Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #49249

Manufacturing the STEM Workforce: The Effect of Structured Undergraduate Research Experiences on Engineering Student Retention

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Enhancing Structured Undergraduate Research Experiences at a Shared Engineering Workspace towards a Resilient Engineering Workforce

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Abstract— **The purpose of this work is to explore the development of structured summer internships targeted toward an emergent and resilient workforce. This works in progress paper is based on multi-year, mixed methods external evaluation studies of mentored research experiences for undergraduate students (REU). These mentored research experiences take place at a shared engineering school (i.e., a Public University and a Historically Black University (HBCU)) workspace. The objective of the REU is to increase the STEM workforce by addressing the challenges faced by underrepresented student groups. These student groups are often identified in previous STEM education reports as facing many challenges that result in incompletion or discontinuance of STEM degrees/pathways. We aim to explore the development of the REU summer internships that are structured to address such challenges using multi-year data collected from the intentionally shared and diverse REU cohorts. Research data from surveys and individual focus group interviews from sixty plus students that have participated in mentored research experiences for undergraduate students across multi-year cohorts to date have been analyzed. We find evidence that the unique structure of these intentionally shared and supportive research experiences addresses many of the challenges to the retention of underrepresented STEM students and can therefore be used to inform retention strategies for historically underrepresented students in STEM programs. Implications are offered with respect to consistent and increased retention as well as the matriculation of these students into the STEM workforce.**

Keywords— ***Student Retention, Higher Education, Materials Science and Engineering, Historically Black Colleges/Universities (HBCUs), Undergraduate Research, Mixed Methods Research***

I. Introduction

Researchers have found that factors such as low-income, self-efficacy, opportunities for professional development, academic support etc. have significant influence on retention in Science, Technology, Engineering and Mathematics (STEM) as well as increases to the STEM workforce[1], [2]. These factors have been found especially compounding in historically underrepresented groups in STEM fields, including Engineering[3]. Research Experiences for Undergraduates (REU) internship programs partner with national laboratories, principal investigators (PI's), graduate mentors and STEM student groups to assess, explore and examine science, technology engineering and mathematics (STEM) topics. Such a program is curated intentionally to retain and increase the STEM workforce by addressing the challenges faced by STEM student groups.

In addition to this, even students who complete the rigorous demands of an engineering major have been found to be indecisive and not necessarily committed to careers in engineering or STEM post-engineering degree[4]. Limited interest in continuing on to engineering graduate programs and/or industry career pathways was found to be associated with the following factors: 1. Singular experiences (i.e., interactions with faculty or even staff, internships, or advice from a mentor), 2. Institutional support in their decision making (i.e., from STEM and non-STEM disciplinary faculty, staff, offices, and/or peers), 3. Institutional differences (i.e., whether or not the institution offers more or less non-technical coursework), and 4. Exposure to a career pathway in the field inclusive of diverse professional experiences rather than a lifetime commitment to a single occupation[5], [6].

This works in progress paper extends from multi-year, mixed methods external evaluation study of mentored research experiences for undergraduate students. This research training takes place at a public engineering school workspace shared between a Historically Black University (HBCU) and a Predominantly White Institution. This program is a case of a much larger set of REU programs across the U.S., but it is positioned to serve as an instrumental study site because of the combination of its diversity – including the high share of women students and comparatively high share of women faculty (including women of color) for a research-intensive REU site as well as students from community colleges.

Despite the engineering school being well-resourced in terms of scientific productivity and training opportunities as well as a community whose diversity could reduce the salience of negative stereotypes and biases around who might truly belong in engineering, assessments in the early years of the REU program found the need to structure supports along the engineering career pathway to help students succeed and want to stay in the field after completing their undergraduate studies[7]. As such, more recent evaluation of the program – including formative and increasingly year-round evaluation engagement – focused on addressing the aforementioned challenges. We leveraged multi-year cohort data from 2018-2024 on Engineering REU students and implications for the matriculation of these cohorts into the Engineering workforce and related STEM areas.

In doing so, this paper focuses on the design of the REU program and how it has adapted over time in response to ongoing formative assessment and evaluation. Specifically, as this is an Engineering program with a focus on Additive Manufacturing, we consider design and in particular, how this REU internship program shapes workforce readiness and retention in the field among a population of students and a setting that is highly diverse and less typically represented among mid- and senior-career engineers. A driving design motivation is cultivating talented and committed students who could emerge resilient, countering stereotypes and resource challenges such as prior math, science, and technology training. This Works-In-Progress paper explains how we leveraged our research skills to innovate in manufacturing and structuring this training program to enhance the following intended outcomes: (1) students' confidence in their abilities, (2) the quality of their mentoring relationships and training experiences, and (3) commitment to continue to pursue engineering after completing the REU.

II. MOTIVATION AND BACKGROUND

Resilient Engineering Workforce: The Development of Research Experiences for Undergraduate Students (REU)

The National Science foundation reports that over 40% of STEM students graduate within 5 years, students from underrepresented groups, however, only make up a small portion of these STEM students who graduate within 5 years[8]. In fact, underrepresented groups are identified as. not completing their STEM degrees due to various challenges such as low-income, self-efficacy, opportunities for professional development, academic support etc. [9]. Past research has found that internships that are structured to target these challenges result in increased retention rates for STEM student groups in general when compared to circumstances where there was a lack of effective targeting of such challenges [6], [10]

Research experiences for undergraduates or REU was initiated in 2011 in direct response to the national science foundations' (NSF) call to increase the global competitiveness of the United States in STEM. The program was originally called Research Experiences for Undergraduate Students - Retaining Engineers through Research Entrepreneurship and Advanced- Materials Training (REU-RETREAT). RETREAT-REU sought to simply increase the number of engineering students to continue into engineering careers in industry or advance to postgraduate training in materials engineering research post bachelor's degree by combining training in multiscale multifunctional advanced composites with entrepreneurship principles. The model focused mainly on curriculum. i.e., guiding students through engineering seminars and lab experiences.

Since 2011, the REU program has diversified in terms of faculty, staff, funding sources, partner universities etc. to facilitate STEM retention and matriculation. Figure 1 shows the diversity in funding partnership which has allowed for the inclusion of various facilities, companies, faculty, staff. projects and student groups. During the summer, students are partnered with laboratory principal investigators (PI's), graduate mentors and research assistants to assess, explore and contribute to real world engineering problems. Notably, students' main institution of enrollment while participating in this program includes institutions across the U.S., with consistent consideration to Minority Serving Institutions (especially Historically Black Colleges and Universities) and recent attention to community colleges in the Southeast, with proximity or relationships with graduate institutions with engineering doctoral programs and/or National Labs. Students who travel to the campus from other locations receive summer housing in addition to the stipends received by all students.

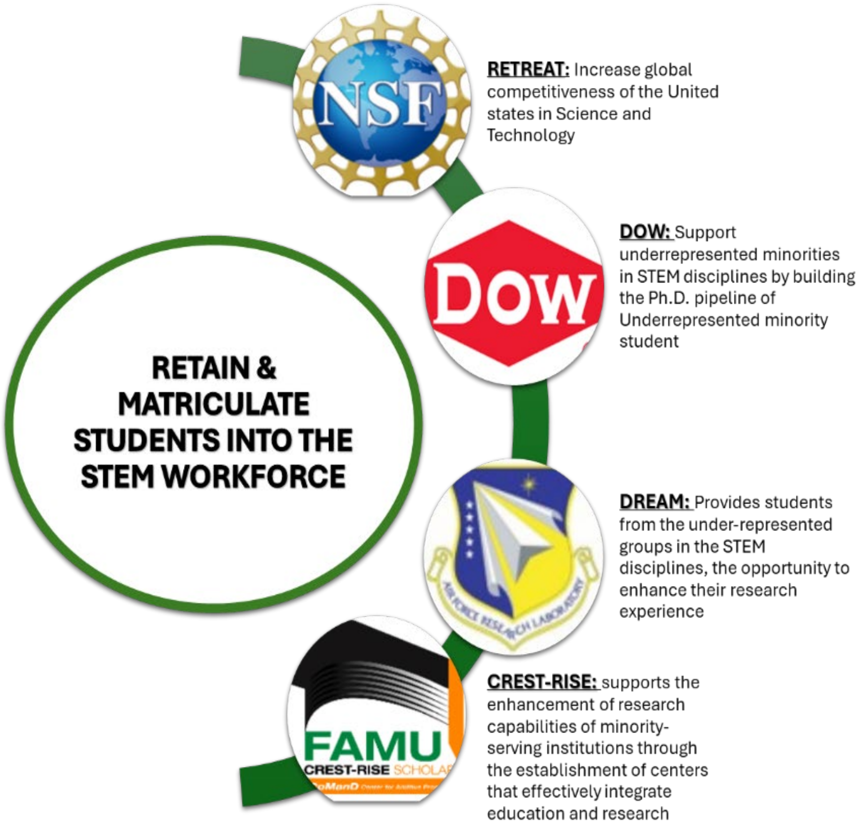

Figure 1: funding partnership which has allowed for the inclusion of various facilities, companies, faculty, staff. projects and student groups

Figure 2 represents the development of the REU model. Since 2011, the model has been advanced beyond curriculum and into ‘student empowered ’pathways. These individually curated pathways take students beyond academic and scholarly performance, but also importantly on how these future engineers see themselves in this field. Unlike the engineering material that are manufacturing in the REU’s engineering labs, REU student trainees have agency and are able to engage in sensemaking about their learning environments. The training model below has been developed over a series of cohorts for nearly ten years, and associated evaluation research. We explain here its application in our study, with focused attention to undergraduates’ pathways to and through completion of the summer research program. The goal of the REU Program is to encourage, empower, and prepare/train students as they matriculate into the STEM workforce through the creation of state-of-the-art student empowered research-based pathways.

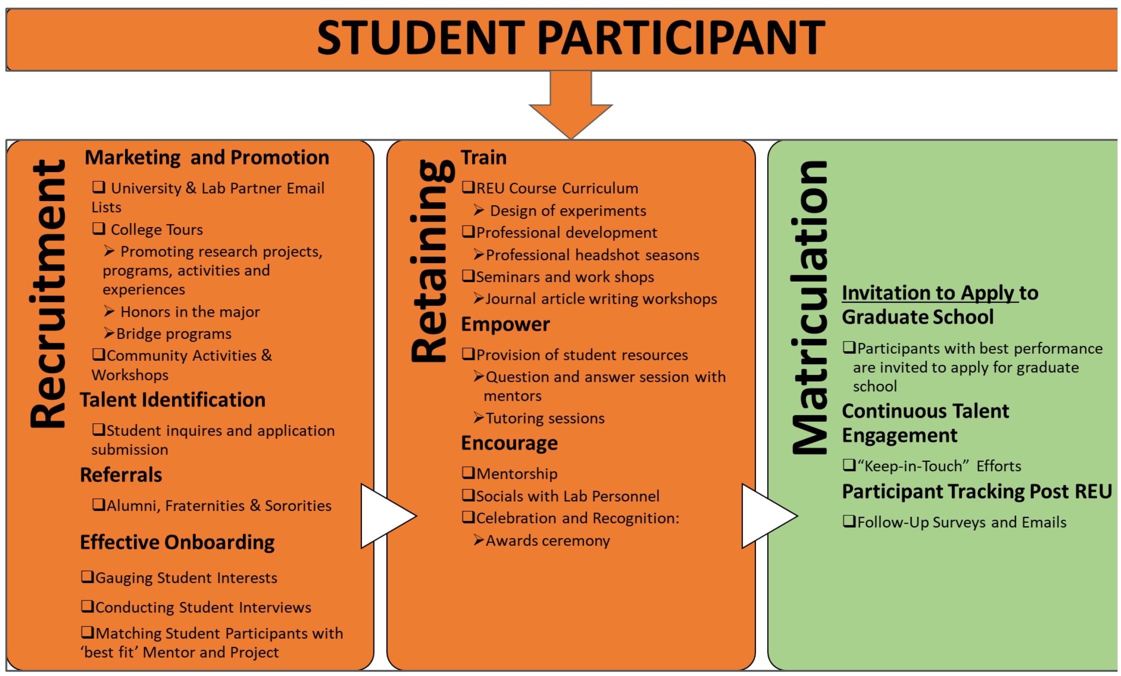

Fig. 2. Student Empowered Engineering Pathways: 2-Dimensional REU Model

Figure 2 shows the outlined linear model for student empowered research-based pathways [11].

There are three key approaches for student empowered research-based pathways with the intent to achieve the REU program goals: 1. Recruitment, 2. Retention and 3. Matriculation. Student Participants are identified through various recruiting efforts such as advertising, marketing, referrals etc. Once identified, these students are assessed for qualification as REU participants based on various aspects of their student profiles (i.e., protentional for success in STEM, G.P.A. etc.,). The selected REU participants are then onboarded into research areas and mentor pairing to foster constant and steady support. The newly onboarded REU participants are retained in the program through training, empowerment, and encouragement activities before matriculation into STEM careers via graduate school.

III. METHODOLOGY

A. Abbreviations and Acronyms

Research Experiences for Undergraduates (REU) programs are funded by federal and other agencies to support summer and academic year research. Underrepresented groups refers to persons historically underrepresented in Engineering and other STEM fields, including Black, Latin*, and Indigenous student populations [see also 1].

B. Sample and Settings

Our analytic sample consists of multiple cohorts of undergraduate students who participated in materials science summer research internship programs between 2019 and 2023 in a diverse Historically Black College/University setting. Table 1 displays self-reported background information for the participants included in this study. The participants were diverse in terms of race, ethnicity, socioeconomic status, and home college/university. Each cohort included students from the engineering college host site as well as students recruited nationally from other campuses including research-intensive universities, other HBCUs, and most recently also community colleges.

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TABLE I. STUDENT DEMOGRAPHICS ACROSS MOST RECENT COHORTS

Self-Reported Identities	**(%)**		
	Gender [a]	***Men***	***Women***
Race and/or ethnicity	Asian, Asian American, &/or Pacific Islander	8.7	2.2
	Black and/or African American	41.5	46.1
	Hispanic and/or Latine	19.6	21.4
	Multiracial, Indigenous, and Other Identities	5.0	10.3
	White	25.2	20.0
Institutional Type	Community College	7.7	4.3
	Historically Black College/University	38.5	43.2
	Other Institutional Types (including HSI)	53.8	52.5

Notes. For the present draft, this table represents the most recent cohorts. An updated table for the final draft will add more nuance to show change in demographics over time as campus institutions became more heterogeneous (including a national vs. originally more regional base as well as more recent attention to community colleges). *a* While a gender binary (man or woman) was not selected by all students, it was a sufficiently small share (n<3) that we do not report these figures to protect their confidentiality.

These REU students were typically not students who had consistent and early exposure to engineering knowledge and training – none of the students interviewed and surveyed self-identified as having childhood training and passion for engineering as a specific career field or discipline of study. We observed learning gains between the beginning and end of the summer on engineering competence in particular, as well as greater commitment to stay in the field and continue in research.

C. Data Collection. Beginning in 2018, REU participants participated in pre-and post-surveys at the beginning of the program (first week if not first day) to gauge their initial experience, confidence, career commitment, and intention to continue to graduate studies and/or industry in the field; they were either interviewed or surveyed again at the end of the summer program (final week). Thus, we have been positioned to compare their baseline skills and career against where they ended, to assess change over time, mindful that part of learning in these research internships also seems to involving at times higher expectations for what they should know to be considered skilled in engineering competencies.

The evaluation team including the second author gathered (a) students' self-ratings of their perceived competence and engineering identity, (b) responses to a hand-written affirmation exercise on sense of belonging see *[12] [13]*, and (c) individual interviews with interns to investigate their research internship experiences and future education and career plans. These occurred each year, with each cohort of 8-22 students depending on funding and mentor availability.

D. Data Analysis

Multiple methodological approaches were employed to analyze these data. Survey data was analyzed using descriptive statistics to assess undergraduate participants' skill gains each summer. Additionally, we transcribed and coded the focus group and interview transcriptions. Thematic coding of interviews attended to engineering identity, mentoring relationships, prior background and motivational experiences, and perceived competence in the field.

E. Trustworthiness

We used triangulation by including multiple data sources to enhance trustworthiness, supported by our mixed methods approach. To thematically code our qualitative data, we employed an iterative process with multiple rounds of review. With our quantitative and qualitative data, we aligned findings to one another to identify patterns that are separate vs. distinct across methods and cohorts.

IV. EMERGING FINDINGS

We summarize below the multiple data strategies employed and associated findings from each approach.

A. Surveys: Descriptive Analysis of Student Demographics

Table 1 below depicts REU intern demographics, focusing on race and gender because these categories are those most frequently reported out to comply with federal reporting mandates. In attending to sense of belonging and self-beliefs, we include these demographics here for context and return to student background characteristics and broadening participation in engineering later in this paper.

TABLE 1. STUDENT DEMOGRAPHICS

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Notes. As noted above, we focus on race (in some cases described in terms of ethnicity by students) and community college enrollment given the comparably limited research base on community college engineering students, and our interest in intentionally including and incorporating their experiences. *a* While a gender binary (man or woman) was not selected by all students, it was a sufficiently small share (n<3) that we do not report this in our intersectional table here, to protect their confidentiality.

B. Observational Mentoring Groups: Community-Engaged Learning

Since joining the team as an investigator and project director, the first and third author regularly engaged with students, staff, and faculty associated with the training program – on the academic and research sides – both during the summer and academic year in preparation for the intensive 10 week summer program. These meetings functioned as regular focus group interview sessions to learn how student trainees – and those who supported them – were experiencing the program, assessing their needs, and responding to challenges and concerns. In addition to supporting implementation, the campus-based staff and faculty communicated regularly among each other, with students and other staff, and with the evaluator. These communication systems added additional data triangulation to supplement collection and analysis of traditional data (e.g., surveys, interviews) to develop context towards lessons learned and informing implications.

C. Individual Interviews and Design Changes

To date, over 60 individual interviews have been conducted with undergraduate interns during this period. It is worth noting that these students were primarily the first in their family to formally pursue engineering as a field of study, yet many of them expressed experiences and interest in working on mechanical tasks at earlier stages in their life and with support from family and educational mentors. This aligns with research on tinkering and other formal vs. informal engineering training differences among underrepresented vs. well-represented engineering students.

In addition to hands-on experience and socialization to engineering (including knowledge networks, career familiarity, etc.), underrepresented students we interviewed also tended to have less mathematical and engineering training prior to college and were therefore entering engineering fields at greater risk of academic difficulties. Accordingly, the REU program worked with affiliated faculty and the engineering school to add 2-4 weeks of formal academic study to deepen concept and mathematical knowledge was added to the program in the early weeks, while the interns studied their topic and trained in associated foundations (e.g., robotics) before entering the lab. Related, the students expressed interest in (1) greater autonomy in shaping decisions about what project to join and (2) exposure and access early to various materials engineering lab environments that might be available to them including but also beyond their immediate lab group assignment, to contextualize their training experience and enhance their understanding of what graduate studies and professional careers in industry might allow them to pursue beyond the projects and coursework they had direct access to. These adaptations were implemented with some minor fine-tuning in the years prior to and after the beginning of COVID-19. Accordingly, students' satisfaction ratings with their training are higher on average than in earlier years and enrollment in graduate training—including at the same university where they interned in summer - is regularly observed. We aim to offer more precise figures in the final paper.

Data informed adaptations also included mentee and mentor in mentor trainings from 2019 onward on mentor communication, responding to concerns raised primarily by mentees about managing expectations and communication especially given the high cost of research equipment. Especially given engineeirng and science investigators may need to be more away in summers for both personal (e.g., childcare, family responsiblities) and professional reasons (e.g., opportunity to study at national and international labs), engaging in clear and consistent shared communication norms and practices is important for the success of the team, especially for trainees. There is opportunity to expand these systems further but the steadiness of trainings and structures such as these in the REU team since 2019 has been associated with a smaller per capita mentor-mentee conflicts per year.

Further, the first author built on the student intern "engi-resilience" trainings to institute a "resilience series" in 2024 that included participation from faculty mentors and other early and mid-career mentors for students to connect with and build connections around working through challenge. These biweekly workshops in the summer may have contributed to the particularly positive affect reported in the most recent year, in particular around interest in returning to this particular lab group/project as well as staying in the field longer-term. [Final paper will add final statistical tests and checks].

D. Synthesis of Findings: Updated Model

These changes and attention to continuous improvement guide our current theory of change and approach to REU design, to inform updates to the program for Summer 2025. Below we show the updated model and discuss implications with respect to programmatic, research, and policy directions for engineering education.

Figure 3. Evaluation Logic Model: World-class integrated Additive Manufacturing (AM) research initiatives, positioned to leverage national and regional relationships developed to date towards transformative impact as an HBCU leader in materials research.

Inputs and resources	Strategies and activities	Outputs	Short-term outcomes	Intermediate-term outcomes	Transformative Impacts
Prior federal funding and synergistic materials research supporting development of team-led subprojects State-of-the-art facilities and equipment (e.g., building space, 3D bioprinters, spectrometer, etc. Existing collaboration networks for impact, incl. national labs, industry, and broader impact partners	Research: AM advancement in polymers, AI/ML, bioprinting Education and training: New labs (academic year) and funded research training for UG->faculty Graduate school preparation Community College and Fresh Start Bridge AM pathways	<u>Research:</u> High-impact articles, presentations Production of bioderived polymers and bio-hybrid materials for advanced & commercial applications <u>Education, Outreach, & Recruitment:</u> Implementation of new interdisciplinary curriculum content Recruitment and retention of US URM students through mentored training	Enhanced AM knowledge and skills among students and faculty. Increase in research productivity, collaboration, recognition (e.g., awards, promotions), patents and innovation Graduation & successful placement of UG-> Postdocs in academia, industry, and government	Expanded equipment and facilities, for research and training, incl. new user facility for advanced materials research Establishment of campus as a hub for robust advanced materials research and education Associated training gains for students, schools, region, and nation, with URM impacts	Sustained innovation in development of AM engineering impacts including progress towards larger more sustainably resourced center. Societal and scientific impacts via successful training of diverse AM scientists and engineers who in turn will train future leaders.

Assumptions & Needs: Collaboration among interdisciplinary teams leveraging state-of-the-art facilities and partnerships with national labs and industry will facilitate transformative impacts and success among UG, G, PD, and faculty.

V. IMPLICATIONS

Findings from this ongoing evaluation study attend to the importance of structured training and development for even talented and motivated undergraduate students who seek out engineering research and training, perhaps especially for those who have been historically underrepresented and continue to face challenges associated with being less well-represented in engineering as well as less access to engineering and STEM-related learning opportunities prior to their engineering studies. To help students be more successful during school and also less at risk for burnout and decreased engineering ambitions after college, it seems important to scaffold supports in postsecondary training programs to support students such as those reported on in this study.

Future research aims to add robustness checks and more empirical displays to explain with greater detail the relationship between data-informed decision making around engineering educational design and student outcomes. We are mindful that these programs are typically supported by federal programs interested in broadening participation and that these initiatives may not continue to exist as widely or at all in the near term because of changing administrations. This study's results suggest enhancing structured supports can support students inclusive of all backgrounds achieve excellence in engineering as well as support the overall success of research centers and programs, following the enrollment success and research excellence achieved by trainees preparing for careers in engineering during their undergraduate studies.

ACKNOWLEDGEMENTS

We would like to acknowledge the following funding sources: Materials-At-The-Extreme (MATE) funded by the Department of Energy (DE-NA0004115) , MSIPP-I AM EMPOWERED funded by the Department of Energy (DE-NA0004004), NSF-RISE funded by the National Science Foundation (1646897), CREST Center funded by the National Science Foundation (1735968), RETREAT: Retaining Engineers through Research Entrepreneurship and Advanced Materials Training funded by the National Science Foundation (1950500), DREAM: Diversity in Research and Engineering of Advanced Materials Training. Funded by Air Force Research Laboratory (FA8651-18-1-0003) and Catalyst Project: A Two-Semester Driven Conceptualization Training of Manufacturing Intelligence in Materials Engineering (MIME) - A Froshmore FUTURES Program (2011853).

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