Enhancing Undergraduate Engineering Design Education through Mini-Prototype Projects and an Entrepreneurial Mindset

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Abstract

This paper addresses the need to close the gap between theoretical knowledge and real-world applications in undergraduate engineering design education to foster sustainable learning. To achieve this, the study incorporates a mini-prototype-based project inspired by textbook problems and an Entrepreneurial Mindset (EM) to encourage curiosity and problem-solving abilities. The study takes place in mechanical engineering within the "Design of Machinery" course. In the study, students were engaged in projects that involve designing and prototyping mechanisms to be completed within a single classroom session or an hour. The paper introduces the methodology and showcases students' feedback regarding this engaging and impactful learning experience, enhancing both technical knowledge and student connection.

Keywords

Entrepreneurial mindset (EM), Mechanism Design, Project-based learning, Team-based learning, Prototyping

Introduction

Engineering education is transforming to provide students with the skills that are applicable and useful in the real world. However, there is often a disconnect between the theoretical knowledge taught in classrooms and the practical applications encountered in the industry. This discrepancy can impede students' capacity to solve real-world problems effectively. To tackle this pressing issue, this paper investigates the integration of mini-prototype projects and an (EM) into undergraduate mechanical engineering courses. By emphasizing practical application and encouraging curiosity-driven learning, this approach seeks to improve sustainable learning outcomes for future engineers. Studies have demonstrated that project-based learning (PBL) can be an effective strategy to bridge the gap by giving students hands-on experiences and chances to apply their knowledge[1-3]. In order for Problem-Based Learning (PBL) to be truly effective, it must be supplemented with activities that promote innovation, collaboration, and an entrepreneurial attitude. The Entrepreneurial Mindset (EM) approach encourages students to look beyond traditional solutions, be inquisitive, and view difficulties as opportunities [4]. Research supports the notion that EM can improve problem-solving abilities and lead to a more comprehensive understanding of the subject matter [5]. Through Entrepreneurial Minded Learning (EML) activities, students are encouraged to explore, recognize possibilities, and create value, with a focus on effectual thinking, which gives priority to adaptive and opportunistic approaches over strictly predictive thinking [6].

The trend of fostering the spirit and practice of teamwork is becoming increasingly popular in universities learning, and teaching [7, 8]. Both educators and students have expressed their positive views on cooperative learning and interactive experiences, which can improve students' productivity and performance [9, 10]. Studies have highlighted the importance and necessity of enhancing college students' teamwork and communication abilities, as well as the development of team-based learning environments in K-12 classrooms[11]. Pedagogies that focus on developing students' team spirit and collaboration should be emphasized, with creative collaborative assignments, team-oriented problem-solving training, and team-based projects. Creating and promoting collaborative mini projects can help to increase students' motivation, engagement, performance, and deep learning [11]. Cooperative learning group activities in team-based learning environments in universities can also enhance students' accountability, interaction and communication skills, self-reflection opportunities, openness to feedback, deeper understanding of knowledge, and the practice of sharing information [12].

This research was conducted within the "Design of Machinery" course in the mechanical engineering undergraduate program. The methodology involved incorporating mini-prototype-based projects into the existing curriculum, which were inspired by textbook problems and aligned with the course's learning objectives. Students were organized into collaborative teams to work on these projects, which encouraged teamwork and peer learning. During the implementation phase, the technical subject content was integrated with the three C's: Curiosity, Connection, and Creating value, as defined by the Kern Entrepreneurial Engineering Network (KEEN) [13]. This approach enabled students to engage with the research process, understand its various phases and interactions, and synthesize information from diverse sources to address both local community and global challenges. Additionally, they learned to formulate and effectively communicate design requirements and solutions, focusing on their societal benefits and economic feasibility. These behaviors were in line with the entrepreneurial mindset principles outlined by KEEN [14].

Method

The mini-prototype projects were carefully designed to be completed within a single classroom session or an hour, ensuring that they fit seamlessly into the course schedule. Students were provided with the necessary resources and materials to construct prototypes of mechanical systems, based on the principles learned in the course. For the project, identification of a textbook problem with its implication in real-world application was required. For example, in this study, a typical three position graphical synthesis problem was used to inspire the activity. The graphical synthesis problems commonly found in textbooks resemble the example presented below, which has been directly taken from "Design of Machinery textbook [15].

***Textbook Problem**: Design a four-bar linkage to move the object shown in* Figure *1 through the three positions shown using points A and B for attachment. All fixed pivots should be on the base.*

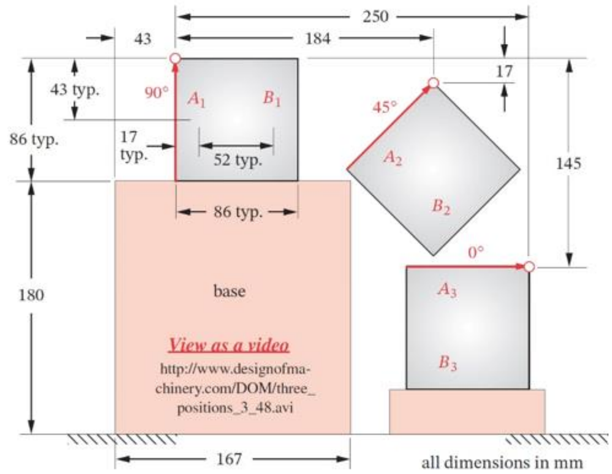

Figure 1: Three Position Synthesis textbook problem [15]

This exercise integrated the problem with EM and was used to design an accessible cabinet door for people with disabilities and limited mobility. Design requirements were set with a target customer in mind, such as the door needing to open vertically with a slight tilt and rest on top of the cabinet due to space restrictions. The students were given 15 minutes to comprehend the requirements, 15 minutes to synthesize the mechanism on paper, and 15 minutes to create a prototype. A summary of the group project and a reflection report were then written and emailed in 10 minutes. To help with the project, students received small cubic boxes containing various pins and links. This task encouraged critical thinking and curiosity about real-world applications of the course material. Groups of five to six members were randomely formed, and the mini-in class project was assigned as a competition among the different groups. When they complete this project, students were expected to gain valuable learning outcomes, such as formulating customer requirements for an engineering problem, utilizeing graphical synthesis approaches to design planar mechanisms, improveing their teamwork and communication skills, and learn to balance the quality of their work with meeting project deadlines.

Task description: The customer, who uses a wheelchair, has requested that a special cabinet be made with remote-controlled doors that are easily accessible. Doors must be placed so that they do not block the front of the cabinet when fully open. Specifically, door A (illustrated in Figure 2) should be able to move from the front to the top position. The group has 60 minutes to finish the task and the yellow smiley face sticker is visible in both positions for reference.

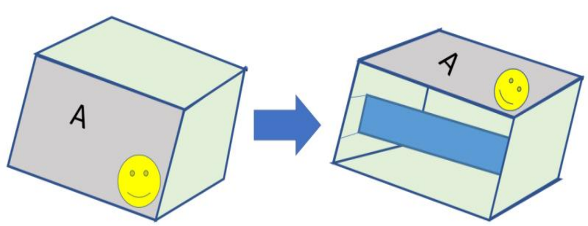

Figure 2: Desired Cabinet door initial and final positions

(a**) Design strategy (15 minutes**) 1. Develop a design strategy taking safety, cost, space, design and manufacturing simplicity, and aesthetic values into account. The plan should include the use of a gift/soft box to develop the concept proof. 2. Identify the mechanism design approach (two position, three position, fixed pivot etc.)

(b) **Perform Mechanism Syntheses (15 minutes)** Perform the mechanism synthesis on a paper showing each position and construction lines for the supervisor's verification.

(c) **Develop the prototype (15 minutes)** Using the available resources, develop a concept proof prototype.

(d) **Compose a report** detailing the design process and how the customer's specifications were met, along with personal reflection. Include a few images of both the synthesis and prototype models.

The students were given the following items, some of them are shown in Figure *3*:

- Rectangular/cubic napkin boxes of similar size to maintain consistent competition levels, with an area to hold the fixed pivots material for the solution.
- Cardboard or thick carton for mechanism linkages.
- Scissors cut the cardboard and create the necessary size of links.
- Push pins to create mechanism joints.
- Single Hole Puncher if small bolts are used for joint connection instead of the push pins.
- A4 and A3 paper for notetaking during discussions and for making the graphical synthesis, respectively.
- Plaster is provided in case it is needed for reinforcing the box or for placement at the pin joints. Sample material lists are shown in the Figure below.

Figure 3: Sample parts for prototype development

This study surveyed 35 undergraduate engineering students at a public university in a Midwestern state. Most of the students were male (70%) and juniors or seniors (63%). The most common racial/ethnic groups were White/Caucasian (55.5%), Asian (22%), and Hispanic/Latino (18.5%). About 88.5% of the students had a self-reported GPA of 3.00 and above, and all Asian students had a GPA of 3.0 or above. Only 11.5% of the students had a GPA between 2.5 and 3.00.

Result and Discussions

This project was a success in many ways. Students showed a strong understanding of the problem and the course material while trying to manage their time to complete the task within the allotted timeframe. The project additionally offered a valuable opportunity for learning. It sheds light on the constraints of specific graphical synthesis techniques when applied to address the given problem. For instance, the challenge of generating satisfactory solutions became evident in cases where two or three-position graphical synthesis methods fell short. Almost all participating groups utilized the entire allotted time span. Among the six groups in total, only two managed to develop a functional prototype to a reasonable extent. The remaining groups either couldn't complete their prototypes or were unable to demonstrate their functionality effectively (refer to Figure 4). Some groups opted for an intuitive approach to the task, diverging from the prescribed synthesis method. This led to the creation of mechanisms with a higher degree of freedom. During the prototype building phase, the students had the opportunity to demonstrate their technical skills by selecting their own materials and combinations. Furthermore, if more time was available, the difficulty of the project could be increased by introducing distance constraints to restrict the opening range of the cabinet door beyond the initial and final positions, providing additional challenges. The wining team prototype is shown in Figure 55.

Figure 4: Final Prototypes from the in class mini project activity

Figure 5: Sample students' prototype

A survey was done to assess students' perception towards this engagement. The participants in this study were asked to write about their perception of doing mini-building group work and their personal experiences of learning through mini-building teamwork. A thematic analysis of their response explored that students have perceived "solving problems as a team a valuable learning experience." Students preferred "working in larger groups of 4-6 individuals, rather than groups of two." They also expressed their interest in "having more mini group projects throughout the semester which can be done in a longer period, compared to individual assignments or the projects that need to be done in a much shorter timeline." According to the students' perception, through mini-building group projects, they have been "able to apply their individual skills, enhance bonding, develop creativity, and grow their communication, organizational, and relational skills." Students believed that mini-building group projects helped them "grasp the mechanism of design more profoundly, develop making sense of theories and linking them to hands-on experiences, and enhance creativity and imagination." Students would like to have "freedom and flexibility" of completing assignments, rather than "mimicking" the instructor. They would like "to be given the minimum requirements, time limit, and the overall expectation of accomplishing the task." In addition, students perceived mini-building projects "entertaining and encouraging" while helping them "develop knowledge." They also would not mind doing more mini-building group projects and being randomly assigned to teams, each time, to help them enhance their "ability and the opportunity of working with different people.

Data analysis showed about 82.38% of participants had positive perception about mini-in class prototype-based team activity. Students perceived mini prototype-based team activities as a contribution and motivation to enhance their teamwork skills, a self-assessment of students' technical capabilities and an understanding of their ability to effectively connect the course content to the real-world application of the projects (Figure *6*).

Results also showed the majority (66.67%) of students agreed that mini-prototype-based team projects had contributed to their teamwork strength. In addition, about 85.18% of the students perceived themselves engaging in the mini-prototype team project. More than 55% of participants agreed that the exercise of understanding the real-world application of the project motivated them to do their best to complete this project. The students could benefit more with longer time for the students to complete their mini-prototype projects though. However, in general, all 100% of students perceived this type of teamwork exercise effectively connected with the course content and 88.88% found this activity a good assessment to evaluate their technical capabilities. Students expressed that the mini-prototype projects provided them with a tangible application of theoretical concepts, making the learning experience more meaningful. Students expressed that the mini-prototype projects provided them with a tangible application of theoretical concepts, making the learning experience more meaningful. The projects also fostered a sense of accomplishment and boosted students' confidence in their problem-solving abilities. The EM approach encouraged them to think creatively and explore innovative solutions beyond what was covered in traditional lectures.

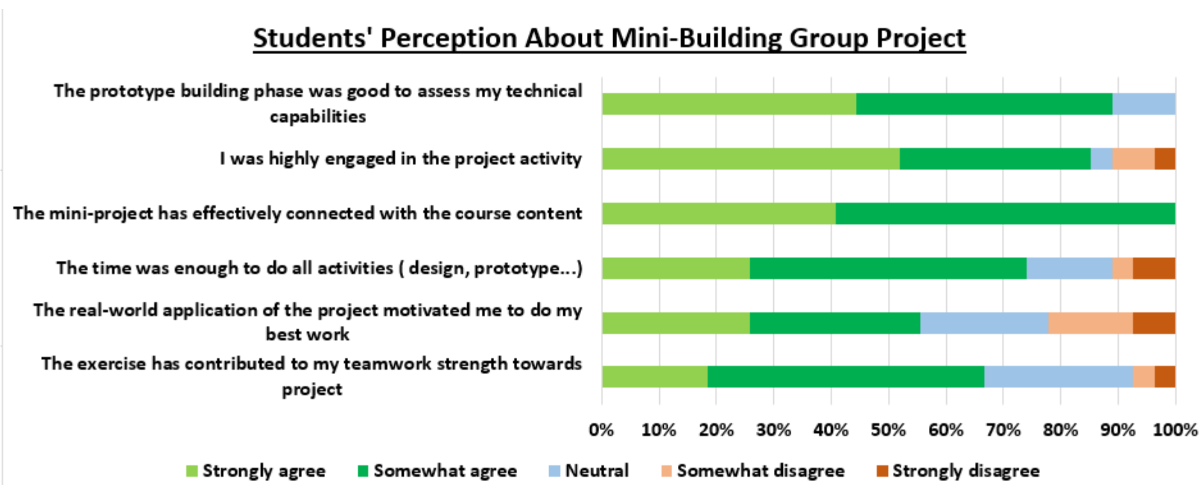

Figure 6: Students' perception

Conclusion

This paper discussed a method to improve engineering design education for undergraduates by combining mini-prototype projects and an Entrepreneurial Mindset. The approach and engagement strategy provided practical ways to foster collaboration among college students while teaching the subject material and topics related to EM. The study results showed the positive effect of this approach on students' technical knowledge, problem-solving skills, and understanding of the subject. By bridging the gap between theory and practice, engineering education can be developed to produce graduates who are better equipped to face real-world problems and contribute to sustainable progress in the field. Further research can explore the long-term effects of this approach and its potential for expansion across various engineering disciplines.

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