Exploring the Impacts of Entrepreneurial Experiences in Biomedical Engineering Research Experiences for Undergraduate Programs

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***Abstract*—This research paper describes the entrepreneurial experiences of biomedical engineering (BME) undergraduate students participating in a summer research program. The field of BME requires advanced knowledge and skills across disciplines to keep up with rapid societal innovation. Research has investigated the importance of having an entrepreneurial mindset (EM) as a crucial part of a biomedical engineer's success, including their ability to make interdisciplinary connections, and understand the needs of others. EM is commonly implemented into undergraduate curricular settings, but EM can also be developed through undergraduate research settings, where students get hands-on experience with the research process through mentorship, laboratory skills, and data analysis.**

With support from the Kern Entrepreneurial Engineering Network (KEEN), we developed a Research Experience for Undergraduates (REU) program focused on BME student EM development. As part of the program, a subset of students are partnered with university-affiliated BME companies as summer research interns, where they gain research experience in an industry setting. These students were called entrepreneurial REU (eREU) fellows. EM was incorporated into professional development sessions built into the programs that all students attended: 8 eREU and 43 traditional REU fellows across three institutions. Both traditional REU and eREU students were asked to complete a pre- and post-program survey, including the Engineering Student Entrepreneurial Mindset Assessment (ESEMA) survey, which has associated validity evidence. These surveys asked students to provide insight into their program experiences and those experiences' impact on students' future plans.

We quantitatively analyzed the pre- and post-data using independent samples t-tests, where we determined that students tend to show statistically significant increases in many areas, including confidence in skills such as research design and laboratory expertise. When analyzing our results by institution, we found that students at institutions with an eREU program rated themselves statistically significantly higher in areas such as confidence in the ability to work in industry, conduct cutting-edge research, and contribute to the research field. Students in programs with eREU fellows were also overall more interested in their work. In addition to evaluating scale items, we analyzed students' open-ended responses to multiple survey questions, where we showed that the eREU and REU programs allowed students to solidify their post-graduate plans that generally consisted of seeking higher education, pursuing careers in research, and entering the field of medicine. Students reported having an overall positive experience with particular positive associations with the support they received from mentors and fellow students.

This study identifies the successes and setbacks of an eREU program designed to facilitate the development of EM in BME students. Based on the results of this study, we look forward to future iterations of this program that can give more students the opportunity to participate in the programming, reach out to more institutions, and continue to encourage BME-EM development. We expect that these results will provide insight into how BME students feel about their research experiences and how it contributes to their development of EM. This will allow for the identification of areas of further improvement to EM interventions in BME research contexts.

Keywords—biomedical engineering; undergraduate research; entrepreneurship

I. Introduction

This research paper explores the experiences of students participating in biomedical engineering summer research programs focused on entrepreneurial mindset development. Society requires that engineering students are prepared to enter the workforce when they graduate. This preparation includes the need for the development of skills, attributes, and attitudes associated with an Entrepreneurial Mindset (EM) [1]. Many engineering programs have integrated interventions throughout the students' degree experience to encourage entrepreneurial thinking, including idea generation, innovation, and problem-solving often using real-world contexts [2], [3]. One example of a previously-explored EM intervention is undergraduate research experiences [4], [5], which have been found to impact students' recognition of societal problems, utilization of critical thinking, and ability to generate their own ideas [4], [6]. However, this has not yet been explored in detail in a biomedical engineering context.

In this study, we analyze the experiences of students who participated in a biomedical engineering summer research experience for undergraduates (REU) and entrepreneurial REU (eREU) programs focused on EM development. We examine both quantitative and qualitative survey responses to understand students' EM experience in a biomedical engineering-specific context.

II. Literature Review

A. Entrepreneurial Mindset in Undergraduate Research

EM learning is commonly incorporated into classroom projects, and has been shown to successfully develop students' EM [1], [6]. Classroom interventions often involve asking students to solve real-world problems, or position themselves as a professional engineer to develop ideas and make decisions [7], [8]. Through assessment, students have reported growth in areas such as societal awareness, creativity, and problem-solving [9], [10].

Undergraduate research involvement gives students the opportunity to be exposed to hands-on projects and develop necessary workforce skills outside the classroom [11], [12], leading researchers have begun to expand the undergraduate research experience to include EM exposure and development [13], [14]. In Nezafati et al [13], research students were trained using 60 minute workshops in six "critical topics" (p. 3): framing your research question, thriving in a research environment, building resilience in research, pitching your research, visualizing your data, and maximizing the impact of your research. Students showed gains in EM-associated areas such as understanding the needs of stakeholders, working both independently and in a collaborative environment, and clearly articulating research findings to others. In another example, Burkey et al. [4] explored the benefits of students' exposure to EM through an REU program. Students were exposed to weekly seminars with different topics, including the impact of industry on innovation and entrepreneurship, idea generation, opportunity assessment, and business model generation. Students also had opportunities to visit start-up companies associated with the REU institution and tour makerspaces. These students reported gains in areas such as thinking outside the box, idea generation, and understanding business planning.

Despite recent research showing promising results in terms of EM incorporation into undergraduate research, the existing research is still minimal. Our work seeks to dive into this further by evaluating a new entrepreneurial REU initiative, which focuses on biomedical engineering students.

B. Entrepreneurial Mindset in Company Involvements

Though less studied, there is evidence to suggest that engineering students' experiences working for companies through internships or external work can contribute to their development of EM [4], [15], [16]. Engineering students often believe internships are beneficial for skill acquisition and career discovery [17], [18]. Through internship experiences, students learn about aspects of specific careers they enjoy and open the door to potential future opportunities for a full-time position [18]. Some universities create partnerships with companies to give students more opportunities for work experience, hoping to encourage these EM competencies [19], [20].

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Students tend to view internship experiences as supportive of their future career choices and entrepreneurial skill development [16], [21]. Students have stated that they develop EM traits not commonly learned through curricular experiences, such as professional development and communication [15], [22]. Our study incorporates both a research experience and company involvement into our eREU program, encouraging both research and career competencies associated with EM.

III. Methods

A. Study Design

This paper describes part of a larger study that explores the experiences of engineering students participating in research experience for undergraduates (REU) programs. With support from the Kern Entrepreneurial Engineering Network (KEEN), three institutions developed entrepreneurial-focused REU (eREU) programs, which, in the first year of implementation, hired two or three students per site to work alongside university-affiliated companies to gain entrepreneurship and research experience simultaneously. Students who participated as eREU fellows engaged in research alongside their company mentors, but also participated in professional development sessions targeting key EM and research skills alongside their REU fellow peers. The three institutions with eREU programs also had 10-20 traditional REU participants at each site. The goal of this work was to understand the perspectives of both eREU and REU students during the first implementation in the summer of 2023.

B. Data Collection

To explore the students' perspectives, both pre- and post-surveys were sent to all REU students at the three institutions who had both eREU and traditional REU participants. The pre-survey included Likert scale questions about their career plans, such as "I plan to continue to pursue education and a career in science or engineering", their skills, such as "I have adequate skills on how to conduct literature searches and produce a research plan", and their research perspectives, such as "I know how research contributes to science and technology". The pre-survey also included the Engineering Student Entrepreneurial Mindset Assessment (ESEMA) survey, a validated survey tool that identifies EM development in engineering students through six constructs: Altruism (contribution to society), Empathy (understanding others' perspectives), Help Seeking (willingness to ask for help), Ideation (generating ideas), Interest (enjoyment in a variety of things), and Open Mindedness (willingness to work with others with different expertise) [23]. There were also a set of open-ended questions where students could discuss their prior experiences and future plans in more detail, including questions like: "How do you think the REU program will relate to your future education or career plans and interests?". These questions sought to explore the impact of the eREU experience on students' long-term career plans.

The post-survey was nearly the same as the pre-survey, but with language reflecting the fact that it was administered at the end of the students' summer internships. Besides the inclusion of the pre-survey questions and ESEMA survey, the post-survey also included additional questions about mentorship,

who fellows interacted with in the program, and the research they completed by the end of the program.

In addition to sending the surveys to the students who participated in the eREU and REU programs at the three collaborating institutions, the survey was used to collect data from one additional institution that offered a traditional biomedical engineering related REU program which would allow us to explore the unique impacts of the entrepreneurial elements of our eREU program model. Three total institutions were used in the data analysis, as one of the eREU institutions (Institution #3) did not have enough survey participants. The total number of participants is shown in *Table I*.

TABLE I. PARTICPANTS FROM BIOMEDICAL ENGINEERING EREU AND REU PROGRAMS

	Institution #1	**Institution #2**	**Institution #3 (not included in analysis)**	**Institution #4 (non-eREU)**
Pre-survey	11	12	3	11
Post-survey	10	9	0	4

C. Data Analysis

The survey data was first cleaned before independent samples t-tests and the Mann-Whitney U non-parametric equivalent tests were performed to analyze the differences between pre- and post-survey Likert scale questions. These tests were chosen because we were concerned with the means of each of the Likert scale items compared to each other. These tests were also performed to compare pre- and post-survey responses for each institution. We recorded the means, standard deviations, and Cohen's D effect sizes for each t-test. We also performed a one-way ANOVA with three groups to compare each of the institutions to each other, and recorded the eta-squared effect sizes. An ANOVA was chosen because we were concerned with comparing the means of the three institutions directly to each other. One of the eREU institutions was not included in the ANOVA due to lack of participants. We also examined the eREU and REU students' data through means and standard deviations, but the sample size of eREU students was too small to complete statistical analysis [24].

For the open-ended responses, both inductive and deductive coding were used to analyze the data [25]. First, two researchers separately read through each response and recorded keywords to determine the general themes of the response. The researchers then met to resolve the keywords into codes for each question. After testing the formulated codes on five responses and finalizing the definitions, one researcher performed the remainder of the coding using the finalized codebooks.

IV. RESULTS & DISCUSSION

A. Competencies Observed Across REU Students

Across all REU programs in our study, we noticed differences from the pre-survey to the post-survey in students' perceptions of their writing ability, research skills, independence, and open-mindedness.

Across all REU students, almost all averages in Likert-scale survey responses were high (>3.5 out of 5) for both pre- and post-program survey responses, meaning students believed in their competencies throughout the entire program. When statistical significance ($p<0.05$) was shown in question responses, it was usually an increase with medium to high effect (Cohen's $D > 0.5$). This can be observed in *Table II*. The singular common decrease in the average response to a question was for the item "I am adequately prepared to contribute to and submit a scientific manuscript". Since students only had 10 weeks to work on their summer projects, it is likely that by the end of the program, students had a more realistic understanding of what is required to contribute to a scientific manuscript.

Students commonly increased in survey statements that expressed understanding of the research process, including research planning, writing, and organizing. For example, students significantly increased with a high effect for the statement: "I know how to conduct scientific research". Therefore, students were not only learning about research, but they were broadening their knowledge in specific research skills, which was also demonstrated by an increase with high effect in the survey statement: "I have adequate skills on how to conduct literature searches and produce a research plan". By the end of the program, students also expressed increased competencies in using laboratory equipment, working independently, and being open-minded.

In their open-ended reflection pre-survey responses, students discussed looking forward to understanding the research process, for example, a student from Institution #2 stated: "I think it will help me gain more research experience and broaden my knowledge of the topics I am most interested in." Students revisited their research skills and abilities in the post-survey, stating "It has expanded my knowledge in the field of research" (Student from Institution #1) and "It was interesting to get first-hand experience of doing research" (Student from Institution #2). Previous research has reported that students who participate in REU programs are often participating in research for the first time [4]. These students tend to experience growth in the areas that we have also observed here, including laboratory and research skills [11], collaboration [26], and confidence in their work [27].

TABLE II. STATISTICALLY SIGNIFICANT SURVEY QUESTIONS ACROSS ALL REU STUDENTS IN THE STUDY (+ DENOTES INCREASE, - DENOTES DECREASE)

Question	**Mean Difference**	**p**	**d**
I know how to conduct scientific research.	0.76 (+)	0.002	0.90
I have adequate skills on how to conduct literature searches and produce a research plan.	0.70 (+)	0.007	0.77
I have adequate laboratory skills, including the use of specialized scientific equipment.	0.63 (+)	0.019	0.66
I am adequately prepared to contribute to and submit a scientific manuscript.	0.79 (-)	0.007	0.76
I am prepared to work independently on portions of my research project.	0.46 (+)	0.005	0.68
ESEMA- Open-Mindedness	0.13 (+)	<0.001	0.38

B. Competencies Observed Institutionally

Next, we examined each institution. Referring back to *Table I*, Institution #3 did not have enough respondents to use in this portion of the analysis, so this section will report on data from the two other eREU institutions (Institution #1 & Institution #2), and the one external institution without an eREU program (Institution #4). We first noticed that Institutions #1 & #2 showed statistically significant increases in areas such as research skills, collaboration, and communication, while Institution #4 had decreases in questions about future career plans in STEM, perceptions of STEM research, and Ideation. This is observed in *Table III*.

For two of the institutions that had an associated eREU program, notable increases were seen in students' pre- and post-program responses. At Institution #1, increases were seen for the statements: "I have adequate abilities to conduct research in a cutting-edge research area" and "I know how to interact with a team of scientists and/or engineers". At Institution #2, one statistically significant increase was seen in ESEMA open-mindedness and one nearly statistically significant increase was seen in ESEMA empathy. According to a participant from Institution #1 in their open-ended reflection, "[The program] has taught me how to work with other people in a research setting." This program allowed students not only to conduct research, but provide a way of collaborating with other researchers effectively, which is also observed in the literature on engineering REU programs [28], [29]. Additionally, increases were present in the statement: "I know how to present and communicate scientific ideas and results." According to a participant from Institution #1, "I learned how to present myself and my results professionally." In previous programs, REU students usually have a writing or presentation component, often coupled with professional development seminars or workshops throughout the summer [5]. Literature indicates that these practices help students feel more confident in their scientific professional development, communication, and collaboration with other researchers [5], [12].

Institution #4, which did not have an associated eREU program, had notable decreases in survey responses from pre- to post-survey which included: "I plan to continue to pursue education and a career in science or technology," and "I know how research contributes to science and technology". These results are in contrast to the results from institutions with eREU programs, where students commonly expressed looking forward to a STEM career. For example, a participant from Institution #1 said, "I plan to apply to graduate school for a PhD. Then I plan to apply for positions in research and development in the BME field." Though there was not enough data to directly compare the students in an eREU fellowship and traditional REU students at each program using statistical tests, we hypothesize that the presence of an eREU program benefits not only the eREU students but all REU students in terms of their intention to pursue STEM careers, research intent, and confidence. This finding was further supported by the open-ended responses from students in the programs with an associate eREU experience. For example, students at the eREU program Institutions stated: "It has given me great feedback and experience within the industry world" (eREU Student from Institution #2), and "I greatly acknowledge this program as having helped me decide to pursue a Ph.D. because of my daily interactions with graduate students that provided great insight into programs to apply to and scholarships to look for" (Student from Institution #1).

Comparing all three Institutions to each other, a one-way ANOVA revealed that within the pre-survey, Institution #4 had a statistically significantly higher average in Ideation than the other two institutions. However for the post-survey, this statistical significance was not observed. While the Ideation scores for Institutions #1 and #2 increased slightly, the Ideation score for Institution #4 decreased with statistical significance (*Table IV*). Ideation is traditionally difficult for students to understand, especially early in their degree programs [30], [31]. It has been suggested that exposure to further hands-on work and experience may help students better understand the big picture that comes with ideation [32]. These results indicate that it is possible that students from Institution #4 felt that their understanding of ideation was high, but then after this exposure, realized that there is more about the ideation process that they did not understand. Though we cannot make definitive conclusions, it is possible that the students at eREU Institutions started to "catch up" in terms of ideation after exposure to this experience, therefore closing the gap enough for this statistical difference between Institution #4 and the eREU Institutions to not be observed in the post-survey.

Literature describing entrepreneurial mindset (EM) in engineering education has explored the effects of EM interventions on undergraduate students, showing that interventions in any capacity (curricular, extra-curricular, etc.) can help students develop aspects of an EM such as leadership, independence, creativity, and critical thinking [1], [3]. It has been suggested that consistent EM interventions can prepare students to enter the workforce with the skills and competencies expected of modern engineers [1]. Outside experiences such as research are generally less studied, but our work aligns with previous literature that suggests that EM experiences in undergraduate research settings help students understand customers' needs, value recognition, and the business and industry worlds [4], [13], [14]. As observed in the One-Way ANOVA test (*Table IV*), students at Institutions #1 & #2 were statistically significantly higher than students at Institution #4 for the survey statements: "I have adequate abilities to work in industry contexts, including in engineering contexts" and "I know how research contributes to science and technology", as well as for the ESEMA categories of Empathy, Help Seeking, and Interest. This indicates that it is possible that the EM interventions throughout the summer as well as the eREU program itself may have contributed to the students' perceived competence in their abilities to pursue research careers outside of academia and apply EM skills in research contexts.

TABLE III. STATISTICALLY SIGNIFICANT SURVEY QUESTIONS ACROSS INSTITUTIONS FROM PRE- TO POST-SURVEY (+ DENOTES INCREASE, - DENOTES DECREASE).

Institution #1 (eREU Program Present)			
Question	***Mean Difference***	***p***	***d***
I have adequate abilities to conduct research in a cutting-edge research area.	0.71 (+)	0.025	1.06

I know how to interact with a team of scientists and/or engineers.	0.54 (+)	0.010	1.26
I know how to conduct scientific research.	1.08 (+)	<0.001	1.84
I have adequate general scientific knowledge.	0.45 (+)	0.029	1.02
I have adequate skills on how to conduct literature searches and produce a research plan.	1.16 (+)	0.002	1.59
I have adequate laboratory skills, including the use of specialized scientific equipment.	0.89 (+)	0.007	1.33
I know how to present and communicate scientific ideas and results.	1.17 (+)	0.007	1.32
Institution #2 (eREU Program Present)			
Construct	***Mean Difference***	***p***	***d***
ESEMA – Empathy	0.81 (+)	0.055	0.81
ESEMA – Open-Mindedness	0.21 (+)	<0.001	0.53
Institution #4 (eREU Program not Present)			
Question	***Mean Difference***	***p***	***d***
I am prepared to work independently on portions of my research project.	1.55 (-)	0.015	1.67
I am interested in conducting research in a cutting-edge research area.	1.20 (-)	0.002	2.36
I know how research contributes to science and technology.	0.50 (-)	0.015	1.10
I have adequate teamwork and collaboration skills in research.	1.25 (-)	0.008	1.89
I am adequately prepared to contribute to and submit a scientific manuscript.	2.4 (-)	0.004	2.09
ESEMA – Ideation	0.41 (-)	0.014	0.44
ESEMA – Open-Mindedness	0.19 (+)	<0.001	0.56

TABLE IV. ANOVA RESULTS ACROSS INSTITUTIONS

Pre-Survey		
Question/Construct	***p***	η^2
ESEMA - Ideation	<0.001	0.002
	Games-Howell Post Hoc	***p***
	Institution #4 > Institution #1	0.001
	Institution #4 > Institution #2	<0.001
Post-Survey		
Question/Construct	***p***	η^2
I have adequate abilities to conduct research in a cutting-edge research area.	0.006	0.44
	Games-Howell Post Hoc	***p***
	Institution #1 > Institution #4	0.028
I have adequate abilities to work in industry contexts, including in engineering start-ups.	0.029	0.33
	Games-Howell Post Hoc	***p***
	Institution #1 > Institution #4	0.002
	Institution #2 > Institution #4	0.041
I know how research contributes to science and technology.	0.012	0.39
	Games-Howell Post Hoc	***p***
	Institution #1 > Institution #4	<0.001
	Institution #2 > Institution #4	0.019
I have adequate laboratory skills, including the use of specialized scientific equipment.	0.046	0.29
	Games-Howell Post Hoc	***p***
	Institution #1 > Institution #4	0.033
I am adequately prepared to contribute to and submit a scientific manuscript.	0.010	0.40
	Games-Howell Post Hoc	***p***
	Institution #1 > Institution #4	0.047
	Institution #2 > Institution #4	0.03
ESEMA - Empathy	<0.001	0.24
	Games-Howell Post Hoc	***p***
	Institution #1 > Institution #4	<0.001
	Institution #2 > Institution #4	<0.001
ESEMA – Help Seeking	0.002	0.11
	Games-Howell Post Hoc	***p***
	Institution #1 > Institution #4	0.027
	Institution #2 > Institution #4	0.001

C. Limitations

Though we believe the results of our study will be beneficial for providing context to our new eREU biomedical engineering programs and demonstrate that our program had a positive impact on students in the 2023 cohort, we recognize some limitations. Not all students responded to the surveys, and some only responded to either the pre- or the post-survey which limited our ability to perform meaningful analyses for all of our eREU sites. Unfortunately, one of eREU sites was not included, indicating that these results may not represent the eREU program in its entirety. Additionally, only one institution outside of the eREU network of institutions agreed to disseminate the survey to their students, so our sample size of traditional REU programs in biomedical engineering was lower than desired. In the future, we have made adjustments to improve our response rates and collect data from more institutions which will expand our understanding of the impacts of our eREU programming.

V. CONCLUSION

Our work explores the effects of a new entrepreneurial REU summer program for biomedical engineering students. Students completed a pre-survey and a post-survey that detailed specific perceived competencies provided by the program. We showed that students felt competent in areas such as the research process, laboratory skills, and working with others, which aligns with previous literature in this area. When examining three institutions separately, we showed that students from the institutions with an associated eREU program expressed higher perceived competence in many areas, including communication, confidence in career path, industry

experience, and desire to remain in the STEM field compared to students at an institution without an associated eREU program. These results suggest that the eREU program may be outfitting students with the entrepreneurial mindset attributes needed to tackle research problems and feel more confident in their abilities in addition to exposing them to research career pathways external to academia.

This project is ongoing, and there are a number of areas that require additional exploration. Our future work will continue to examine and improve our upcoming offerings of the eREU programs. Beyond the survey data presented in this paper, we also collected interview data from a subset of participants in the first iteration of the eREU program. We expect to perform a qualitative interpretation of those interviews through narrative analysis to explore the details of students' life experiences, leading up to and including their summer research experience, and how it relates to EM in three areas: cognitive, behavioral, and emotional. We expect that, with more iterations, students will experience more EM development and through sharing our findings, more institutions will begin to recognize the benefits of this program and implement our program elements into their own REU programs.

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