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# Board 106: Innovation through Making Course: Creating a Distinctive Prototyping Experience as Part of a New Entrepreneurial Pathway (Work in Progress)

**Mitra Varun Anand, Worcester Polytechnic Institute**

Mitra Anand serves as the Associate Director of Makerspace, and Innovation and Entrepreneurship, in addition to being an Adjunct Faculty of Mechanical Engineering at Worcester Polytechnic Institute.

Anand's research interests lie in combining hands-on Maker skills with an entrepreneurial mindset and value creation, aiming to develop practical solutions for real-world problems. He is enthusiastic about innovation in engineering education, design thinking, prototyping, program development, crafting interactive curricula, and bringing ideas to fruition.

With over 8 years of experience in Mechanical and Mechatronics Engineering, Anand possesses a solid background in Innovation and Entrepreneurship education, Additive Manufacturing, and Digital Fabrication technologies. He has taught lectures and workshops on advanced subjects to more than 1000 undergraduate engineering students and 150 graduate students, while advising on over 500 student and faculty research projects.

His academic credentials include an M.S. in Mechatronics and Robotics Engineering from New York University and a B.E in Mechanical Engineering from Anna University.

**Prof. Ahmet Can Sabuncu, Worcester Polytechnic Institute**

Dr. Sabuncu holds a Ph. D. in Aerospace Engineering from Old Dominion University. Dr. Sabuncu's professional interests spans from engineering education research, history of science and engineering, thermo-fluids engineering, and microfluidic technology.

**Dr. Curtis Abel, Worcester Polytechnic Institute**

Curtis Abel, PhD, MBA is the Executive Director of the Innovation and Entrepreneurship Center (I&E) at WPI. He is responsible for the I&E eco-system, Value Creation Initiative, Maker Space & Rapid Prototyping Lab, and Massachusetts Digital Games Institute. He joined WPI in 2015 as a Professor of Practice through the support of the Kern Family Foundation to create a vibrant entrepreneurial mindset culture on campus with both faculty & students. Prior to WPI, Curtis has 20+ years of experience in leadership positions at large corporations, including American Express, MasterCard, United Retail, and Bethlehem Steel. He's held full ”Profit and Loss” responsibility for several multi-million-dollar businesses, generating double-digit annual growth for each. He also held positions in new business development, marketing, strategic alliances, and R&D implementing new technology into manufacturing facilities. Curtis holds a Ph.D., ME and BS from Carnegie Mellon University in Materials Science & Engineering and Chemical Engineering, respectively, and an MBA from Cornell University. He also held international Postdoctoral Fellowships at Cambridge University and Technische Universität Wien.

# Work in Progress: Innovation Through Making Course: Creating a Distinctive Prototyping Experience as part of a New Entrepreneurial Pathway

## Introduction:

Engineering education is at a crossroads, with a need to produce graduates who can meet the demands of a rapidly changing and complex global environment. Technology is advancing so rapidly that an estimated 85% of jobs in 2030 have not been invented yet [1]. The pace of change will be so rapid that people will learn "in-the-moment" using new technologies to learn fast, pivot quickly, fail forward, develop timeless skills, and educate for life. However, students often find themselves short of timeless skills they need to pivot in the world of uncertainty and navigate uncharted waters.

Many research studies [2 - 4] affirm that students who can (1) innovate in the face of challenges, (2) focus beyond technical competencies to develop key skills in critical thinking, complex problem solving, written and oral communication, and (3) learn to create value in a real-world setting, are key to a sustainable future. One of the biggest challenges in creating future-ready engineers is to address the existing problems with students' approach to engineering education, particularly related to the risk-averse mindset of the current generation of students. Today's students often have a fear of failure that inhibits them from venturing beyond the scope of their major field of study to try and learn new things [5], resulting in them not stepping out of their technological comfort zones throughout their course of study. This refers to the familiar tools and techniques that students are comfortable using within their field of study.

In this context, it is crucial to equip engineers with the necessary skills to innovate and tackle challenges. However, a risk-averse mindset among students has become a hindrance to their learning and growth, hindering their ability to develop skills in critical thinking, problem solving, and value creation [6]. This research paper aims to address this challenge through the introduction of an innovative multi-disciplinary project-based pilot course called "Innovation Through Making".

The "Innovation Through Making" course blends Entrepreneurial Mindset skills with core Engineering Sciences (ES) curriculum providing aspiring engineers with a fundamental understanding of knowledge and skills necessary for success in specialized areas of engineering, including mechanical, electrical, civil, chemical, and computer engineering. By mastering the core engineering sciences, students develop a strong analytical and problem-solving ability that is essential for success in the field of engineering [7-8].

In this work-in-progress paper, we explore the development of the pilot course and aim to present the initial findings of the course's impact quantitatively and qualitatively on students' development of engineering and entrepreneurial skills through a pre- and post-course competencies evaluation survey and prototype evaluations. The paper also details our deliberate approach to fostering diverse, equitable and inclusive teams.

## Entrepreneurial Mindset:

The term entrepreneurial mindset and what it means in engineering education is often misunderstood. Engineering students continue to associate the term with "starting a business" [9-

10], which deters them to see the importance of building career-distinguishing entrepreneurial mindset and value creation skills that create well-rounded engineers. Entrepreneurship refers to the process of starting, managing, and growing a business venture with the goal of creating value and generating profit, while having the willingness to take on risk.

On the other hand, entrepreneurial mindset and value creation skills are an approach to critical thinking and solving important problems which is characterized by opportunity identification, creativity, innovation, risk taking, resilience, customer focus, and a bias towards action. It involves a set of skills, attitudes, and behaviors that enable students to identify and address important unmet societal needs with solutions that have superior value to other alternatives, while overcoming risks. These professional skills are career-distinguishing because they can be applied to any situation in solving problems that matter to others and yourself, while elevating influence on society in a positive way. Our understanding of the entrepreneurial mindset is informed by a comprehensive review of several studies [11 - 14] and our participation in the KEEN foundation.

While entrepreneurship is important for us, we take a broader lens by focusing on developing these skills. In its simplest form, value creation is about improving the impact of projects through unique value creation tools to accurately identify stakeholder needs and peer iteration for rapid learning [15]. Identifying the right stakeholder needs is often missed. One of the critical entrepreneurial mindset skills in developing innovations is resilience and perseverance, that is the ability to bounce back from failure and setbacks, and to persist in the face of adversity. The current generation of engineering students tend to lack this skill. They are afraid to fail and strive for perfection, which leads them to not stepping out of their technological comfort zone.

This course helps prepare students for their projects by developing important transferable skills and a mindset around “Fail Forward, Learn Faster” through a “Discover, Ideate, Test, Feedback, Learn, and Iterate” methodology. While developing these maker skills, the course also provides the students with the entrepreneurial mindset and value creation tools to solve problems that people care about and realize the idea through prototyping. Creating a community that encourages students to navigate ambiguity, take risks, and experiment with new ideas can lead to breakthroughs and innovative solutions that have extraordinary impact on society.

In the following section, we provide a brief description of the course structure.

## Innovation Through Making Course:

Innovation Through Making is an introductory multi-disciplinary project-based course at Worcester Polytechnic Institute, that introduces students to digital fabrication and provides hands-on experience with the basics of hands-on engineering design and combines it with entrepreneurial mindset training that includes design thinking and value creation. The course runs for 8 weeks and is offered under the Engineering Sciences 2000-level, satisfying 3- credit hours of engineering or free elective requirement based on students’ major field of study.

Students develop their own creative innovations through prototyping, testing, learning, getting feedback, and iterating through activities and methods to spark discovery. The course culminates in a team project that uses human-centered design thinking and value creation approaches to develop a sustainable solution to a real-world problem and fabricate a product prototype, using the United Nations Environment Programme (UNEP) sustainable development goals as a framework for choosing open-ended final projects. This leads to a Prototype Showcase where students pitch their value proposition and demonstrate their prototype to test, validate and get feedback on their product idea as they compete for an award.

Multiple introductory design courses were studied and analyzed during the development of the course pedagogy, including currently offered introductory design courses in Mechanical Engineering, Electrical Engineering, Robotics Engineering, and Engineering Sciences at Worcester Polytechnic Institute. This was done to identify gaps in curriculum that affect student outcomes, as well as to identify course structure and delivery methods that students are more (or less) receptive to.

The structure of the course involves the exploration of the multi-faceted engineering design process (different ways to approach engineering problem solving), additive and subtractive manufacturing methods, microcontroller interfacing, ideation, design thinking, value creation and design challenges. This is accomplished through an equal combination of active learning style curricular lectures [16 - 17], hands-on team-based workshops, and guest speaker series by subject matter experts (SMEs). Students are evaluated through a series of methods aimed at entrepreneurial skills training as well as the application of the engineering design process. The following briefly highlight the essential evaluation components.

- **Design Challenges:** A series of four design challenges that test the students' ability to work individually and in teams to actively apply concepts learned in class through the execution of a hands-on mini project.
- **Open Ended Final Project**: Student teams use human-centered design thinking and value creation approaches to develop a sustainable solution to a real-world problem and fabricate a product prototype,
- **Value Proposition Pitch:** Students pitch their product's value proposition and demonstrate their prototype to test, validate and get feedback on their product idea to a group of SME judges as they compete for an award.
- **Failure Journal Reporting**: Students are required to actively maintain a digital journal of project related failures to foster the fail-forward methodology. The term "failure" is categorized broadly and could be in the form of failure of ideas, prototypes, tests, or methods.

**Fostering Diverse, Equity and Inclusion:**

At the core of our course design approach is a commitment to promoting diversity, equity, and inclusion (DEI) in the classroom and beyond. Fostering a diverse and inclusive learning environment is essential for preparing future engineers to work in a globally connected and culturally diverse world [16]. We recognize that diversity takes many forms, including but not limited to race, ethnicity, gender, sexual orientation, ability, socio-economic status, and cultural background. Our course design strived to create an inclusive and welcoming atmosphere for all students, regardless of their individual differences. In designing our course, we committed to promoting DEI through the following efforts:

- **Inclusive Classroom Environment:** Creating a safe and supportive classroom environment where all students feel valued and respected. This includes active learning style classroom activities to foster open and respectful discussions [16 - 18], encouraging active participation from all students, and being mindful of cultural sensitivity and bias in engineering classrooms.
- **Curriculum Development:** Ensuring that the course curriculum is inclusive and reflects the diverse perspectives and experiences of all students [19] through incorporating diverse case studies, examples, and readings into course materials including lectures and design challenges.
- **Student Recruitment:** Active recruitment of a diverse student body to participate in the course, including students from underrepresented groups in engineering [20-21], such as women and individuals from different racial and ethnic backgrounds. This was done through targeted informational emails, collaborating with student clubs to promote the course, and hold information sessions with the instructor during the course registration period.
- **Diverse Student Teams:** A key aspect of the course is to foster a culture of collaborative innovation that thrives on the diversity of thought [22]. To facilitate knowledge-sharing and multi-disciplinary teamwork, a deliberate effort is made to group students from different academic backgrounds and complementary skillsets together.
- **Faculty and Staff Diversity:** Bringing a diverse group of SME guest speakers, student assistants, and workshop-support staff who bring different perspectives and experiences to the course improved student engagement and learning outcomes [23].
- **Assessment and Evaluation**: Striving to ensure that our assessment and evaluation methods are inclusive and free from bias [24]. This includes using multiple forms of assessment, such as ideation and design challenges, and group projects and individual assignments, to evaluate student learning.

Qualitative analysis of the DEI results from the pilot course will be available in the full paper. We acknowledge that promoting DEI is a continuous process and are committed to actively incorporating feedback from a wide range of stakeholders. By embracing DEI in the design and implementation of our new course, we aim to create a more equitable and inclusive learning environment for all students and prepare them to succeed in a diverse and changing world.

**Research Methods:**

The first phase of the study aims to measure the improvement and impact of the "Innovation Through Making" pilot course on students' development of engineering and entrepreneurial mindset competencies. Essential competencies of interest were carefully identified, defined, and standardized for the scope of this research to ensure valid and reliable results. The competency questionnaire used in the assessment process was developed by the authors, based on their expertise in the field and the course objectives. Although the questions were not pulled from existing validated instruments, the authors ensured validity through survey description and discussion held during class to enable students to create a baseline for their self-assessment. The full paper will also implement a modified Student Assessment of Learning Gain (SALG) instrument [25-26] for evaluating student learning and assessing the effectiveness of specific course components associated with the learning gains.

In this study, the Engineering competencies of focus included Engineering Design, Additive Manufacturing, and Subtractive Manufacturing skills. Entrepreneurship Mindset competencies of focus included were Problem Solving, Human-Centered Design (Design Thinking), and Value Creation skills. These competencies were defined for the scope of this study as follows.

- **Engineering Design:** Ability to demonstrate the use of systematic and structured process of identifying and resolving technical or design issues to meet specific requirements or goals in the context of prototyping to solve engineering problems.
- **Additive Manufacturing:** Demonstrating the ability to design for and use additive manufacturing tools in the context of prototyping using Fused Deposition Modeling 3D Printing technology.
- **Subtractive Manufacturing:** Demonstrating the ability to design for and utilize non-additive prototyping techniques using paper prototyping, laser cutting, molding, forming/ casting and waterjet cutting.
- **Problem Solving:** Ability to apply analytical and critical thinking skills, as well as a thorough understanding of relevant technical knowledge, to generate practical and effective solutions to problems in engineering.
- **Human-Centered Design (Design Thinking):** Ability to apply human-centered approaches through iterative short sprints of the design thinking process (Empathy, Problem Definition, Ideation, Prototype, Test, Iterate) under ambiguous situations in the context of prototyping to solve real-world problems.
- **Value Creation:** Capacity to apply the "learn-fast" mindset to develop a value proposition pitch to a solution and communicate it in a compelling way through prototypes and storytelling.

The following research methods were used to gather and analyze quantitative data:

- **Pre- and post-course competencies assessment survey:** A pre-course 6-point Likert-scale survey was administered to measure students' initial levels of predefined Engineering and Entrepreneurial Mindset competencies, and a post-course survey was administered to measure their improvement in these competencies [27]. The scales on the survey range from 0 (no competency) to 5 (highly competent).
- **Statistical Analysis (Wilcoxon and Paired t-tests):** Paired t-tests, Wilcoxon test, and Cohen's d effect size evaluation were conducted on the data collected from the pre- and

post- competencies assessment survey to determine the significance of the difference in mean scores for each of the targeted skills [27]. This allowed us to determine if there was a significant statistical improvement in students' targeted competencies after taking the course.

Self-assessment questionnaires were chosen as the primary method for measuring students' engineering and entrepreneurial competencies in this study due to their ability to capture students' perception of their own learning and growth. Self-assessments can reveal insights into the learning process and help identify areas where students feel they have improved or still need further development. Additionally, self-assessment encourages students to reflect on their learning experiences and engage in metacognition, which is considered an essential skill for lifelong learning and success in engineering and entrepreneurship [28,29]. By incorporating a modified SALG instrument in the full paper, the reliability and validity of the self-assessment data will be further strengthened. Similar instruments have been used in studies such as [30,31].

The pilot course had an enrollment of 28 students from the following majors: Mechanical and Materials Engineering (ME), Robotics Engineering (RBE), Game Development (IMGD), Computer Science (CS), Biotechnology (BIO), Civil Engineering (CE), Architectural Engineering (AE), Physics (PHY). The course had 15 students identifying as Male, 12 students as Female, and 1 student identifying as non-Binary. The students were all between 18 and 21 years of age. Identifying information with ethnicity is currently unavailable, but efforts will be made to include this in the full paper.

**Results:**

Diverse teams were intentionally created that connected students from different educational backgrounds and skillsets that worked on their design challenges and final project together.

The pre course (first day of classes) and post-course (last day of classes) competencies assessment surveys, as well as statistical testing methods including Wilcoxon, Cohen's d, and paired t-tests, were used to measure the quantitative impact of the course on the targeted skills. The results from the survey (n=18) are shown in Table I and Figure 1.

**Table I.** Paired T Test, Wilcoxon Non-Parametric Test and Cohen's d Effect Size scores for comparing the pre and post course gains in targeted competencies.

| Competency | Paired T Test P-Value | Wilcoxon Test P-Value | Cohen's d Effect Size |
|---|---|---|---|
| Additive Manufacturing | 0.00014746 | 0.00081 | 2.0987 |
| Subtractive Manufacturing | 0.00009031 | 0.00061 | 0.998 |

| | | | |
|---|---|---|---|
| Engineering Design | 0.00053854 | 0.0122 | 1.0587 |
| Problem Solving | 0.0116036 | 0.0015 | 1.2587 |
| Design Thinking | 0.00141063 | 0.0008 | 1.0002 |
| Value Creation | 0.00533836 | 0.00061 | 1.02318 |

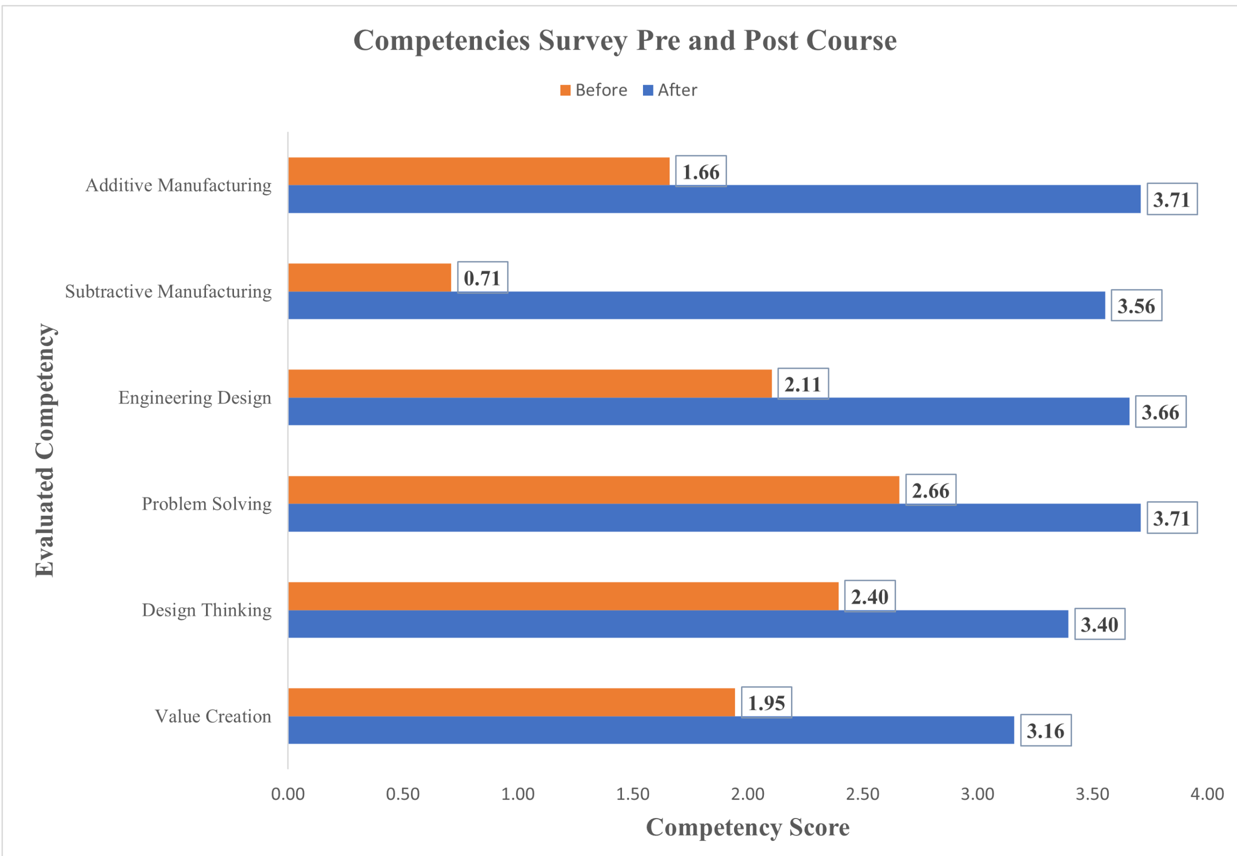


**Figure 1.** Bar graph comparison of self-reported competencies in the pre and post course evaluation survey. The competencies were evaluated using a 6-point 0-5 level Likert Scale, with 0 representing no competency and 5 representing high competency

As shown in Table I and Figure 1, the results indicate statistically significant improvements in all targeted competencies for the students who participated in the "Innovation Through Making" pilot course. All p-values for the paired t-test and Wilcoxon test are less than 0.05, demonstrating a significant improvement in students' self-reported competencies after the course.

Cohen's d effect sizes for all competencies show large effect sizes, with Additive Manufacturing having the largest effect size of 2.0987, followed by Problem Solving with an effect size of

1.2587, and Engineering Design with an effect size of 1.0587. Subtractive Manufacturing, Design Thinking, and Value Creation have effect sizes of 0.998, 1.0002, and 1.02318, respectively.

The quantitative results of this study provide strong evidence that the "Innovation Through Making" pilot course was successful in enhancing students' engineering and entrepreneurial mindset competencies. These results, combined with the qualitative analysis of DEI efforts and the full paper's implementation of a modified SALG instrument, will provide a comprehensive evaluation of the course's impact on students' learning and development. The insights gained from this study will inform future course iterations and contribute to the broader conversation on engineering education and entrepreneurial mindset development.

It is important to note that the sample size for this study was relatively small (n=18), which may limit the generalizability of the findings. Additionally, the self-assessment method used for measuring students' competencies is subjective and may be influenced by students' perceptions of their abilities. Students may overestimate or underestimate their skills and abilities. Competencies such as problem solving and design thinking are difficult to quantify, making it challenging to accurately assess students' development in these areas. Also, the survey only provides a snapshot of students' competencies at two points in time (before and after the course), making it difficult to assess changes and improvements over the course of the program.

Nevertheless, the significant improvements in all targeted competencies and the large effect sizes suggest that the course had a positive impact on students' learning and development. Efforts to include a larger and more diverse sample of students in future studies, as well as the use of additional assessment tools, such as the modified SALG instrument, will help to strengthen the validity and reliability of the findings. In future studies, it would be beneficial to incorporate more objective measures of student performance and skill development to complement the self-reported data.

Table II and Figure 2 showcase some of the final project prototype ideas and their team distribution by major field of study.

**Table II.** Final prototyping projects proposed by student teams and their team distribution

| Project | Description | Team Distribution |
|---|---|---|
| VR Force Feedback Glove | A feedback control device for VR with applications in medical and emergency training services | ME, IMGD, CS, RBE |
| StovaDonna | Device to prevent accidental household fires | ME, CS, RBE, PHY |

| | | |
|---|---|---|
| Noverdose | Device to prevent opioid abuse | ME, CS, AE, CE |
| WARK | Device to clear trash from water bodies | ME, ECE, RBE, IMGD |
| Eco Sensor | Device to track and aggregate indoor air quality data across colleges | ME, BIO, CS, AE |

These final projects serve as a qualitative reflection of students' ability to solve real problems through the application of skills learned throughout the course.

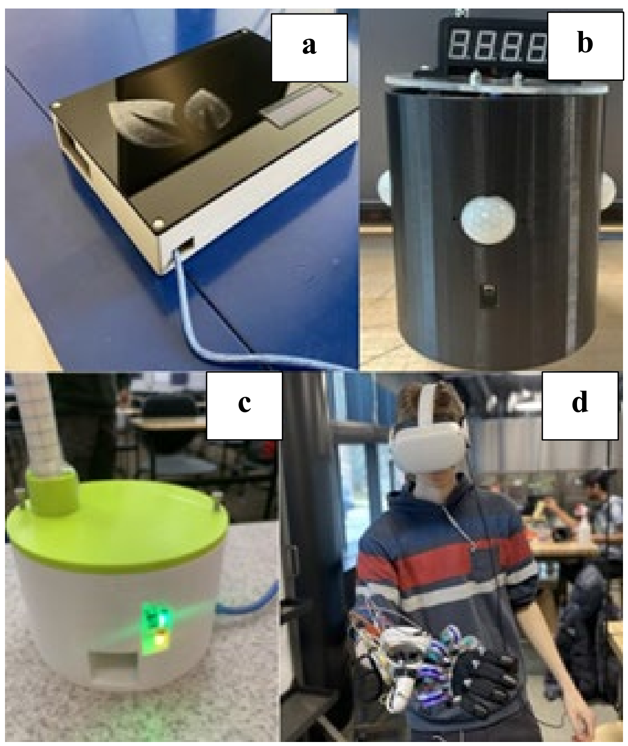


**Figure 2.** Successful student prototypes from the pilot course showing a) Eco Sensor, b) StovaDonna, c) NoverDose, and d) V.R Force Feedback Glove

Students were also given an optional prompt to an open-ended question that aimed to study the qualitative impact of the course components in improving the students' ability to connect the entrepreneurial mindset to help them solve engineering problems. "Using an example, please explain how learning about the entrepreneurial mindset through this course has changed the way you approach problem-solving and decision-making in design-based engineering classes?". Table III shows sample student responses to this question.

**Table III.** Sample student responses to the open-ended question

| Student | Answer |
|---|---|
| Student 1 | I liked how we formed into groups after the first class, and how the instructor encouraged his students to speak up. It was a very fun learning environment. I also liked learning topics I had never been taught at school and have just been expected to know, like laser cutting, 3D printing, and vacuum molding through a new concept like entrepreneurial mindset. |
| Student 2 | I really enjoyed the opportunity to learn more about different opportunities to solve real problems as I have been at this school for several years and this was my first real time stepping into the hands-on making with a structured concept. I particularly loved the 3D printing and laser cutting opportunities. |
| Student 3 | I enjoyed how much I got to work with my hands and learning how to use the makerspace through the design thinking process. |
| Student 4 | It is an awesome concept and a really fun way to learn a lot of things like value creation at a basic enough level to help with a project through problem solving skills. |

The qualitative results presented in Table III were selected from a larger pool of student responses to showcase a diverse range of perspectives on the impact of the course. The thematic analysis of these results involved identifying common themes and patterns in the students' responses, which were then used to select representative quotes. While only four quotes are presented here, they capture the essence of the broader themes that emerged from the data, such as the value of hands-on learning, the benefits of a structured approach to problem-solving, and the importance of integrating entrepreneurial mindset in engineering education.

Overall, the results of this study suggest that the "Innovation Through Making" pilot course had a positive impact on students' development of both engineering and entrepreneurial mindset competencies.

**Conclusions:**

These results from the pilot course offering support the continued implementation of this course and the importance of incorporating elements of both engineering and entrepreneurship into engineering education.

Results from the following on-going studies will be included in the final paper.

- Incorporating data from the additional course offerings, which will increase the sample size to over 40 students. This larger sample size will strengthen our statistical analysis and further seek to validate the course findings.

- Measuring the quantitative and qualitative impact of failure experiences through the Failure Journal implementation on student teams' ability to embrace the fail-forward methodology in prototyping solutions for engineering problems. Our work will specifically aim to study the results of teams that embrace failure as an opportunity to learn and their ability to better develop innovative solutions to complex problems.
- Integration of a modified Student Assessment of Learning Gain (SALG) based survey as an integrated instrument for evaluating student learning and assessing the effectiveness of specific course components associated with the learning gains.
- Full thematic analysis of the of qualitative results in identifying common themes and patterns in the students' responses, including qualitative evidence of improvement in hands-on learning and skill development, real-world problem solving, design thinking and value creation, active learning environment, and Makerspace exploration.

In conclusion, the results of this study suggest that the "Innovation Through Making" pilot course had a positive impact on students' development of engineering and entrepreneurial mindset competencies. The ongoing studies mentioned in the full paper will further enhance these findings by increasing the sample size, evaluating the impact of failure experiences, integrating a modified SALG-based survey, and conducting a comprehensive thematic analysis of qualitative results.

This study has the potential to offer valuable insights into the effectiveness of project-based learning in fostering a growth mindset and developing critical skills among engineering students. By exploring the impact of this innovative course, this research paper aims to contribute to the ongoing discussion on the future of engineering education.

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