Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #48592

Integrating Course-based Undergraduate Research and Entrepreneurial Mindset (CURE-E) in to Mechanical Engineering Curriculum

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Integrating Course-based Undergraduate Research and Entrepreneurial Mindset (CURE-E) into Mechanical Engineering Curriculum

ABSTRACT

Engaging undergraduate mechanical engineering students in research offers a substantial opportunity to enrich their educational experience and increase their interest in STEM fields. However, undergraduate students at many institutions often face significant barriers to engaging in research such as limited access to research opportunities, heavy course work, study-work schedule, and lack of research experience and knowledge. In order to address these challenges and introduce research to undergraduate engineering students, Course-based Undergraduate Research Experience and Entrepreneurial Mindset (CURE-E) is implemented to a lower division Mechanical Engineering course, Materials Science and Engineering Laboratory, at California State University, Chico. CURE-E is created as part of the Cultivating a Culture of Entrepreneurial Mindset and Undergraduate Research (CEMUR) project funded through a National Science Foundation (NSF) Improving Undergraduate STEM Education Hispanic Serving Institution grant. Incorporating the CURE-E project into the Materials Science and Laboratory course aimed to integrate research experiences into the curriculum, focusing on developing research skills and entrepreneurial mindset of engineering students. As part of the project, students conducted literature reviews, fabrication, and material property characterization of hydrogels for bio-related applications/tissue regeneration. Students collaborated closely with faculty and a student research mentor, applying materials science and engineering concepts to practical, real-world challenges. At the end of the course, students completed a 58-question survey to assess the impact of the CURE-E project on their self-perceived capabilities, their connection to the STEM community, and their interest in research and STEM fields. The results demonstrate high level of student satisfaction with research teamwork on important research, strong value alignment with STEM professional. In addition, students reported increased confidence in their ability to learning and applying STEM skills. This projects shows the impact of scientific collaboration and hands-on research on undergraduate engineering students and indicates students gain valuable experience and confidence that may positively influence their future success as engineers.

INTRODUCTION

The scientific community has increasingly prioritized efforts to diversify Science, Technology, Engineering, and Mathematics (STEM) fields, driving investigations into strategies to promote equity. Despite minor progress, studies have consistently reported a significant underrepresentation of women, minorities, and persons with disabilities in engineering, particularly among individuals earning graduate degrees [1, 2]. This disparity has been attributed to a perceived lack of connection to the engineering community and limited access to research opportunities, both of which contribute to feelings of isolation [3]. Students experiencing such isolation often report self-discouragement and declining interest in STEM careers, including seeking advanced degrees in engineering [4, 5, 6, 7].

Additional barriers for underrepresented groups include a lack of role models, mentorship, and a welcoming environment, all of which have been identified as factors contributing to disinterest in pursuing graduate education in engineering [6,7, 8, 9]. A critical contributor to this disparity is the feeling of isolation from the community and limited access minorities have to undergraduate research experiences which serve as a vital gateway to graduate education [4]. Studies have shown that undergraduate research experiences not only increase interest in graduate education, but also build research skills and confidence [10]. However, overburdened faculty and insufficient funded research positions often necessitate reliance on selection criteria such as GPA and prior research experience for these opportunities [11, 12]. These metrics disproportionately disadvantage underrepresented students, who may face isolation and discouragement that negatively impact their academic performance, further exacerbating inequities [3, 4, 5, 7, 8, 11]. Additionally, minority students often face inadequate academic preparation and cultural adjustment challenges, which amplify feelings of isolation and may influence their decision to not pursue higher education [13]. These compounded barriers leave underrepresented students further disadvantaged when faculty rely on metrics like GPA and prior research experience as indicators of competence for filling research positions. Such unintended biases perpetuate systemic inequities and reinforce barriers to access for minority students, ultimately contributing to their underrepresentation in graduate education.

Course-based Undergraduate Research Experience (CURE) provide an effective approach to addressing these barriers by offering low-risk, valuable exposure to research and scientific teamwork. These experiences enable students to collaborate with peers and mentors, gain experience in data collection, and present findings through methods such as presentations, posters, and group discussions. Hands-on experience allows students to work as teams and advance their understanding of the topics, further enhancing their research skills and collaborative abilities [14, 15]. By participating in CURE, students enhance their preparation for graduate school and strengthen their applications [16, 17, 18, 19]. Participation in CURE also provides students with exposure to engineering research career pathways, fosters an understating of relevant technological advancements, and cultivates a stronger sense of belonging within the research community [13, 20, 21, 22]. The perception of feeling connected to peers and mentors, as well as personal alignment with scientific values has been demonstrated to increase with CURE implementation [23, 24, 25]. Additionally, students report better-defined career goals, with perceived barriers shifting from a lack of experience to the need for developing industry connections [23]. Engagement in research has also been significantly associated with a greater sense of inclusion, positively influencing persistence and graduation rates [26, 27].

California State University, Chico, (CSU, Chico) is a Hispanic-Serving Institution, has been adopting the CURE-E model in science, technology, engineering, and mathematics (STEM) courses. We implemented CURE-E in Materials Science and Engineering Laboratory course in Mechanical Engineering curriculum as part of this effort. Students in this course investigated mechanical properties of hydrogel scaffolds for tissue engineering application in addition to the traditional course activities.

In this manuscript, we described an implementation of CURE-E in Mechanical Engineering curriculum and report its impact on student engagement and perception.

METHODS

Course Description: The CURE-E project is integrated into two sections of the Materials Science and Engineering Laboratory course, at CSU, Chico, with each section accommodating a capacity of 20 students. Materials Science and Engineering Laboratory provides practical experience with standard equipment used in materials testing, focusing on the procedures involved. The course's primary objectives include exploring the processes, structure, properties, and performance characteristics of engineered materials. It is a 3-hour laboratory course worth 1 unit, offered in both the spring and fall semesters.

The traditional structure of Materials Science and Engineering Laboratory course includes experiments on Hardness, Scanning Electron Microscopy (SEM), Fourier Transform Infrared Spectroscopy (FTIR), Strain Hardening, Microscopy for Grain Analysis, Jominy Quench Hardenability, Stress Concentration, Toughness, Precipitation Hardening, Raman Spectroscopy, and Tensile Testing. After completing the course, students gain the following experiences.

1. Determine the crystal and chemical structure of materials.
2. Measure the hardness of metals and plastics.
3. Prepare microscopy samples of steel and analyze the grain structure.
4. Execute a tensile test and interpret the results.
5. Harden a metal with cold forming.
6. Identify stress concentration in a body under force.
7. Execute a Charpy Impact Test and interpret the results.
8. Execute a Jominy Quench Hardenability Test and extrapolate the results.
9. Increase the hardness of aluminum with the Precipitation Hardening method.
10. Obtain an infrared spectrum of a plastic and interpret the results.
11. Interpret commercial data sheets of the mechanical properties of a metal or plastic.
12. Prepare a professional looking laboratory report.

Students in this course engage in hands-on experiments and are required to prepare and submit laboratory reports within one week after each experiment. These reports must include the following sections: Title Page, Assignment (from the Laboratory Manual), Objectives, Materials/Apparatus, Results, Calculations, Conclusion, and Raw Data. There are two quizzes in the semester which are based on the covered laboratory experiments and a comprehensive final exam which consist of questions related to the theory, measurements, and calculations of each experiment. Final course grade is traditionally calculated based on the laboratory reports (65%), two quizzes (15%), and a final exam (20%).

CURE-E Implementation: The integration of the CURE-E project into Materials Science and Engineering Laboratory aims to offer students genuine research experience, enhance their research skills, foster scientific thinking and approach, promote research ethics, and provide additional opportunities to support their career aspirations. In addition to the materials testing experiments, the CURE-E project enables students to gain practical experience in conducting literature searches, utilizing research databases effectively, identifying research questions and objectives, and further developing their research capabilities and cultivate an entrepreneurial mindset. In order to allocate sufficient time for the CURE-E materials, the traditional syllabus was modified by combining, removing, or integrating certain experiments within the CURE implementation. Table 1. shows the experiment and CURE-E project schedules for the semester.

Table 1: Materials Science and Engineering Laboratory (with CURE-E) course schedule.

Week	**Experiment**
1	Lab Report Prep.-Safety
2	*Introduction to CURE-E Project*
3	SEM
4	FTIR
5	Microscopy for Grain Analysis and *CURE-E Literature Review Group Discussion*
6	Hardness
7	Quiz#1
8	*CURE-E Literature Review Submission and CURE-E Project-Sample Fabrication*

Week	**Experiments**
9	Tensile-Compressive Test *Compressive Test for CURE-E Fabricated Scaffolds*
10	Strain Hardening
11	Stress Concentration
12	Impact Test
13	Quiz#2 *CURE-E Experiment Results and Entrepreneurship Mindset Discussion*
14	Fall Break
15	Jominy Quench Hardenability
16	No Lab (Dead Week)
17	*CURE-E Report Submission and Presentations*

In the first week of the semester, students were introduced to laboratory report preparation and participated in a workshop focused on this topic. Additionally, laboratory safety procedures were covered during the same week. The CURE-E project was introduced to the students in the second week and on. Course grading with CURE-E is determined based on the laboratory reports (60%), two quizzes (15%), final research project report (15%), and final research presentation (10%). The research report was required to be formatted as a manuscript for submission to peer-reviewed journals. The final research presentations were approximately 10 minutes per group.

CURE-E Project Description: Tissue engineering is an interdisciplinary field that combines engineering principles with life sciences to develop biological substitutes aimed at restoring, maintaining, or enhancing tissue function or even entire organs. This field focuses on regenerating injured or damaged tissues by utilizing scaffolds, which serve as essential building blocks. For successful tissue regeneration, cells must be seeded onto these scaffolds and supported with appropriate growth factors. The effectiveness of tissue growth is strongly influenced by the mechanical properties of the scaffolds.

Poly(ethylene glycol) diacrylate (PEGDA) hydrogels are widely recognized as ideal scaffolds for bone tissue engineering due to their biocompatibility, hydrophilicity, and highly tunable mechanical properties, which allow them to replicate the extracellular matrix of living tissues. These scaffolds are typically synthesized by combining liquid PEGDA, water, and a photoinitiator, followed by cross-linking through methods such as photolithography or thermal processing. The choice of photoinitiator and curing method influences the resulting scaffold's properties; however, the PEGDA concentration plays a particularly critical role in modulating the mechanical properties of the hydrogel. This tunability enables researchers to tailor scaffold properties, such as stiffness and strength, to meet the specific requirements of bone tissue engineering applications and facilitate cell proliferation [28, 29, 30, 31].

In CURE-E projects, PEGDA scaffolds were fabricated and determined their mechanical properties. The CURE-E project was implemented in two sections of Materials Science and Engineering Laboratory where students investigated the impact of material concentration and temperature on the mechanical properties of scaffolds. In Section 1, the effect of material concentration on scaffold properties was analyzed, while in Section 2, the influence of temperature on these properties was explored.

Students worked on the research projects in groups of 4-5 members, with each section consisting of four research groups. The objectives of the research projects are as follows: Research Goal 1: Identify the candidate materials for scaffolds. Research Goal 2: Fabrication of scaffolds at different concentrations (20%, 40%, 60%, 80%, and 100% for Section 1) and temperature-time (room temperature, 24 hr, 48 hr, 72 hr in the fridge for Section 2). Research Goal 3: Investigate the mechanical properties of PEGDA scaffolds and evaluate the impact of concentration, as well as temperature-time conditions, on these properties.

The implemented research project and PEGDA polymers were not included in the traditional Materials Science and Engineering Laboratory course, as it was part of the author's research. Integrating faculty research as a CURE-E project was intended to enhance student engagement by allowing students to actively participate in a real scientific project.

Project Deliverables and Assessment: Through the implementation of the CURE-E project in Materials Science and Engineering Laboratory course, students developed the following skills and prepared required reports and presentations.

Conducting Literature Searches and Effective Use of Databases: Students engaged in a comprehensive literature review, analyzing peer-reviewed publications to identify potential materials, conventional methods, fabrication techniques, and testing approaches. This process allowed students to determine the research questions, refine their literature search skills, and select appropriate materials for scaffold fabrication. They were required to review at least five peer-reviewed research papers published within the past five years, sourced from databases. Literature review process was discussed in the first week with CURE-E project description and example published papers were provided to the students. Through this exercise, students developed proficiency in conducting literature searches and effectively utilizing research databases. They also gained a deeper understanding of the role scaffolds play in bio-related applications and tissue regeneration. Additionally, students evaluated the advantages and disadvantages of candidate materials, fabrication methods, and testing techniques. The completed literature review was submitted by the eighth week of the semester.

Fabricating and testing scaffolds: Students developed research skills by fabricating scaffolds at various concentrations and conducting experiments to assess the mechanical properties of these scaffolds. They were tasked with identifying the most suitable material for scaffold fabrication and proposing appropriate fabrication and testing techniques covered in the course to evaluate the mechanical properties. Students also analyzed the advantages and disadvantages of their chosen fabrication techniques and established the relevant standards for the selected testing methods. In week eight, students, working collaboratively in groups with the research assistant, fabricated the scaffolds. In week nine, they performed compressive tests on the fabricated scaffolds to evaluate mechanical properties of the scaffolds such as strength and elasticity modulus.

Analyzing the Collected Data: Students analyzed the experiment results to assess the impact of concentration and temperature on the mechanical properties.

Entrepreneurship Mindset: The entrepreneurial mindset was introduced in week ten. The discussion was focused on how ideas and research results could be translated into tangible products. Entrepreneurial mindset resources provided to students via the CSU, Chico. The Cultivating a Culture of Entrepreneurial Mindset and Undergraduate Research (CEMUR) website. Students reviewed two impact stories and watched related videos. At the end of the semester, students were asked to submit a written report and deliver a presentation, both emphasizing the entrepreneurial mindset. In these assignments, students explored strategies for disseminating research findings and product information to the research and medical communities, as well as methods for reaching patients. Additionally, they were asked to outline their plans for identifying key stakeholders, addressing societal needs, and analyzing market gaps.

The CEMUR Project assesses student progress and success in CURE-E modified courses by administering the STEM Course Experience Survey to students at the end of the semester. The goal of the survey is to measure the degree to which a student feels connected to their STEM field and if they recognize the characteristics and activities associated with being in a STEM class and in developing an entrepreneurial mindset. The feedback is shared with course instructors as well as the CEMUR leadership team for review, discussion, and continuous improvement. The STEM Course Experience Survey was developed mainly from three sources, Hanauer, Graham, and Hatfull [32] The Persistence in the Sciences (PITS) Assessment Survey, Gold and Rodriguez [33] Measuring Entrepreneurial Mindset in Youth: Learnings from NFTE's Entrepreneurial Mindset Index and Corwin, et al., Laboratory Course Assessment Survey [34]. These resources were adapted into the 58-question STEM Course Experience Survey. It is delivered through a Google Form and takes approximately 20 minutes to complete. The CEMUR leadership team provides support to introduce the assessment tool in a CURE-e course and, whenever possible, faculty members provide time in class to complete it.

The survey administered at the end of the semester assessed the benefit and impact of the CURE-E project on *how often* students were engaged in developing research skills and *how apparent* students' perceptions of the project goals and research skills were. The survey also had a question on whether the entrepreneurial knowledge and skills learned in the course would help in their career.

The survey sought for how often students were engaged in research activity in 7 dimensions such as discussions with classmates, reflection on learning, being curious, contributing to the class, helping other students, constructive criticisms, and seek input. Students evaluated the questions using a 6-point scale: Weekly, Monthly, One or two times, Never, I don't know, I prefer not to respond. The questions are as follows:

In this course, I was encouraged to

1. discuss elements of my investigation with classmates or instructors.
2. reflect on what I was learning.
3. be curious.
4. contribute my ideas and suggestions during class discussions.
5. help other students collect or analyze data.
6. provide constructive criticism to classmates and challenge each other's interpretations.
7. share the problems I encountered during my investigation and seek input on how to address them.

The survey had 17 questions dedicated to analyze students' perception of the research activity. Student evaluated the questionnaire with a 8-point scale: Strongly agree, Agree, Somewhat agree, Somewhat disagree, Disagree, Strongly disagree, I don't know, I prefer not to respond. The questions are as follows:

In this course,

1. learning was often interactive.
2. I was expected to generate novel results that are unknown to the instructor and that could be of interest to the broader scientific community or others outside of class.
3. I was expected to conduct an investigation to find something previously unknown to myself, other students, and the instructor.
4. I was expected to formulate my own research questions or hypothesis to guide an investigation.
5. I was expected to develop new arguments or explanations based on data.
6. I was expected to explain how my work has resulted in new scientific knowledge.
7. I was expected to revise or repeat work to account for errors or fix problems.
8. I had time to review alignment of hypotheses and results, and make changes to improve the methods of investigation.
9. I had time to share and compare data with other students.

10. I had time to collect and analyze additional data to address new questions or further test hypotheses that arose during the investigation.
11. I had time to revise or repeat analyses of data or results based on feedback.
12. I became more comfortable with making decisions on how to move forward even when there was some uncertainty or challenges.
13. I had time to revise drafts of papers or presentations about my investigation based on feedback.
14. I was given opportunities to take initiative and work through obstacles in projects independently.
15. I was treated with respect by other students.
16. I was comfortable asking questions and proposing ideas.
17. I increased my ability to generate ideas and create solutions to problems.

Students used the same 8-point scale to respond to an item in the survey on entrepreneurial mindset: "I feel like the entrepreneurial knowledge and skills I learned in this course will help me in my major and career."

RESULTS:

Seventeen students volunteered to respond the survey (N=17). The results showed that majority of the responders were engaged "Weekly" basis in "discussing", "reflection", "curiosity", "contributing", "helping", "constructive criticisms", and "seeking input" as seen in Figure 1. The second most popular response was "Monthly" frequency and none of the participants reported "Never". The "weekly" response indicates the most frequent engagement and shows the course was able to successfully and regularly stimulate students to show STEM and researcher characteristics. We do not have any data on whether or not the students were actively engaged in these activities outside the class, and/or in higher frequency. Nevertheless, it is encouraging to see that no student responded with "Never" to any of the 7-dimensions of the questionnaire.

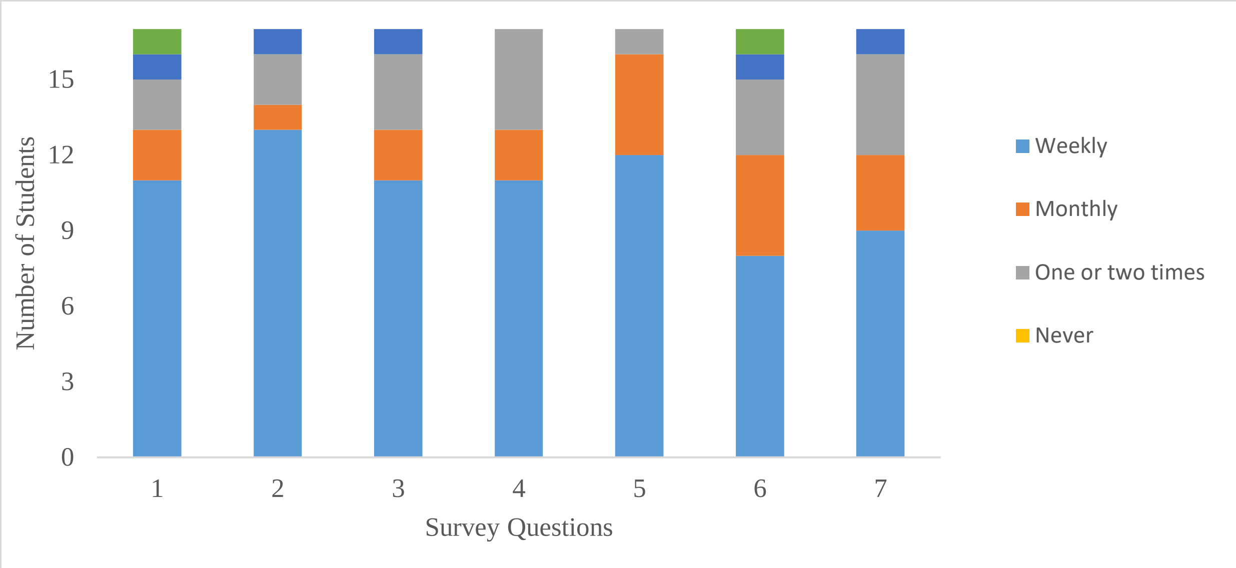

Figure 1: Survey results on “How *Often*” students felt engaged in STEM characteristics.

For the next section of the survey questioning students’ perception of the course, the majority of the student participants responded with “Strongly agree” and “Agree” to all questions as seen in Figure 2. These results demonstrate that students were aware of the merit and engaged with the elements of the course and scientific process. Students understood that the research topic was novel and had scientific merit and broad impact. Students agreed or strongly agreed that they were expected to formulate a research question, develop arguments for their data, and improve their methods. Students also agreed or strongly agreed that they shared and compared results with peers, helped each other, and revised and repeated the work based on feedback. These results demonstrate that the course succeed in introducing the all the critical elements of scientific methodology and approach.

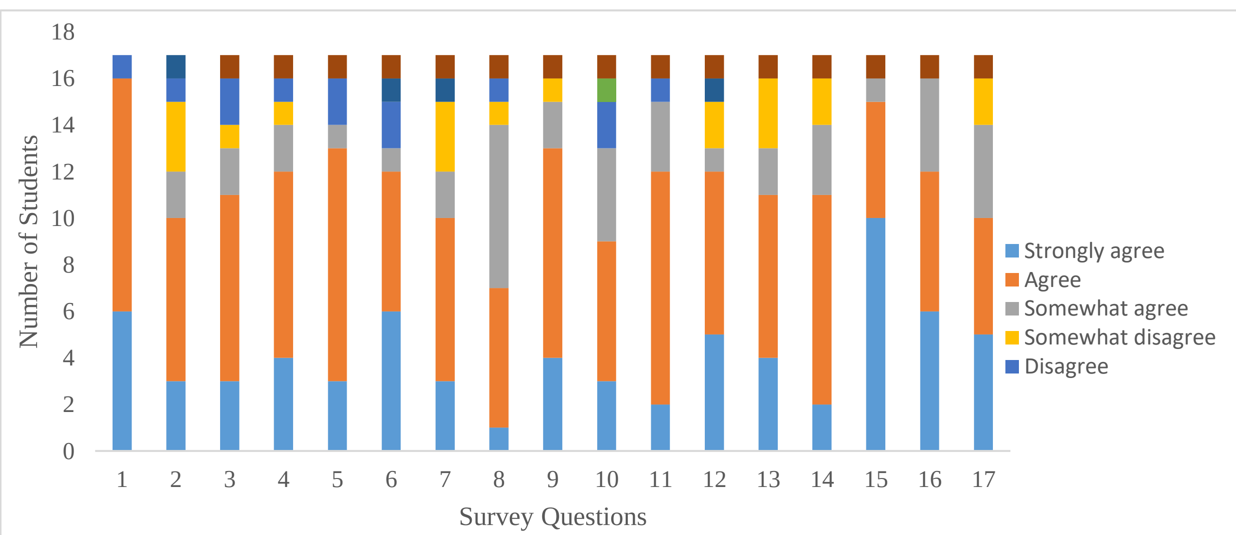

Figure 2: Survey results on “How Apparent” STEM characteristics were.

On the entrepreneurial knowledge and skill question more than half the student participants (64%) responded with "Agree" or "Strongly agree".

In the survey, students were also asked whether they heard about undergraduate research and 10 students indicated they first heard about it in this course. In addition, for a question of "Are you planning to apply for a faculty-mentored student research experience while you are at CSU, Chico?" 9 students responded as "Yes, I was motivated by this course".

DISCUSSION

California State University, Chico is a minority-serving institution with a large portion of student body being first generation college students. Students from these underprivileged communities often lack support and guidance from their inner circles and lack role models that would encourage success and rigor in academic education. Taking part in faculty-directed research helps students to stay motivated, improves STEM skills, and increases post-graduate education opportunities and career options. However, student researcher positions are limited and likely filled by informed students, which leads to inequity in these opportunities. CURE-E model integration in traditional curriculums helps break this inequity and increase diversity.

By implementing a CURE model in a materials science course within a mechanical engineering curriculum, this study seeks to evaluate the impact of such experiences on student outcomes. The integration of advanced biomaterials research, such as PEGDA hydrogels, into the curriculum provides students with practical, application-oriented learning opportunities that foster skill development, build confidence, and enhance their sense of belonging to the research community, thereby indirectly addressing barriers to equity and inclusion in STEM education.

Overall, the survey results indicate that the course effectively engaged students in key aspects of the scientific process, encouraged collaboration, and introduced elements of entrepreneurial mindset. Although further investigation into engagement outside of class would be valuable, the positive feedback from the participants suggests that the course structure and activities contributed to their understanding of scientific and entrepreneurial practices.

The fact that majority of the student responders indicated that they have not heard of undergraduate research before taking this course is significant and supportive of the argument made above about the underprivileged students. It is also exciting that CURE-E implementation in this course helped students become informed about research activities among the faculty and gain research skills to some degree. In conclusion, in this manuscript, we showed that CURE-E integration in Materials Science and Engineering Laboratory course in Mechanical Engineering curriculum helped students frequently engage in STEM activities, learn research skills, and develop an entrepreneurial mindset. Encouraged by the result of this study, the future implementations of CURE-E in different courses with control groups in collaboration with other faculty are considered.

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