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Examining student entrepreneurial mindset in a large first-year design course

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Abstract

Many engineering problems require both critical and creative thinking knowledge and skills to generate unique solutions. To give students the opportunity to practice this, university engineering programs often focus on team design projects to connect course content with real-world applications that are open-ended and require novel ideas. One goal of these projects is for students to develop an entrepreneurial mindset (EM), defined as the student's ability to be curious, draw connections, and create value. In this study, we developed materials targeting each of these aspects of the EM for an introductory engineering graphics and design course. The course has 400+ students enrolled annually, with a majority being first-year mechanical, industrial, and systems engineering students. This new content was introduced throughout the pilot semester to engage students' ideation skills and inspire curiosity about design concepts. To determine the impact of this modified content on aspects of students' EM, a survey was administered to 150 students at the beginning and end of the semester. The survey included Likert scale questions (range from 1-5) to gauge students' perception of their creative ability and the components of EM (Curiosity, Connections, Creating Value, Creativity, Collaboration). This work analyzes quantitative response data from the beginning (n=128) and end (n=70) of the semester, corresponding to before and after intervention, respectively. Quantitative analyses revealed statistically significant increases in Creating Value scores from beginning to end of the semester (9.94%, p=1.52E-5), and no changes in other categories. Additional insights from a question-level analysis revealed mixed results, with significant changes from beginning to the end of the semester ranging from decreases of 15.66% in a question targeting students' ability to make connections, and a 21.05% in a question related to students' ability to create value. Moving forward, we aim to develop and assess activities to further target students' ability to be curious and draw connections, while maintaining the curricular modifications that impacted students' ability to create value. Assessing the impact of these new activities can inform best practices to expand students' EM earlier in their post-secondary education, both within similar introductory engineering design courses and other engineering courses that utilize team design projects to reinforce EM concepts.

Introduction

Engineering problems have grown increasingly complex, requiring engineers to develop not only strong technical skills but also the ability to innovate, connect different ideas, and create value with their designs. These abilities, collectively referred to as the entrepreneurial mindset (EM), are captured in the KEEN framework's three C's: Curiosity, Connections, and Creating Value [1, 2]. However, despite widespread adoption of entrepreneurial thinking in engineering programs, many introductory design courses do not provide opportunities for students to practice these skills.

The aim of this study was to design and integrate three EM-focused intervention activities into the lab component of an introductory engineering design course at the University of Illinois Urbana–Champaign and evaluate the impact of these activities on students' entrepreneurial mindset. This first-year course consists of a semester-long design project where students learn and practice the design process, computer-aided design, and engineering drawings. Intervention activities were created to support this project and also develop students' EM. To measure the impact of the intervention on students' EM, pre- and post-semester surveys were administered and analyzed for significant changes.

Methods

For this study, three intervention activities were created to develop students' EM. The results of these activities and the course curriculum as a whole on students' EM was measured by administering a survey at the beginning and end of the course. The survey featured twenty-one Likert scale questions (range 1-5) with each question grouped into one of five categories: curiosity, connections, creating value, creativity, and collaboration.

Course Description

ME 170 is a Computer-Aided Design (CAD) course offered to primarily first-year students at the University of Illinois Urbana-Champaign. While it is a required introductory design course for all students in the Mechanical Science and Engineering department, it also enrolls students from related disciplines such as Engineering Undeclared. The course consists of twice weekly lectures and weekly lab sections. In lectures, students are introduced to a range of topics relevant to the engineering design process, including manufacturing methods, human-centered design, engineering drawings, and geometric dimensioning and tolerancing.

There were 155 students enrolled in this course during the Spring 2025 semester, with smaller lab sections each consisting of about 40 students. Students apply lecture concepts and develop their CAD skills through a semester-long group design project in which they develop a novel consumer product. This project requires students to conduct target user interviews, document their design decisions, create complete CAD models, and produce detailed manufacturing drawings. Many of the components of the final project lend themselves to EM development, as students must exercise curiosity in identifying problems and target users, connect information from various sources, and identify opportunities to create value for their end users and in the manufacturing process. Therefore, this course provides a unique opportunity to introduce students to EM early in their engineering career.

Intervention Activities

Three new EM-focused lab activities were introduced to the curriculum with the goal of targeting the three C's of the KEEN educational framework: Curiosity, Connections, and Creating Value.

The first intervention activity was a product exploration activity, intended to develop students' curiosity. In this activity, students were tasked with considering design decisions behind mass-produced consumer parts. Students began by creating a list of 40+ consumer items used in their daily lives, and worked in pairs to identify one specific consumer item to analyze. They considered the needs the product is addressing, any potential issues users may experience, and ways the design might be improved. Finally, students researched similar products online to compare prices, function, and design complexity.

The second activity focused on ideation strategies for the design project, intended to develop students' curiosity and ability to create value. Using Design Heuristics (DH) cards [3], students were tasked with ideating solutions for their design project. Each group was given 30 DH cards, with each card containing a unique prompt that inspires ideation in new directions (e.g. adding motion, changing geometry, using interchangeable parts). Groups used the cards to generate at least ten new ideas for their project.

The third activity focused on the physical meaning of dimensional tolerances found in engineering drawings and was intended to develop students' ability to draw connections between course content and real-world applications. For this activity, a machined plate with ten holes of slightly different nominal dimensions was created. Students were also given a set of dowel pins of varying sizes and dimensional tolerances. During the activity, students were tasked with calculating and classifying the types of fit (clearance, transition, or interference) for a chosen dowel in the series of holes. Lastly, students physically verified their calculations by inserting the dowels into the plate to establish a physical relationship between a fit type and how it ”feels” in reality. Students then reflected on what they observed, considering why tolerances matter in real-world manufacturing, and how to choose appropriate tolerances for their project based on functional requirements.

Surveys

Two surveys were administered to students at the beginning and end of the semester to quantify changes in students' EM. Some questions were adapted from an entrepreneurial mindset survey from Gillespie et al. [4]. The survey consisted of 21 multiple choice questions spread among the 3 KEEN categories (Curiosity n=8, Connection n=3, Creating Value n=6), as well as two additional categories: Creativity (n=2) and Collaboration (n=2). One Curiosity question (”Agree/Disagree: If I don't know how to do something, I ask for help right away.”) was reverse-coded. The complete list of questions can be found in the Appendix.

Statistical Analysis

Questions were grouped by category (Curiosity, Connection, Creating Value, Creativity, and Collaboration) and each student's category score was calculated by averaging their responses to all questions in a category. This resulted in each student having 5 scores. Scores were compared within the same time period (beginning and end of the semester), and between the beginning and end of the semester. All statistical analysis was completed in R (v4.5.1). A Shapiro–Wilk test was used to test for normality. Because not all scores were normally distributed, a paired Wilcoxon signed-rank test was used for comparisons between scores within the same time period (beginning or end of semester). Because not all students completed both surveys, Mann–Whitney U tests were used to compare unpaired scores between beginning and end of semester. Finally, individual survey questions within each category were compared with Mann-Whitney U tests to identify question-specific changes from the beginning to end of the semester.

Results

This study was determined to be non-human subjects research by the University of Illinois Institutional Review Board (IRB24-2012). 128 students completed the survey at the beginning of the semester (week 2), and 70 students completed the survey at the end of the semester (week 16). All data used in this analysis was collected following informed consent.

Beginning of Semester

At the beginning of the semester the Creating Value score was significantly less than all other categories (p = 3.21E-09 - 5.05E-04), while the Collaboration score was significantly higher than all other categories (p = 3.21E-09 - 4.02E-03) (Fig. 1). There were no other differences between any of the other categories during the beginning of the semester.

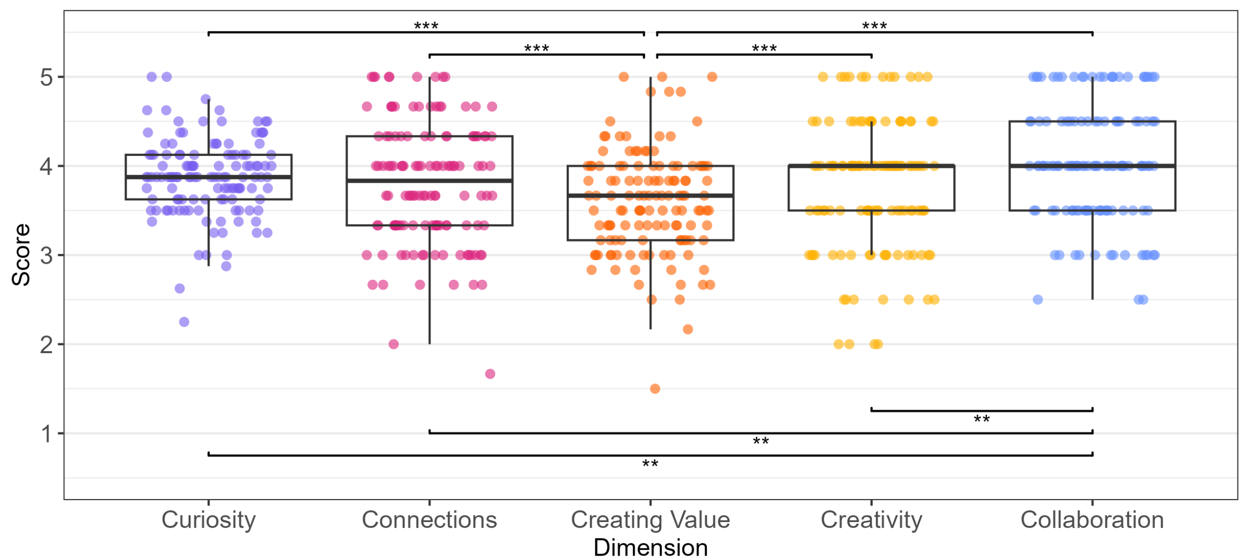

Figure 1: Category distribution comparisons from beginning of semester. * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$ indicates significance in distribution.

End of Semester

At the end of the semester, the Collaboration score remained significantly higher than all other categories (p = 1.01E-04 - 4.75E-02, Fig. 2). However, the mean Creating Value score was only greater than the mean Connections and Collaboration score (p = 1.36E-02). There was no difference in mean Creating Value score and mean Curiosity or Creativity scores at the end of the semester (Fig. 2).

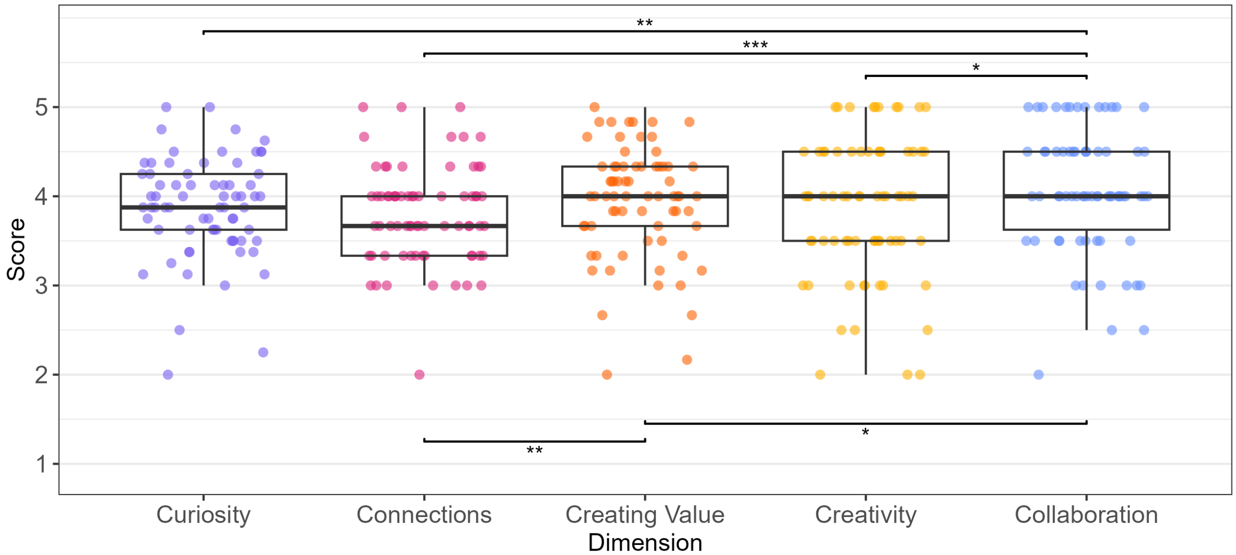

Figure 2: Category distribution comparisons from end of semester. *$p < 0.05$, **$p < 0.01$, **and** ***$p < 0.001$ **indicates significance in distribution.**

Across Timepoints

Category scores were also compared between timepoints to examine changes from the beginning to the end of the semester (Table 1, Fig. 3). Creating Value was the only category to significantly increase from the beginning to the end of the semester, (9.94% increase, *p* = 1.52E-05). While not significant, Creativity and Collaboration scores increased (2.47% and 0.90%, respectively), and Curiosity and Connections scores decreased (2.73% and 0.05%, respectively).

Table 1: Category distribution comparisons. Data are mean (SD). *$p < 0.05$, **$p < 0.01$, **and** ***$p < 0.001$ **indicates significant difference from beginning to end of semester.**

Category	Beginning	End	Percent change (%)
Curiosity	3.85 (0.42)	3.75 (0.51)	-2.73
Connections	3.80 (0.69)	3.80 (0.55)	-0.05
Creating Value	**3.59 (0.59)**	**3.95 (0.63)**	**9.94*** **
Creativity	3.79 (0.73)	3.88 (0.79)	2.47
Collaboration	4.04 (0.66)	4.07 (0.69)	0.90

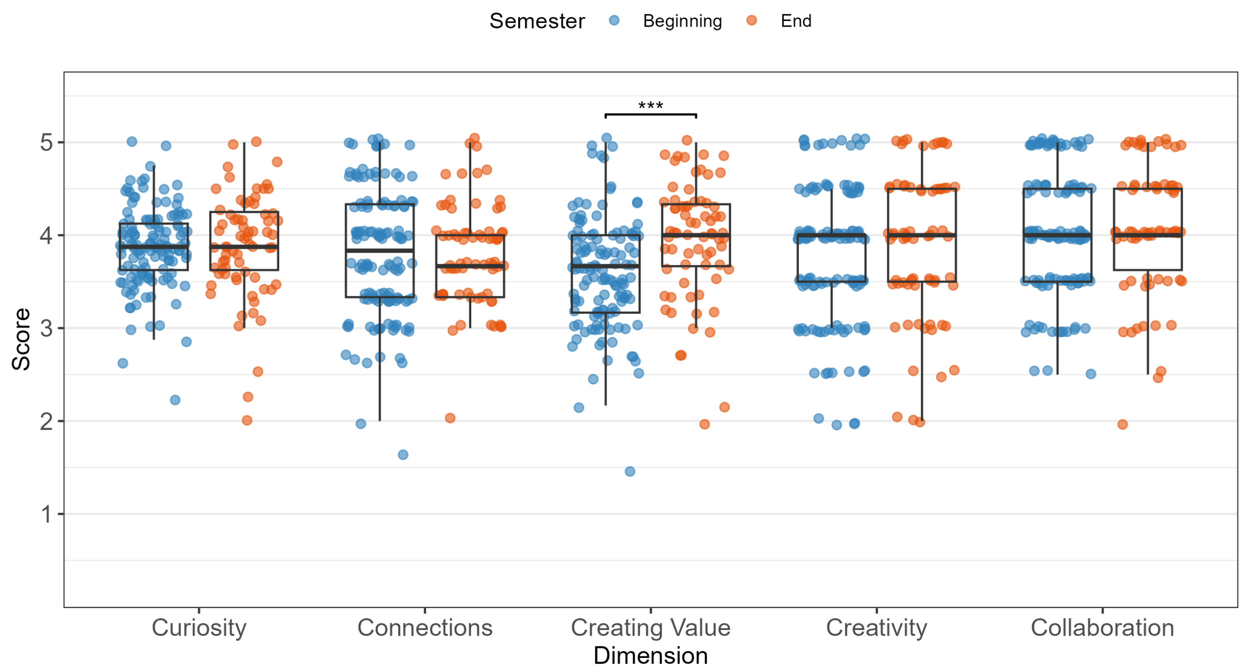

Figure 3: Student scores and percent change in each category during the beginning and end of the semester. * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$ indicates significant difference from beginning to end of the semester.

Differences in individual question scores from the beginning to the end of the semester were also examined (Table 2). Of the Curiosity questions, there were only two which were significantly different at the end compared to the beginning of the semester: the mean score for question 6 decreased by 9.61% (p = 0.017), and the mean score for question 7 decreased by 14.47% (p = 2.21E-03).

All three Connections questions had significant changes at the end of the semester compared to the beginning. The mean scores of questions 9 and 11 increased by 6.54% (p = 3.85E-02) and 9.17% (p = 6.64E-03), respectively. However, the mean score of question 10 decreased by 15.66% (p = 4.18E-06). This combination of increases in two questions and a decrease in the third question resulted in a non-significant change in the Connections score.

Five Creating Value questions (questions 12, 13, 14, 15, and 17) were significantly higher at the end of the semester compared to the beginning. The smallest increase was 7.31% (p = 2.92E-02, question 17) and the largest was 21.05% (p = 1.14E-07, question 14). These increases cumulatively contribute to the 9.94% (p = 1.52E-05) increase in the mean Creating Value score from the beginning to end of the semester (Fig. 3).

None of the individual Creativity questions changed from the beginning to the end of the semester.

There were significant changes in both Collaboration questions. Question 21 increased by 9.19% (p = 1.06E-02) whilequestion 20 decreased by 6.55% (p = 1.50E-02). The overall combination of both changes resulted in a non-significant change to the Collaboration score.

Table 2: All survey questions, grouped by category. Data are mean (SD). * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$ indicates significant difference from beginning to end of semester. Annotations: A/D (Agree/Disagree)

Question	Beginning	End	Percent change (%)
Curiosity			
1. To what extent does course content make you curious to learn more about engineering problems?	4.16 (0.81)	3.94 (0.85)	-5.13
2. To what extent do you enjoy discovering how and why things work?	4.35 (0.86)	4.19 (0.89)	-3.81
3. To what extent do you enjoy thinking about ways to improve things?	4.15 (0.85)	4.26 (0.86)	2.62
4. A/D: I always ask questions when I receive information	3.41 (0.88)	3.63 (0.82)	6.28
5. A/D: I know how to collect feedback from customers	3.74 (0.90)	3.77 (0.82)	0.78
6. A/D: I like to explore multiple ideas before solving a problem	4.11 (0.69)	3.71 (1.08)	**-9.61***
7. A/D: If I don't know how to do something, I ask for help right away	2.91 (1.01)	2.49 (0.79)	**-14.47****
8. A/D: If I don't know how to do something, I try to figure it out by myself	3.98 (0.76)	3.99 (0.69)	0.03
Connections			
9. A/D: I think about the consequences of a design decision	3.88 (0.85)	4.13 (0.70)	**6.54***
10. A/D: I can relate my classwork to real-world applications	3.83 (0.82)	3.23 (0.84)	**-15.66*****
11. A/D: I can describe the risks of a specific solution	3.70 (0.86)	4.04 (0.75)	**9.17****
Creating Value			
12. How confident do you feel in your ability to identify problems and new places to innovate?	3.55 (0.81)	3.90 (0.92)	**9.96****
13. How confident do you feel in your ability to tackle real-world engineering problems?	3.31 (0.88)	3.70 (0.87)	**11.70****
14. A/D: I know multiple strategies of brainstorming solutions for customer needs	3.35 (0.88)	4.06 (0.80)	**21.05*****
15. A/D: I can describe the needs and motivations of different stakeholders	3.48 (0.95)	4.06 (0.74)	**16.70*****
16. A/D: I like to modify my ideas based on feedback	4.16 (0.75)	4.00 (0.72)	-3.76
17. A/D: I can create a solution using technology	3.69 (0.88)	3.96 (0.81)	**7.31***
Creativity			
18. To what extent do you believe that you are creative?	3.60 (0.79)	3.67 (0.86)	1.94
19. To what extent do you enjoy coming up with lots of interesting ideas?	3.97 (0.88)	4.09 (0.88)	2.95
Collaboration			
20. A/D: I enjoy listening to and learning from my peers	4.25 (0.64)	3.97 (0.76)	**-6.55***
21. A/D: I prefer to work in a team environment over individual work	3.82 (0.93)	4.17 (0.76)	**9.19***

Discussion

Category-Level Changes

At the beginning of the semester, students' Creating Value score was significantly lower than all other categories, which could suggest that students lack confidence in their ability to create effective products or solve engineering problems. This is not surprising considering ME 170 consists primarily of first-year engineering students with little to no formal engineering experience. While Creating Value was significantly lower than all categories at the beginning of the semester, it was only significantly lower than Collaboration at the end of the semester, and was significantly higher than Connections. This suggests that throughout the course students become more confident in their ability to create designs that have value for their customers and end users.

Collaboration was significantly higher than all the other categories at the beginning of the semester, suggesting that students begin the course already confident in their ability to work together with their peers. Many of these students may have been previously exposed to group projects and team-based learning in their secondary education. Collaboration is likely an area where student feel comfortable, even in an introductory course.

At the end of the semester, Collaboration remained significantly higher than the other categories. The high Collaboration score is not surprising considering there are many group-focused activities throughout the course, and a final design project that is completed together in a group. Consistently high Collaboration scores (at both the beginning and end of semester) suggest a positive experience among students working with their peers to complete the design project. High Collaboration scores are encouraging as most engineering careers exhibit a high degree of teamwork, and students feel confident in their ability to work with others in a design context.

Question-Level Changes

Curiosity

There were two Curiosity questions (questions 6 and 7) that decreased at the end of the semester compared to the beginning. This could suggest a decrease in students' motivations to be curious. However, there are additional reasons which may explain the negative impacts in these two questions. In the beginning of the semester, first-year students are likely excited to be in their first engineering course, and eager to learn about design. The beginning of the design project is structured to give students the freedom to investigate and explore different ideas. At the end of the semester, students are working on the documentation aspect of their design, creating engineering drawings and Bill of Materials for their product. It's possible that students feel less curious at the end of the semester, where they have been most recently focusing on documentation, and not ideation.

Given the responses from students, there are opportunities to develop new activities that target students' curiosity more frequently throughout the semester, or modify existing activities to keep students consistently thinking and discovering during their design projects. In professional engineering practice, curiosity is critical for navigating complex problems, adapting to evolving constraints, and identifying novel solutions [5, 6]. Incorporating activities that better reflect the iterative and exploratory nature of engineering work, even at the end of a project's timeline, may provide additional opportunities to cultivate students' curiosity and strengthen their EM.

Connections

Some Connections questions (Table 2) increased at the end of the semester compared to the beginning. Specifically, it is promising to observe increases in students' confidence in identifying consequences of their design decisions (question 9) and describing risks of a specific solution (question 11). Through activities in the design project and interventions, students are consistently asked to analyze and provide rationale for their design decisions. In the ideation lab activity, students discuss the risks and potential flaws of new ideas built from the DH cards.

However, there was a significant decrease (15.66%) in students' perception of how their classwork related to to real-world applications (Connections question 10). One possible explanation is that students' understanding of "real-world applications" becomes more critical over time. As students gain exposure to engineering design processes and constraints, they may recalibrate their standards for what is "authentic" real-world relevance, resulting in more conservative self-assessments [7]. Additionally, although this course incorporates project-based activities aligned with EM principles, the real-world motivations behind these activities are not always be made explicit to students. Intentional framing is important for students to recognize connections between coursework and engineering practice [8, 9]. Therefore, strengthening explicit discussion of real-world context may improve students' perceived ability to make meaningful connections between course content and real-world applications at the end of the semester.

Creating Value

The Creating Value category stands out as the only distribution to significantly change at the category level (2). This result was driven by the large increases of 7.31-21.05% in questions 12-15 and 17. Questions 12-15 are closely to the foundational objectives of the semester-long design project. At the beginning of the semester, the project is introduced to students as a challenge to develop a novel consumer product for a targeted audience. With intervention activities like the Project Exploration lab and components of the design project, students considered the effects of design decisions and their implications on consumer feedback. The increase in question 17 can be attributed to the primary activities of the design project as well: all components of the product are designed and assembled using CAD software, exposing the utility of similar technologies to students.

The increases in Creating Value question scores are promising for the continued development of course content and the intervention activities. Identifying needs is important for exercising an entrepreneurial mindset [8]. In the ideation lab intervention using the DH cards [3], the prompts encouraged students to consider new perspectives and create more complex product ideas. This activity provided students dedicated time to brainstorm new strategies and identify problems. It appears the activities and the design project in general are helpful for students to see the value they are creating with their designs when evaluating their confidence in identifying problems, tackling real-world engineering problems, and similar themes discussed in the survey questions.

Creativity

It appears that the course and intervention activities did not have a significant effect on students' beliefs in their creative ability (question 18) or enjoyment in brainstorming interesting ideas (question 19). The lack of significant changes in the category and questions highlights an opportunity for development of activities or lecture content focused specifically on Creativity. For example, the ideation lab may be reviewed and modified to better target students' creative thoughts. Furthermore, the development of new Creativity activities may be beneficial in developing students' creativity beyond brainstorming a variety of ideas.

Another consideration with the Creativity category is the nature of the questions. There were only two Creativity questions, which is a limitation to the current survey. Future evaluations could include additional questions to gauge how students define creativity.

Collaboration

The Collaboration question results are mixed. Students preferred working in groups more at the end of the semester compared to the beginning, but also increasingly disliked listening to and/or learning from their peers. In the context of the design project, these results suggest that students enjoy the concept of group work because it provides an opportunity to delegate large tasks into individually completed components. Many components of the design project activities are structured in a way that promotes collaboration during completion, but are often divided into sections which members complete individually. Future work could involve restructuring some of these group assignments to require a more collaborative nature in which students need to work together to complete the activities, rather than splitting up tasks and completing them individually.

Limitations

There are some limitations in this study. First, there were 155 students enrolled in the course, and 128 students (83%) completed the beginning of semester survey, and 70 students (45%) completed the end of semester survey. Due to this discrepancy, the two data sets could not be treated as paired samples, limiting comparisons that could be made between beginning and end of semester datasets. The smaller number of responses at the end of the semester may not have accurately reflected the student population in ME 170.

A second limitation concerns the ability to attribute changes in student responses to specific intervention activities. Students participated in a variety of lecture topics, lab tasks, and project work throughout the semester. As a result, improvements in individual questions cannot be conclusively tied to any single intervention.

Finally, the study relies on self-reported measures of competence, which inherently carry uncertainty. Students at the start of the semester may overestimate their abilities due to limited exposure to course content, while end-of-semester responses may be influenced by increased self-awareness rather than actual skill development. This makes it difficult to fully separate perceived growth from actual growth.

Conclusion

The purpose of this study was to evaluate the extent to which the introduction of new instructional activities in an introductory design course facilitated the development of students' entrepreneurial mindset (EM). By comparing beginning- and end-of-semester survey responses, we can start to understand how various components of the course shape students' perceptions of their EM-related abilities.

Among the five dimensions examined, Creating Value was the only category to exhibit a significant change at the end of the semester compared to the beginning. This suggests that the design project and associated intervention activities were particularly effective in fostering students' abilities to identify stakeholder needs, recognize opportunities for innovation, and develop feasible engineering solutions. In contrast, Curiosity, Connections, Creativity, and Collaboration did not change at a category level, although there were several question-level changes. Therefore, the influence of course activities may be strongest during early ideation and problem identification phases, and some EM dimensions may require more targeted interventions during the semester.

As engineering programs continue to emphasize innovation, stakeholder awareness, and complex problem-solving, supporting the growth of an entrepreneurial mindset is increasingly important. The results of this study provide a foundation for future iterations of this course and offer guidance for the continued development of course activities that can develop an entrepreneurial mindset in first-year engineering students.

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Appendix

Survey questions

Listed below are the questions posed in the survey filled by students in this study. All questions were Likert-style questions, where responses ranged from 1 to 5. The scale values associated with each number are dependent on the question type (Table 3, row 1).

Table 3: Descriptions associated with each score value used depending on question type

Score	Agree/Disagree: ...	To what extent...	How confident do you feel...
1	Strongly Disagree	Not at all	Not at all confident
2	Somewhat Disagree		A little
3	Neutral	Somewhat	Somewhat confident
4	Somewhat Agree		Quite confident
5	Strongly Agree	Very much	Very confident

Curiosity:

1. Agree/Disagree: I always ask questions when I receive information
2. To what extent does course content make you curious to learn more about engineering problems?
3. To what extent do you enjoy thinking about ways to improve things?
4. Agree/Disagree: I know how to collect feedback from customers
5. Agree/Disagree: I like to explore multiple ideas before solving a problem
6. Agree/Disagree: If I don't know how to do something, I ask for help right away
7. Agree/Disagree: If I don't know how to do something, I try to figure it out by myself*
8. To what extent do you enjoy discovering how and why things work?

Connections:

1. Agree/Disagree: I think about the consequences of a design decision
2. Agree/Disagree: I can describe the risks of a specific solution
3. Agree/Disagree: I can relate my classwork to real-world applications

Creating Value:

1. How confident do you feel in your ability to tackle real-world engineering problems?
2. Agree/Disagree: I know multiple strategies of brainstorming solutions for customer needs
3. How confident do you feel in your ability to identify problems and new places to innovate?
4. Agree/Disagree: I can describe the needs and motivations of different stakeholders

5. Agree/Disagree: I like to modify my ideas based on feedback
6. Agree/Disagree: I can create a solution using technology

Creativity:

1. To what extent do you believe that you are creative?
2. To what extent do you enjoy coming up with lots of interesting ideas?

Collaboration:

1. Agree/Disagree: I enjoy listening to and learning from my peers
2. Agree/Disagree: I prefer to work in a team environment over individual work

**This question was reverse coded.*