment and application process are being undertaken. These efforts include the addition to the application a short description of the potential summer research projects with an indication of the applicability of specific majors to the research effort. Applicants will rank their top choices for consideration of potential alignment. During year 1, participants learned the relational value of different majors to overall team research efforts and the need for different skill sets of others to advance work. As such, a more intentional effort to align various majors to the project descriptions intended for cohort 2 is underway. Additionally, several of the research projects from year 1 are continuing into year 2. This continuation of effort allows future REU cohorts to see how the work of their predecessors is being advanced by them. Lastly, year 1 was hosted by one of the three collaborating institutions. As such, all participants lived and learned at that host institution and the research projects were carried by faculty members employed by the host institution with contributing faculty members from the other two collaborating institutions who participated either in person or remotely. Cohort 2 will be hosted by a different collaborating university in year 2 with research projects led by faculty mentors at that host institution. Similarly, faculty members from the other two host institutions will contribute to the overall effort to aid in the research and mentorship of participating undergraduate students. In some cases, the individual research projects are continuation efforts from year 1, while in other instances, the research projects are new efforts with new collaborations among the three institutions underway to provide synergy

among the three universities. In all cases, the research projects aim to align a component of the work to the UN's SDG and to social justice to foster meaningful student engagement and bolster culturally sensitive attributes of the research itself.

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References

Borrego, M., Mastronardi, M., Choe, H., Hartman, R. (2021) The Impact of Undergraduate Research Experiences on Participants' Career Decisions, *Stem Education Innovations and Research,* v. 22, n. 2, pp. 5 - 12.

Jackson, M.C., Galvez, G., Landa, I., Buonora, P., Thoman, D.B. (2017). Science That Matters: The Importance of a Cultural Connection in Underrepresented Students' Science Pursuit. *CBE-Life Sciences Education*, v. 15, n. 3, p. 1-12.

Jin, Y.F., 2022, June. Closing the Loop: A 10-year Follow-up Survey for Evaluation of an NSF REU Site. In *ASEE annual conference*.

Miller, C.T., Drewery, M., Waliczek, T.M., Contreras, R.N., Kubota, C. (2022). Engaging Undergraduate Students in Research, *HortTechnology,* v. 33, n. 1, pp. 1 - 7, 2022.

Mathews, L., Whitlock, C., Diaz-Loar, E., Eichenlaub, B., Vicenty, T., Hamilton, L. (2019). The Contribution of Undergraduate Research Experiences to Skill and Career Development: A Multi-Institutional Analysis, *NACTA Journal,* v. 63, n. 2, pp. 250- 257.

Nguyen, T. P. L., Nguyen, T. H., Tran, T. K. (2020) STEM Education in Secondary Schools: Teachers' Perspective towards Sustainable Development, *Sustainability,* v. 12, n. 21.

Nyarko, K., 2021, October. Lessons Learned in Adopting a Multi-Site Combined REU/RET Program for Exclusive Remote Participation Due to the COVID-19 Pandemic. In *2021 Fall ASEE Middle Atlantic Section Meeting*.

Weinberg, A. E., Trott, C. D., Sample McMeeking, L. B. (2018) Who produces knowledge? Transforming undergraduate students' views of science through participatory action research, *Science Education,* v. 102, n. 6, pp. 1151-1406.

Wittich, C. and Bartelt-Hunt, S., 2022, August. Impacts of a sustainability-focused REU site on student products and career trajectory for underrepresented groups in engineering. In *2022 ASEE Annual Conference & Exposition*.