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A Multi-Institutional Assessment of Entrepreneurial Mindset Perceptions of Students Participating in Entrepreneurial REU Programs Through Concept Maps

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Abstract

Entrepreneurial mindset (EM) development in undergraduate biomedical engineering students ties to development of traits, such as innovation, designing for a customer base, and communication, that are highly valued for the development of new biomedical devices and products. One approach to instilling an EM for biomedical engineering students can be through the inclusion of research experiences, such as the Research Experience for Undergraduates (REU) program, where students develop research-based skills and learn to communicate effectively in a research setting. These research experiences have shown prior improvements in general engineering students' EM skill sets such as confidence and critical thinking, and have promoted retention in engineering programs. A recent initiative, supported by the Kern Entrepreneurial Engineering Network (KEEN), created biomedical engineering-focused entrepreneurial experiences called entrepreneurial REUs (eREU) that involve mentorship by start-up company researchers and seamless integration within existing, traditional REU programs at three partnering institutions. This initiative aims to foster the development of an EM in undergraduate biomedical engineering students under the well-studied paradigm of REUs.

As part of the program, seventeen students who participated in biomedical engineering REU programs as traditional REU or eREU students at one of the three partnering institutions were asked to engage in an activity where they defined EM through the creation of a concept map. Concept maps were selected as an assessment method due to their ability to directly assess students' perceptions of EM, as compared to indirect assessments such as self-reported surveys. These concept maps were assessed using categorical scoring with six categories: Creating Value, Education, Design Process, Business/Company/Organization, Innovation/Intellectual Property, and Knowledge, Skills, and Attributes (KSAs). We found that students most often used KSAs, Business/Company/Organization, and Design Process in their concept maps. When separating the sample between eREU and REU students, we found that there was no statistically significant difference in the categorical scores between the two groups, showing that although eREU students were exposed to an entrepreneurial intervention, it did not necessarily strengthen their perception of EM from a concept mapping standpoint over the short duration of this intervention. eREU students tended to use the KSAs category, aligning more with the perceptions of business students and professionals rather than other engineering students, which may be due to their exposure to working in a business and research setting in tandem. This study identifies the impacts of exposing biomedical engineering students to entrepreneurial research experiences during their undergraduate years to assist in development of the necessary understanding of EM and identify areas of potential further development to assist in better preparing biomedical engineering students for the roles that they will serve in their profession.

Introduction

Biomedical engineering (BME) programs tend to emphasize students developing skills from many different disciplines such as competencies in chemistry, physics, and electronics [1], [2]. However, this curricular approach may leave students unsure about potential careers [3], since it often does not include integrating innovation, ideation, and developing new products, which are crucial areas within the cutting-edge BME field [1], [4].

One way to improve BME students' confidence in their career preparation has been to introduce them to undergraduate research in BME-specific areas, such as research experience for undergraduates (REU) programs [5], [6], [7], as a way to encourage them to pursue graduate-level research and apply their curricular knowledge to practice [2], [8]. Generally, REU programs have encouraged development of communication skills through both oral presentation and writing technical research, laboratory and computer skills, and collaboration with other researchers [9], [10], [11]. Students tend to enjoy REU programs and find them valuable in helping direct their future plans, often including graduate school and further research [12], [13].

Recent research argues for developing an entrepreneurial mindset (EM) in engineering students [14], [15], suggesting that it is crucial that BME programs, including research experiences, emphasize EM competencies [16], [17]. EM interventions in engineering education exist to enhance the traditional technical-focused education engineers receive and encourage well-rounded engineering graduates [14], [18]. Students exposed to EM interventions in research experiences expressed gaining confidence in business skills and value recognition [19], [20], which are also important for the advancement of BME as a field [21], [22]. However, there is a gap in studying BME-specific research experiences in an EM context.

To address this gap, we developed an entrepreneurial REU program (eREU) that offers students the opportunity to work at a BME-specific, university-partnered startup company during their 10-week summer REU program, providing them hands-on access to an entrepreneurial process. To understand the impact of the eREU program, we sought to answer the following research questions: *(1) How do undergraduate students participating in summer biomedical engineering research experiences express their understanding of EM through concept maps?* And *(2) What differences exist in students' understanding of EM between students participating in BME entrepreneurial REU programs and students participating in traditional BME REU programs?*

Literature Review

Undergraduate Research Experiences for Engineering Students

Undergraduate research can be an opportunity for students to develop skills they are not often exposed to in their curricular programs such as teamwork and exposure to solving engineering problems through research [23], [24], [25]. Laboratories [26], [27], research-based courses [28], [29], and summer research programs [25], [30] have been developed to prepare students for different post-graduation options [24], [31]. The programs also encourage development of research skills, which cover a variety of topics that promote effectiveness in research [24], [31]. According to Minerick [24], advanced research skills include "Safety, Research and the laboratory, How to maintain a lab notebook; Literature searches and article applicability to your research; Dissection of a research article; Effective scientific presentations; Preparing an abstract of your research project, and Preparing a scientific poster" (p. 6). The National Science Foundation (NSF) funds Research Experiences for Undergraduates (REUs), which are programs dedicated to increasing the number of STEM students who pursue advanced degrees, focused on recruiting traditionally underrepresented students in the field [24], [32]. Students who are offered a position in an REU program at a university are provided with housing, meals, and a stipend for, commonly, 9-11 weeks during the summer months [33], [34], [35]. Students have the opportunity to work directly alongside faculty and graduate student mentors, complete an oral presentation or research paper, and sometimes pursue publication of their work [34], [36].

Students who participate in REU programs are commonly asked to answer surveys that detail their perceptions of their skills and experiences [11], [34], [37], where students commonly express having an increase in research skills, such as keeping lab notebooks and writing/reading research papers [31], laboratory skills [34], and collaboration [37]. In Nepal et al.'s study [11], students answered pre- and post-surveys about their experiences in mechanical, industrial, and systems engineering REU projects. Steady increases in perceived competence were shown for all aspects of scientific communication such as oral presentation and generating a scientific argument. Others explored students' career plans before and after exposure to a research program, and found that many students start to consider graduate school as an option after their REU experience [30], [34], [38]. For example, Moturu et al. [38] showed that before exposure to an REU, only 43% of students felt they were prepared to pursue a graduate degree in STEM; this increased to 70% after the completion of their REU program.

Biomedical engineering (BME) programs specifically have stressed exposure to undergraduate research due to the need for more BME graduate students and BME industry positions commonly requiring research competencies and experience [1], [26], [29]. Some undergraduate research experiences have been tailored to specific problems that require BMEs, such as researching a specific disease [7], [39] or creation of biomedical devices [6]. While BME REU programs have diverse approaches, the overarching goals of these programs are similar: to encourage STEM students to pursue STEM careers and/or graduate school [5], [6], and to strengthen research-based skills [7]. In Huffstickler et al.'s study [7], undergraduate research students were more likely to recognize creativity as an important aspect of being a biomedical engineer after exposure to their summer research experience. Though these students tend to recognize betterment of specific research skills, such as reading research papers and formulating a research project, and understanding of the research process, limited work has been done to explore entrepreneurial skills in BME research programs, which are valuable for the generation of biomedical innovations and students’ success in non-academic contexts [40], [41]. Traditionally, REU programs have been developed to encourage students to pursue graduate school, so the expansion of BME REU programs to include industry preparation through things like entrepreneurial skills development is new and in need of further exploration.

Entrepreneurial Mindset Development in Biomedical Engineering Students

Outside of undergraduate research experiences, some research has been done to understand how BME students develop an entrepreneurial mindset (EM). These studies explore curricular EM interventions designed to encourage development of EM skills such as curiosity about the course topics [22], reflective thinking [16], and designing for a certain customer base [17], [42]. In King et al.'s study [40], BME students participated in capstone design projects where they worked in teams to design prototypes based on existing patent applications of industry professionals. These students were able to learn about the engineering design process as well as the business side of intellectual property development such as patents, customer discovery, budgeting, and communication of results [40].

In several studies on EM development within a BME context, the expected outcomes of the study have been focused on the KEEN 3C's EM framework: Curiosity, Connections, and Creating Value [16], [17], [22]. The 3C's act as a tool for assessing how students develop their EM by designing survey questions specific to each of the 3C's [17], [22], or analyzing reflections using the 3C's as themes [16], [43]. For example, first-year students in Bell-Huff et al.'s study [16] created portfolios with reflections on their EM development. Students emphasized how they used their curiosity to explore different areas such as 3-D printing, made connections to build solutions to engineering problems, and understood customers' needs to create value [16].

Through EM interventions, BME students reported proficiency in skills such as problem identification, understanding user needs [22], teamwork [43], and persistence [17]. These results indicate that exposing BME undergraduates to EM-specific content throughout their curriculum yields positive results, but exposure outside of coursework and projects, such as in undergraduate research experiences has yet to be explored.

Entrepreneurial Mindset Assessment using Concept Maps

Student EM development in BME contexts has commonly been assessed using survey responses and qualitative analysis of open-ended reflections [16], [22]. Research also indicates the benefits of using concept maps as a direct assessment method of student EM understanding [44], [45]. Concept maps are a depiction of knowledge about a specific topic through connecting different concepts together to create a graphical map [46], [47]. Concepts are connected using propositions, or linking phrases, which provide context to the connections being made related to one overarching topic. In EM education, students commonly create concept maps with an overarching topic of EM or a related topic such as creating value [48], [49], [50]. These concept maps are assessed in a number of ways, including quantitatively through counting elements of the map and applying them to a formula [51], qualitatively through assigning scores based on quality and correctness of the content [52], and mixed methods through qualitatively assigning concepts to predetermined categories and applying category counts to a quantitative formula [53].

EM-specific concept mapping studies are commonly focused on analyzing types of scoring methods used to determine the best approach to assessing EM in engineering students [48], [50]. For example, Cartwright et al.'s study [48] compared three types of scoring, known as traditional (quantitative), holistic (qualitative) and categorical (mixed methods), and showed that there were no statistically significant differences in scores across methods, indicating the interchangeability of the scoring methods. Across studies, researchers have determined that EM concept map scores are relatively high, implying that concept maps are beneficial for helping students depict their understanding of EM and EM-related areas [49], [54].

In this study, we use categorical scoring due to its ability to produce quantitative scores while also analyzing the qualitative elements such as overall map quality and complexity [55]. Categorical scoring was developed by Segalas et al. [53] as a way to score sustainability-focused concept maps with high complexity, and was then adapted by other researchers to score concept maps for different topics such as infrastructure [56] and technology [57]. Though a validated set of categories does not yet exist for EM, recent research has formulated a codebook based on feedback from EM experts, student concept maps, and faculty who teach EM [45]. Our study will utilize an expanded version of the codebook developed in Bodnar et al. [45] to score BME REU students' EM concept maps [58].

Methods

The following section will detail our methods in designing, collecting data, and analyzing data to answer our research questions. This study was reviewed and approved by the Rowan University Institutional Review Board prior to any data collection taking place.

Study Design
This work is part of a larger initiative to develop EM in undergraduate students through REU programs. Through this initiative, BME REU students are provided with summer positions working for university affiliated start-up companies. They become involved with the entrepreneurial aspect of running and working for a company, while also developing research skills in line with a traditional REU program. One of the overarching goals of this program is to expose BME students to the multitude of career options for a biomedical engineer with a graduate degree and/or research experience, encouraging them to utilize their entrepreneurial skillsets in a number of contexts.

The first iteration of the entrepreneurial REU (eREU) program was offered for 10 weeks during the summer of 2023 at three institutions, Worcester Polytechnic Institute (WPI), Wake Forest University (WF), and Rowan University. As part of each program, 2-3 students participated in the eREU initiative, while 10-20 participated in the traditional REU program, all in BME research areas. All students attended robust professional development seminars and lectures once per week that included entrepreneurial topics, and designed a poster to present at a final research symposium.

This work presents one aspect of our assessment of the summer program, where a subset of REU students and all of the eREU students were recruited to participate in a qualitative interview and concept mapping activity related to EM.

Data Collection
Student participants created concept maps with the main topic "Entrepreneurial Mindset". The researcher gave a brief five-minute introduction to concept maps and how to build them before giving a maximum of 20 minutes for the participant to build their EM concept map by hand. The participants were not given any information about EM before or during the activity, and were specifically instructed to use their own perceptions and draw on previous experiences that have shaped how they view EM.

Participants
There were 17 total participants who completed the EM concept maps, representing the three institutions (WPI, WF, Rowan). Immediately following the concept map preparation, students provided their own pseudonyms that were used to de-identify their concept maps, and confirmed their demographic information. The participants' demographics are provided in aggregate in Table 1.

Table 1. Aggregated Participant Demographics (sample size in brackets)

Institution	**Position**	**Gender**	**Race/Ethnicity**
WPI (5)	eREU (8)	Female (11)	White (9)
WF (6)	REU (9)	Male (6)	Hispanic or Latino (3)
Rowan (6)			Asian/Pacific Islander (2)
			Black or African American (1)
			Middle Eastern/North African (1)
			Biracial or Multiracial (1)

Data Analysis
Concept maps were first manually copied from paper into the CmapTools software for consistent assessment and readability. Concept maps were then scored by two researchers using categorical scoring, a mixed methods assessment approach where concepts in a map are assigned to a predetermined list of categories specific to the main topic. We used a pre-existing EM categorical scoring codebook developed by Jackson et al. [58], depicted in Table 2.

For the categorical scoring process, the two researchers scored two randomly selected concept maps together to calibrate their understanding of the codebook. Then, the same two researchers separately scored another five randomly selected concept maps and met to discuss discrepancies. The remaining concept maps were then again scored separately and the two researchers met to finalize the assigned concept map categories. As all concept maps were scored by the two researchers and discrepancies reconciled, no inter-rater reliability was calculated for the scoring process. After concept maps were scored, quantitative metrics were recorded such as the number of concepts per map (NC), the number of interlinks between concepts (NIL), the number of categories included at the main category level (NCAT), and the complexity index of each map (CI = NC * NIL/NCAT). A higher complexity index equates to a more developed understanding of EM, and a lower complexity index equates to a less developed understanding of EM. Further details about these metrics can be found in Watson et al.'s [55] paper, which investigated concept map scoring methods in detail. Across concept maps, the average scores were calculated as well as the frequency of categories. Qualitative metrics were also recorded such as themes across concept maps. Concept maps were then grouped by eREU students and REU students and the quantitative and qualitative metrics were interpreted using this grouping. Statistical analysis was performed using independent samples t-tests to compare the eREU and REU students across their total number of concepts, categories, interlinks, and overall complexity index. Both the parametric (t-test) and non-parametric (Mann-Whitney U test) tests were completed due to small sample size, and the Cohen's D effect sizes were calculated.

Table 2. EM Categorical Scoring Codebook (from [58])

Indicator	Main Category	Sub-Tag	Definition	Example
1	***Creating Value***		***Elements related to creating a positive impact on beneficiaries***	***Value Proposition***
7		Problem Identification	General elements related to value creation and creating a positive impact	World problems, grand challenges, meeting needs
8		Beneficiaries	Elements that show the value created for a specific person or entity. This includes beneficiaries that are not the entrepreneur or the company, such as specific users, customers, or any other external recipient of the value	Society, customers, end user
9		Types of Value	Elements illustrating the various types of value that will have an impact by meeting a specific need or solving a specific problem. This includes the end result or outcome	Economic, environmental, societal
2	***Education***		***Elements that illustrate how a person learns and develops an EM through a formal process***	***Career preparation***
10		Education System	Elements denoting the formal education system or progression in the education system	Progression, institution, degree
11		Curricular	Elements related to the curriculum including EM interventions	Classroom, course project, engineering
12		Co-curricular/ Extra-curricular	Elements relating to co-curricular (university-sponsored) and non-curricular (not university-sponsored) activities that help develop an EM	Clubs, research/ personal experience, co-op
3	***Design Process***		***Elements that demonstrate specific actions one takes to progress toward a goal, make decisions, communicate with others, and develop a product, process, system, or service***	***Making connections, feedback, decision making***
13		Planning/ Strategy	Elements of the planning and strategy phase of the design process related to providing a product, service, system, or process	Planning, goal setting, opportunity recognition
14		Development/ Implementation	Elements denoting the methods and activities that lead to a prototype of a product or idea	Ideations, prototype development
15		Evaluation/ Assessment	Elements noting the experiments and tests used to evaluate if a product, process, system, or service meets stated needs or objectives	Testing, experiment, assessment

16		Collaboration	Elements noting the process or actions involved in working with others toward a shared goal	Networking, cooperation, discussion, teamwork
4	***Business/ Company/ Organization***		***Elements of EM that refer to the skills, necessities, and outcomes of providing a product or service***	***Partnership, nonprofit***
17		Channels	Elements showing the means through which an organization communicates with and delivers a specific product or service (i.e. value) to its customers or end users	Supply chain, marketing a product, distribution system
18		Start-up	Elements of organizations referring to things needed to start a business or a new business line or service	Investment/investors, mission statement,
19		Operations	Areas of expertise and management specifically related to business operations	Accounting, financial advising, economics, legal
20		Resources	Elements noting the inputs needed to produce the desired skills, solve necessities, deliver outcomes, or provide a product or service	Capital, equipment, infrastructure
5	***Innovation/ Intellectual Property***		***Elements noting original products, services, processes or research used to fuel the creation process or that are produced from the creation process***	***Make something new, something out of nothing***
21		Novel/New invention	Elements referencing innovations in technology, products, ideas, or research that does not yet exist	New application, creation of technology
22		Existing/ Modifying	Elements referencing innovations in technology, products, or ideas that already exist or that are modified	Existing products, making changes to products
6	***KSAs***		***Elements of Knowledge, Skills, and Attributes specific to an individual with an EM***	***Personal or career goals, learning from experience***
23		Knowledge & Skills	Elements related to knowledge and abilities that an individual can learn (through education or engineering practice) as they develop their EM	Technical skills, leadership, problem solving, time management
24		Attributes & Attitudes	Character traits that describe a person with an EM. It includes concepts related to their personality such as attitudes and personal traits	Creativity, curiosity, empathy, persistence
25	***Uncategorized***		***Terms that do not fit within any of the categories, or fit within too many categories to select one***	***Industry, understanding***

Results & Discussion

Research Question 1
Our first research question asks: *How do undergraduate students participating in summer biomedical engineering research experiences express their understanding of EM through concept maps?*

To answer this question, we examined how students scored overall on their concept maps, which categories they were frequently including in their concept maps, and the themes we saw across concept maps. Table 3 depicts the concept map metrics included in the categorical scoring formula: number of concepts, number of categories, number of interlinks and the complexity index.

Table 3. Categorical Scoring Metrics Across Concept Maps (n = 17)

	Average Value	**Standard Deviation**	**Highest Value**	**Lowest Value**
Number of Concepts	21	5.41	32	10
Number of Categories	4	1.20	6	2
Number of Interlinks	5	4.08	13	0
Complexity Index	24	19.85	58.5	0

From these metrics, students tended to be fairly consistent in the number of categories and concepts in their concept maps, but much less consistent in their use of interlinks which led to the substantial spread in complexity scores obtained. Some concept maps, like the one in Figure 1a, kept their ideas separate, leading to each hierarchy of the map staying within one category. Others, like the one in Figure 1b, weaved their EM conceptualizations throughout their map, leading to more interlinks and a higher score. The concept maps similar to the one presented in Figure 1b show a stronger ability to make connections between different aspects of EM.

There is still much debate about how to define EM within an engineering context [15], [59], which has led to many EM interventions focusing purely on EM concepts rather than an overarching definition. This approach to EM interventions may contribute to a more basic understanding of EM where students separate concepts by category rather than looking for connections between them. Additionally, some students may have had different exposures to EM before their REU or eREU experience, leading to diverse approaches in how they connect concepts from different categories.

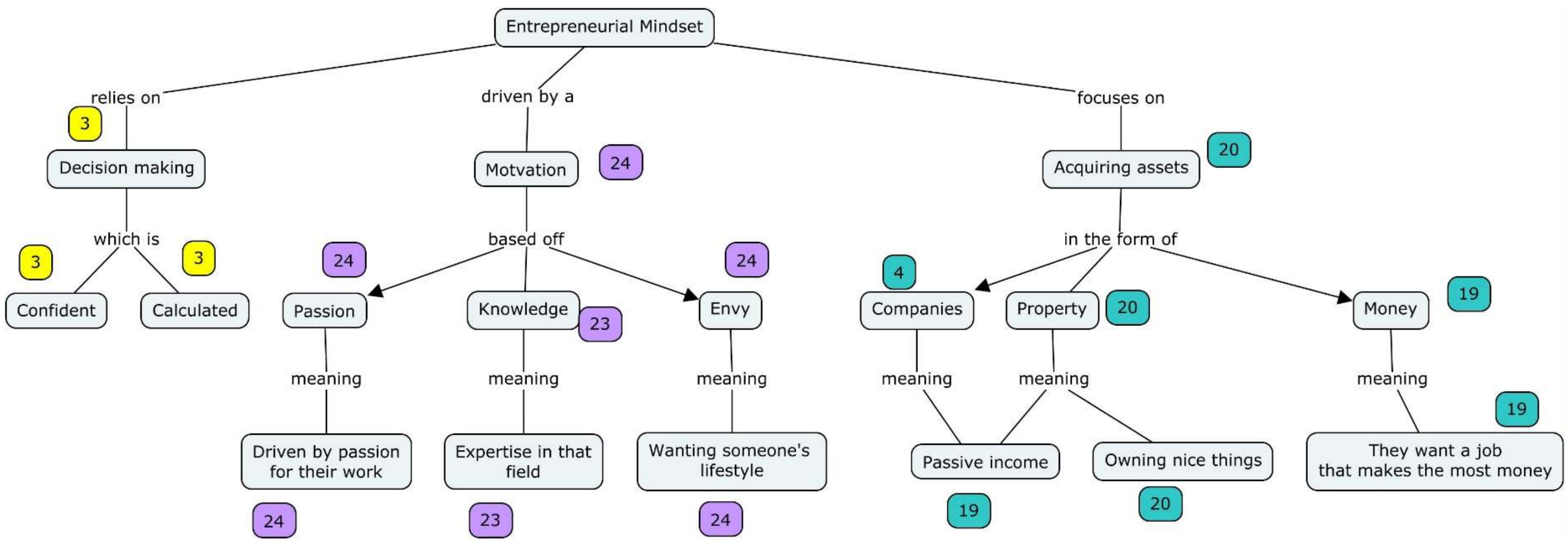

Figure 1a. Concept Map Featuring No Interlinks (CI = 0)

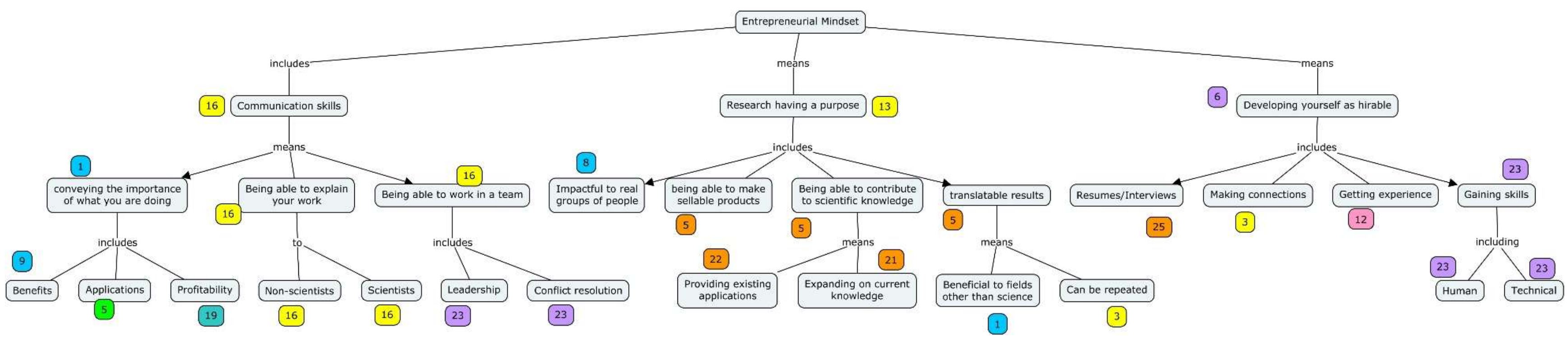

Figure 1b. Concept Map Featuring 13 Interlinks (CI = 58.5)

In terms of individual categories, KSA's was the most used, accounting for nearly 40% of all concepts used. This was followed by Business/Company/Organization (23%), Design Process (19%), Creating Value (9%), Education (7%), and finally Innovation/Intellectual Property (5%). Out of the 17 concept maps, 16 used KSA's at least once, 14 used Business, 15 used Process, 10 used Creating Value, 6 used Education, and 7 used Innovation/Intellectual Property. From these results, the students were mostly understanding EM through KSA's, Business, and Design Process concepts.

There were 40 total concepts that were uncategorized across maps, with at least one uncategorized concept appearing in 11 out of the 17 maps. Some of these terms included very general terms such as "success", "advantage", and "exhaustion". Though these terms may be linked to EM in some contexts, the students did not provide sufficient information to allow for their accurate categorization leading to them being classified as uncategorized. Therefore, we concluded that students were not necessarily misinterpreting EM with the uncategorized terms, rather their ability to represent this understanding in a concept map may have been limited. For this reason, uncategorized terms were not analyzed further.

Knowledge, Skills, & Attributes
KSA's were overwhelmingly the most used across the 17 concept maps, used a total of 117 times. Within the KSA's category, the subcategory "Attributes and Attitudes" was coded the most, where students commonly listed motivation, passion/dedication, confidence, and creativity. Under the "Knowledge & Skills" subcategory, two common concepts seen across concept maps were organizational skills and risk taking.

In previous research, engineering students view EM from the lens of business more than personality [54], [60], which is not consistent in these results. Biomedical engineering students tend to differ from engineering students in other disciplines in that their reasons for selecting a BME major may involve an interest in unique subjects to engineering such as human health, the human body, or medicine [61], [62]. Therefore, these students may be more focused on the unique knowledge, skills, and attributes required of an entrepreneurial biomedical engineer as compared to other engineers, leading to their focus on KSAs in their concept maps.

Additionally, the REU and eREU programs exposed students to research experiences that encouraged research skills, and introduced students to seminars that discussed career options, which often involved discussing interests, motivation, and passion as part of selecting a career path. Therefore, it is possible that the students' experiences with the REU program contributed to their focus on KSAs in their concept maps.

Business/Company/Organization
This category made up the second most used across student concept maps, appearing a total of 73 times. The most common subcategory was "Operations", where themes of money and finance were frequent. Students also used the business category in concepts such as advertising, marketing, investors/investments, and clients/customers. These findings seem to align more with what has been seen of engineering students' general perceptions of EM than anything that could be attributed to their REU experiences. Engineering students' understanding of EM tends to be much narrower than that of business students or instructors, which often involves the inclusion of

business aspects that are not seen in the definitions of these other stakeholders [60], [63], [64]. This has been attributed to their lack of experience with entrepreneurship [63], pointing to the importance of EM interventions that broaden their perceptions.

Design Process

The design process category was the third most used, showing up a total of 61 times. Two subcategories appeared 14 times each: "Planning/Strategy" and "Collaboration". Within the planning subcategory, students listed concepts such as research and identifying the problem, customers, and goals. Within the collaboration subcategory, students listed concepts such as communication, networking, and teamwork.

REU programs typically recruit underrepresented and/or minoritized students with no or minimal research experience [6], [32], so they are often heavily focused on introductory research concepts commonly included in the planning/strategy subcategory. Though many of the students had exposure to equipment, data analysis, and evaluation of projects, it is likely they felt most comfortable describing the planning and strategy stage of EM since that involves the opportunity identification and goal setting they were consistently coming back to throughout the entire duration of the program. REU programs tend to require a presentation or report at the end of the program, some of which include writing and/or presenting workshops that commonly emphasize the importance of conveying the goal of the project and project planning [19], [38]. Students in this REU/eREU program were similarly required to complete and present a poster at the end of the program, which may have influenced their more in-depth understanding of conveying the early stages of their project. Like many other REU programs, students also had the opportunity to collaborate with their mentors, graduate students, and other students throughout the program [6], [7], [39], which may have influenced their focus on the collaboration subcategory as part of their understanding of EM.

Research Question 2

Our second research question asks: *What differences exist in students' understanding of EM between students participating in BME entrepreneurial REU programs and students participating in traditional BME REU programs?*

To answer this question, we analyzed the map metrics separately for eREU and REU students. These can be found in Table 4.

Table 4. Concept Map Metrics for eREU and REU Students

	eREU (n = 8)		**REU (n = 9)**		**p-value**	**Effect Size**
	Average	**Standard Deviation**	**Average**	**Standard Deviation**		
Number of Concepts	22.38	5.95	20.33	5.02	0.46	0.37
Number of Categories	3.75	1.04	4.33	1.32	0.33	0.49
Number of Interlinks	3.88	3.83	5.78	4.29	0.35	0.47
Complexity Index	20.31	20.42	27.34	19.93	0.48	0.35

As found in Table 4, similar to the categorical scoring analysis of all concept maps, both eREU and REU students showed a lot of variability in the number of inter-links present on their concept maps leading to the broader range of complexity indices. When specifically comparing the two populations, eREU students had lower values for every metric except concepts, where they had, on average, 2 more concepts in their concept maps, however, none of these metrics showed statistically significant differences. The effect sizes for these analyses are also listed, where it shows medium effect for each p-value. This shows that although eREU students are receiving entrepreneurial interventions, their depictions of EM do not show evidence of greater understanding of what EM is than those students in traditional REU programs, although this may change with larger sample sizes.

It is possible that eREU students are developing aspects of an EM through their programs, but they are unable to make the connections to their definition of EM through the concept mapping exercise. In a previous study where students were interviewed about their definitions of EM, students described a very basic understanding of EM before being introduced to a literature based conceptualization, where they then expanded upon their own perceptions of themselves to include the EM elements described by the interviewers [60]. Since EM was not briefly introduced to the students in this study before asking them to define it explicitly in a concept map, it is possible that they were unable to make the connections between the EM developed through their eREU experience and the concept mapping activity.

In terms of the individual categories, a greater variety in the number of categories represented on their concept maps was noticed for REU students as compared to eREU students. eREU students tended to focus on KSAs with much fewer concepts pertaining to other EM categories. The graphical display of the categorical representation of concepts can be found in Figure 2.

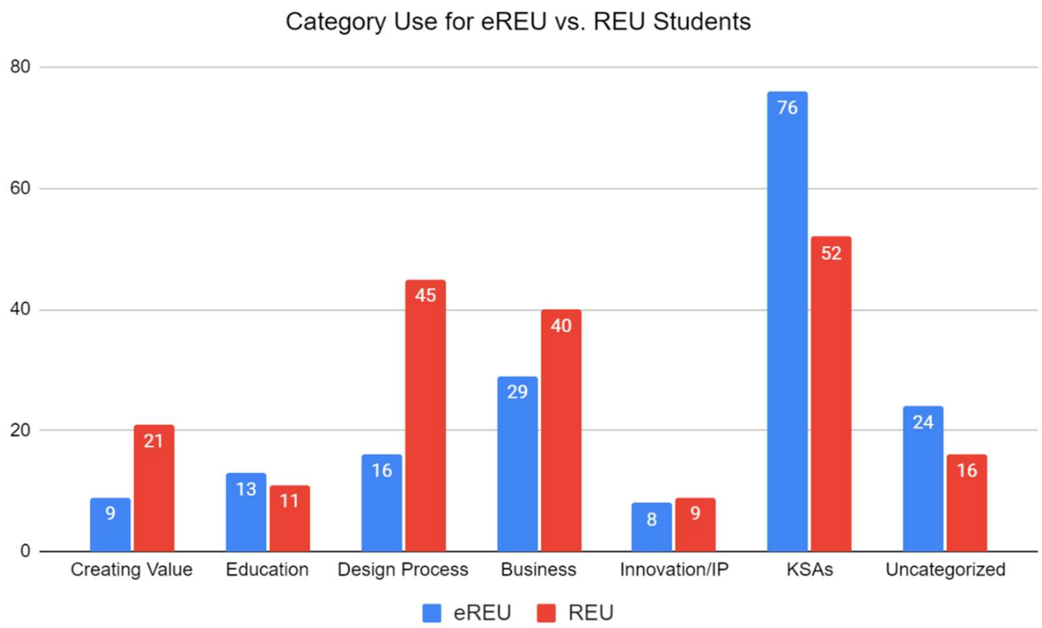

Figure 2. Categories Used in eREU and REU Student Concept Maps

Though the use of KSAs is prominent in both eREU (100%) and REU (89%) students' concept maps, KSAs made up 43% of the eREU concepts, and only 27% of the REU concepts. This indicates that eREU students view EM with more emphasis on the personality attributes and skills of someone with an EM, but much less on the other aspects that make up this complicated construct. We noticed the same trend in the design process category but in the opposite direction, where although the category itself appeared at least once in 88% of the eREU maps and 89% of the REU maps, the REU students used more design process concepts overall (23% of REU students' total concepts versus 9% of eREU students' total concepts). This indicates that REU students are associating EM with the design process by adding more concepts associated with this category when describing this component of EM. When looking at the category use from the perspective of the number of concept maps that utilized each category, we found that the business category appeared at least once in only 5 of the eREU students' concept maps, whereas it appeared in 8 of the REU students' concept maps.

The focus of eREU students on KSAs provides further insight into our earlier discussion point, where students may be focusing less on business and design and more on KSAs after their exposure to research and an entrepreneurial experience. Previous studies on undergraduate research experiences in BME point to students' ability to acknowledge their increasing creativity, confidence, and identity development [6], [7], [39], all of which are elements we saw in eREU students' concept maps under KSAs. It is possible that the eREU students' experiences with start-up companies and research at the same time gave them opportunities to refine their entrepreneurial knowledge in a personal way, leading to their focus on KSAs over any other category. Additionally, individuals with a business background have been shown to minimize the focus on business creation and not include topics related to design as part of their EM definition [50], [63], [65], [66]. Since these students were exposed to entrepreneurship in a different way than most engineering students, it is possible that their EM perceptions were shaped in a way more similar to those with a business background than other engineering students.

Limitations

Though our study makes contributions to understanding BME students' EM through direct assessment, we acknowledge some limitations. Our sample size was 17 students, which does not provide enough data for generalizability of our results. The students were also participating in different REU and eREU interventions, which may have exposed them to different aspects of EM. Finally, some students had different levels of concept mapping experience, which may have contributed to higher or lower scoring concept maps. Some students at one institution took part in a concept mapping workshop earlier in the summer, and other students may have had previous experience with mapping prior to the eREU or REU program.

Conclusions & Future Work

It is crucial that biomedical engineering students develop an entrepreneurial mindset (EM) to gain the necessary skills to enhance the value creation required by professional biomedical engineers. Though EM has been investigated in traditional BME curricular settings, it has not yet been explored in BME research experiences, which have been emphasized as necessary experiences for undergraduate students. Our entrepreneurial REU (eREU) program was created to expose BME students to research through working with a start-up company to encourage their EM development. We analyzed concept maps created by both eREU and traditional REU students at three institutions to assess their EM development, which pointed to students' diverse use of interlinks between categories and their focus on the Knowledge, Skills, and Attributes (KSAs) associated with having an EM. When examining eREU and REU students separately, eREU students generally scored lower and had a greater focus on KSA's than traditional REU students. In previous research, engineering students focused mainly on business in their perceptions of EM, which was not seen in our eREU students, who may have been influenced by their entrepreneurial experiences to perceive EM more similarly to business professionals than engineers.

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