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Work in Process: Transformative Integration of Problem-Based Learning and Entrepreneurial Mindset in Early and Middle Stages of Mechanical Engineering: A Focus on Statics and Dynamics

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Work in Progress: Transformative Integration of Problem-Based Learning and Entrepreneurial Mindset: A Dynamic Approach in Mechanical Engineering Education

Introduction

This research initiative stands at the forefront, focusing on the areas of problem-based learning (PBL) and entrepreneurial mindset learning (EML) to transform the early and middle stages of mechanical engineering education. With an unwavering focus on the foundational courses of statics and dynamics, our transformative approach seeks to sculpt well-rounded engineers equipped with theoretical prowess, practical acumen, and an entrepreneurial spirit. This study is focused on the effects that the PBL had on the entrepreneurial mindset (EM) of the students in both courses. The EM was assessed with the Engineering and Science Entrepreneurial Mindset Assessment (ESEMA) [1].

The findings of this investigation reveal positive effects on students in the statics course, albeit some changes not reaching statistical significance due to the small sample size (n=13). Similarly, the dynamics class exhibited positive changes in certain ESEMA factors, illustrating the potential of PBL to shape the entrepreneurial mindset of mechanical engineering students.

Problem-Based Learning (PBL)

Problem-Based Learning (PBL) is an instructional method that redefines the educational experience by placing real-world challenges at its center [2, 3, 4]. In PBL, students actively deal with realistic problems, promote critical thinking, collaborative problem solving, and self-directed inquiry. This approach shifts the focus from passive information reception to active problem exploration, deepening students' comprehension of theoretical concepts and their practical applications.

Engineering Student Entrepreneurial Mindset Assessment (ESEMA) Survey

The Engineering Student Entrepreneurial Mindset Assessment (ESEMA) [1] is a self-report instrument, developed by Burnhaven et al. ESEMA survey evaluates entrepreneurial mindsets in undergraduate engineering students based on the Kern Entrepreneurial Engineering Network's 3Cs framework: Curiosity, Connections, and Creation of Value [5]. The ESEMA survey has been widely employed to gauge the EM progress of students in STEM courses. Carroll et al. [6] highlight the integration of the ESEMA in a first-year civil engineering curriculum. The study underscores how the ESEMA survey reveals significant enhancements in entrepreneurial attitudes among students, particularly in ideation and help-seeking behaviors. Jackson et al. [7] examined EM development in engineering students over four semesters using ESEMA. Significant growth in Empathy, Help Seeking, Interest, and Open Mindedness was observed. These findings highlight the importance of curricular interventions for EM enhancement, urging further research for a comprehensive understanding of EM development in engineering programs.

Administered both before and after project implementation, the ESEMA survey consists of 34 items across seven factors, including Ideation (Id), Open-Mindedness (OM), Interest (In), Altruism

(Al), Empathy (E), Help Seeking (HS), and an Unnamed (U) factor for negatively worded items. This comprehensive evaluation facilitates a nuanced understanding of the impact and effectiveness of the integrated PBL and EML elements in our project deployment. It offers insights into students' entrepreneurial mindsets, contributing valuable data before, during, and after engaging in entrepreneurial experiences. Table 1, which displays the ESEMA seven factors and corresponding items, utilizes a Likert scale.

Table 1—Engineering Student Entrepreneurial Mindset Assessment Items [1]

Factor 1: Ideation (Id)	
1.	I like to reimagine existing ideas
2.	I like to think about ways to improve accepted solutions
3.	I typically develop new ideas by improving existing solutions
4.	I like to think of wild and crazy ideas
5.	I tend to challenge things that are done by the book
6.	Other people tell me I am good at thinking outside the box
7.	I prefer to challenge adopted solutions rather than blindly accept them
8.	I tend to see my ideas through even if there are setbacks
9.	I look for new things to learn when I am bored
Factor 2: Open-Mindedness (OM)	
10.	I am willing to consider an idea put forth by someone with a different background than my own
11.	I am willing to compromise if another idea seems better than my own
12.	I appreciate the value that different kinds of knowledge can bring to a project
13.	I appreciate the value that individuals with different strengths bring to a team
14.	I recognize that people with different backgrounds from my own might have better ideas than I do
15.	I am willing to learn from others who have different areas of expertise
16.	I recognize the importance of other fields even if I don't know much about them
17.	I am willing to update my plans in response to new information
Factor 3: Interest (In)	
18.	I tend to get involved in a variety of activities
19.	I enjoy being involved in a variety of activities
20.	I participate in a wide range of hobbies
Factor 4: Altruism (Al)	
21.	The idea of tackling society's biggest problems does not motivate me (reverse scored)
22.	I believe it is important that I do things that fix problems in the world
23.	I am driven to do things that improve the lives of others
Factor 5: Empathy (E)	
24.	I can easily tune into how someone else feels
25.	Other people tell me I am good at understanding their feelings
Factor 6: Help Seeking (HS)	
26.	I know when I need to ask for help
27.	I am comfortable asking others for help
Factor 7: Unnamed (U)	
28.	I prefer what I am used to rather than what is unfamiliar (reverse scored)
29.	I would rather work with what is familiar than what is unfamiliar (reverse scored)
30.	I am less likely to change directions on a project after putting forth a lot of effort (reverse scored)
31.	I tend to resist change (reverse scored)
32.	I like to work on problems that have clear solutions (reverse scored)
33.	I prefer tasks that are well-defined (reverse scored)
34.	I tend not to do something when I am unsure of the outcome (reverse scored)

Aim and Significance

This research demonstrates the implementation of Problem-Based Learning (PBL) in Statics and Dynamics courses within the Mechanical Engineering program, typically taught during freshman and junior years, respectively. The primary purpose of this endeavor is to address the challenges encountered by students in their initial year of engineering studies. Condoor, S., et al. [8], highlighted the difficulties students encounter when embarking on the Statics course, often the first engineering course in their program. Gorlewicz et al. [9] provide an extensive literature review on implementing EML and the KEEN framework's 3Cs (Curiosity, Connections, and Creating Value) in engineering courses. The study demonstrates the successful integration of EML modules into Dynamics, Linear Vibrations, and Controls, with results indicating strong student consensus (>80%) on their effectiveness in linking engineering principles with practical, innovative tools.

It is crucial for engineering students not only to solve numerical and textbook problems but also to establish connections with the world around them. By focusing on statics and dynamics courses as foundational pillars, our aim is to bridge the gap between theoretical knowledge, practical application, and entrepreneurial thinking. This holistic approach seeks to equip students with the requisite skills and mindset to navigate the complexities and evolving nature of the mechanical engineering field.

Application of the EM and PBL in Statics and Dynamics

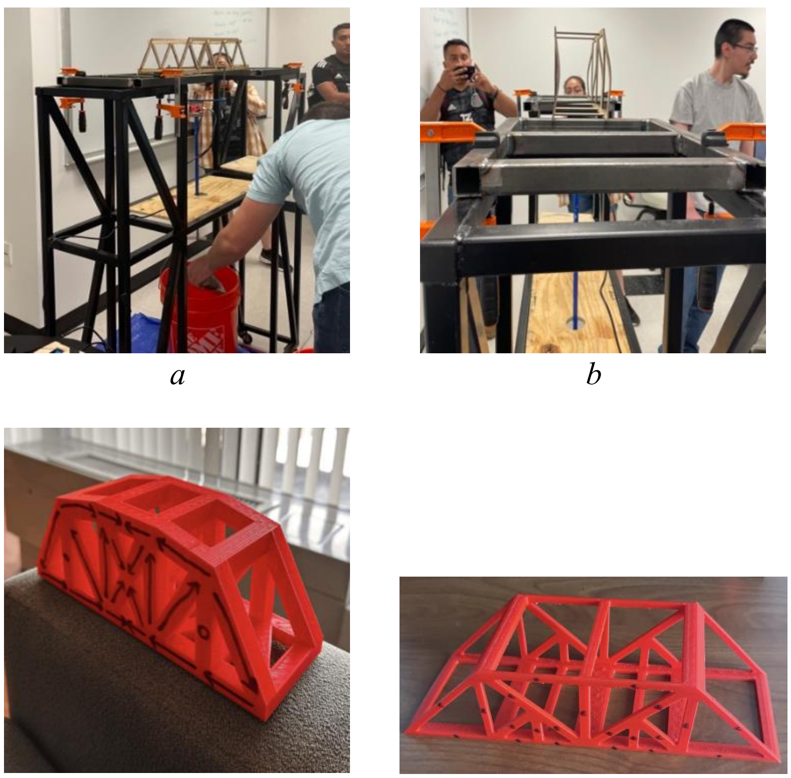
Entrepreneurial Mindset Learning (EML) constitutes a vital element of this study, strategically incorporated into mechanical engineering education to cultivate essential attributes aligned with the three Cs from the KEEN framework—Curiosity, Connections, and Creating Value [5]. Within the context of this initiative, Truss Bridge Design (Statics) and Pendulum-Powered Hockey Stick Launcher (Dynamics) projects, EML transcends mere theory, becoming a guiding principle. It not only prompts students to explore opportunities, fostering Curiosity, but also intertwines theoretical engineering concepts with real-world applications, thereby forging Connections. Going beyond conventional skill sets, EML instills adaptability, resilience, and a keen awareness of the broader implications of engineering solutions—Creating Value [5, 6, 7 and 9].

This deliberate integration of EML within the projects ensures that students not only acquire technical proficiency but also develop the entrepreneurial acumen essential for navigating the dynamic landscape of mechanical engineering. Rather than being presented with neatly packaged problems, students are confronted with semi-open-ended scenarios. While they receive initial instructions outlining variable limitations, the task of developing the mathematical model becomes their responsibility. For instance, in the Dynamics project, students were engaged in a stakeholder-client scenario where they were provided with a change of specifications and tasked with justifying design alterations to stakeholders and clients. This approach instills in them the ability to overcome challenges and approach problem-solving with ingenuity and resourcefulness.

Implementation of EM and PBL in Statics

The integration of Problem-Based Learning (PBL) unfolds across three distinct phases within each project, cultivating a comprehensive learning experience in the Statics course.

In the initial half of the Statics course, students engage with fundamental concepts such as vectors theory, moments, equilibrium, rigid body equilibrium, supports, two-force members, and truss calculations. They also become proficient in methods like the joint and section methods for structural analysis. Aiming to spark their curiosity, preceding the exploration of truss calculations in class, students are tasked with conducting a background review as their inaugural assignment. Subsequently, in the second part of the project, students focus on determining support reactions using the method of joints. Throughout the first two segments of the project, students are encouraged to delve into the state-of-the-art truss bridge design, classical geometries, and real-world examples. They are then challenged to select a semi-complex truss, adhering to specific constraints such as total length, height, width, and maximum number of joints. To ensure a seamless transition between parts two and three, the third phase occurs just before the completion of the second part, involving the creation of 3D drawings and subsequent 3D printing of the truss designs. Finally, students present their 3D-printed bridges in class for measurement, ensuring that prototypes conform to the specified parameters. Previous iterations of the course students constructed bridges using craft sticks in one semester, while in another, they utilized laser cutting for constructing trusses and cross members.



a *b*

c *d*

Figure 1 – Final bridge prototypes: *a* and *b*, laser-cut bridge testing from Spring 2023 class, *c*, and *d*, 3D printed bridges from Fall 2023 class.

Figure 1 illustrates a selection of bridge prototypes developed by students during the Spring and Fall terms of 2023. Figures 1a and 1b showcase the laser-cut bridges undergoing testing within a controlled setup. Students positioned their bridges atop a spacious span, with a rod attached to the bridge's deck and suspended. Pre-weighted sandbags were systematically added to the recipient at

the opposite end of the rod, applying a concentrated load precisely at the center of the bridge deck. Through meticulous observation, students documented the deflection, buckling, and eventual failure of their bridges, while also recording the maximum load capacity achieved. Testing was performed in the last week of the semester.
Figures 1c and 1b, show two 3D printed bridges. The truss was selected by students, and they had to create a spreadsheet following the Matrix method [10] to calculate the internal forces and identify the zero force members.

Implementation of EM and PBL in Dynamics

In a typical Dynamics course, the curriculum is structured into two main sections: particle analysis and rigid body analysis, both the study of kinematics and kinetics of engineering systems. The kinetics segment delves into equations of motion, various mechanical energies, energy conservation principles, power, efficiency, and linear and angular impulse and momentum.

The Pendulum-Powered Hockey Stick Launcher project was introduced to students before concluding the particle analysis section of the Dynamics course. During this initial phase, students explored the materials, shapes, and geometry inherent to the hockey stick. This inquiry-driven approach sparked curiosity and prepared students for engineering calculations in subsequent stages.

At this stage, students were tasked with formulating an equation to determine the length of a hockey stick-shaped pendulum. The objective was to launch the hockey stick from a horizontal position, striking a hockey puck when it reached a vertical position to ensure the puck traveled a specified distance. Students needed to calculate the mass and length of two distinct hockey sticks to meet distance constraints (one stick for 20 ft and one for 2 ft), employing principles of energy conservation, linear and angular momentum for the stick, and kinematics for the puck using particle analysis as a primer approach. Following this, students performed a sensitivity analysis to determine the optimal length, mass, and coefficient of restitution combination, considering provided ranges for the coefficient of friction between the puck and ground. Most teams utilized spreadsheets to conduct the sensitivity analysis, running ranges of values for length and coefficient of restitution.

The deliberate incorporation of these preliminary phases aligns with the essence of PBL, promoting active engagement, critical thinking, and self-directed inquiry. In the final phase of the project, students faced a new challenge: modifying their design to meet new requirements from a stakeholder, Toys Inc., a toy company interested in investing in the pendulum setup for toddlers. This necessitated adjustments in weight, material density, and height constraints. Additionally, students were tasked with providing a prototype of the toy by 3D printing the setup, including two supports, a pivot, and the hockey stick. (See Figure 2 for illustration.)

a *b* *c*

Figure 2. – Final Pendulum-Powered Hockey Stick Launcher prototypes

Figures 2a and 2c showcase the distinct hockey stick shapes present in the students' final prototypes. Particularly, Figure 2c displays an alternative geometry to the typical hockey stick design. Upon conducting calculations and considering the new density restrictions, some teams concluded that modifying the geometry and mass associated with the stick head would enable the puck to travel longer distances. Consequently, these teams submitted a request to the stakeholders to alter the geometry, providing justifications for their proposed changes. Remarkably, the stakeholders granted their request. The principal stakeholder was personified by the course instructor.

This proactive and insightful response from students underscores their deeper understanding of product design and their commitment to satisfying client needs. Such initiatives set the stage for a deeper understanding of theoretical principles and practical applications, ultimately preparing students for the multifaceted challenges inherent in real-world problem-solving within the dynamic field of mechanical engineering.

Methods

Statics and Dynamics had 28 and 38 students in the Fall classes, respectively. A total of 13 statics and 29 dynamics students completed both the pre- and post-surveys for response rates of 46.4% and 76.3%, respectively. The data sets did not include responses from other students who only completed the pre- or post-survey or left questions blank. Each Likert scale response was coded from 1-5 as Likert et al. [10] with questions 21 and. 28-34 reverse scored. The responses were divided into the seven factors, and the sub-score was calculated along with the overall total. The total number of questions for Ideation (Id), Open-Mindedness (OM), Interest (In), Altruism (Al), Empathy (E), Help Seeking (HS), and Unnamed (U) were 9, 8, 3, 3, 2, 2, and 7, respectively. The data was analyzed in SPSS. The scores for each factor and the overall total for the pre- and post-tests were checked for normality and outliers. Interest and Altruism were found not to have a normal distribution for at least one data set in Statics and Interest and Empathy were found not to have a normal distribution for at least one set in Dynamics. There were no outliers in the Statics course, but data for six respondents in dynamics were removed because they were an outlier for at least one factor. A parametric paired t-test was performed on all data sets with normal distributions, and a non-parametric Related-Samples Wilcoxon Signed Rank Test was performed on the other data sets without a normal distribution.

Table 2 shows a summary of the results for the statics course (n = 13). The mean for all factors except for Unnamed increased. Ideation increased by 2.54; Open-Mindedness increased by 0.23; Interest increased by 0.08; Altruism increased by 0.23; Empathy increased by 0.62; and Help Seeking increased by 0.54. Unnamed decreased by 0.77. Also, the overall total increased by 3.46. While all factors except for Unnamed along with the overall total average increased, only Ideation saw a statistically significant difference with a p-value of 0.009. All other comparisons resulted in p-values greater than 0.05.

Results and Discussion

Table 3 shows a summary of the results for the Dynamics course (n = 24). The mean score increased for Ideation, Interest, Help Seeking, and Unnamed, but decreased for all other factors. Ideation increased by 2.54; Interest increased by 0.17; Help Seeking increased by 0.17; and Unnamed increased by 0.62. Open-Mindedness decreased by 0.75; Altruism decreased by 0.50; and Empathy decreased by 0.33. The overall total increased by 1.92. Like Statics, only Ideation showed a statistically significant difference with a p-value less than 0.05. All other p-values were larger than 0.05.

Table 2—Descriptive statistics of pre- and post-test ESEMA surveys for statics

	Pre			Post				
Factor	Average	St. Dev.	Shapiro-Wilk Sig.	Average	St. Dev.	Shapiro-Wilk Sig.	Normality	p-value
Id	31.46	6.36	0.891	**34.00**	6.47	0.438	P	0.009
OM	35.54	3.91	0.186	**35.77**	4.21	0.085	P	0.756
In	12.00	2.80	0.036	**12.08**	2.81	0.096	NP	0.831
Al	11.77	2.35	0.329	**12.00**	2.27	0.029	NP	0.670
E	7.23	2.24	0.286	**7.85**	1.46	0.615	P	0.136
HS	6.08	1.85	0.226	**6.62**	1.94	0.154	P	0.237
U	20.69	5.50	0.804	19.92	3.40	0.758	P	0.526
Total	124.77	18.37	0.305	**128.23**	16.44	0.935	P	0.118

Table 3—Descriptive statistics of pre- and post-test ESEMA surveys for dynamics

	Pre			Post				
Factor	Average	St. Dev.	Shapiro-Wilk Sig.	Average	St. Dev.	Shapiro-Wilk Sig.	Normality	p-value
Id	27.92	6.90	0.680	**30.46**	6.80	0.605	P	0.029
OM	34.04	3.90	0.325	33.29	5.18	0.062	P	0.467
In	12.04	1.99	0.027	**12.21**	1.93	0.107	NP	0.679
Al	11.42	2.15	0.536	10.92	2.24	0.656	P	0.137
E	7.21	1.59	0.069	6.88	1.48	0.038	NP	0.265
HS	5.96	2.10	0.096	**6.13**	1.87	0.733	P	0.622
U	18.21	3.18	0.805	**18.83**	3.77	0.167	P	0.285
Total	116.79	10.37	0.664	**118.71**	13.98	0.674	P	0.292

Conclusions

The results of this study offer valuable insights into the effectiveness of integrating Problem-Based Learning (PBL) and Entrepreneurial Mindset Learning (EML) in mechanical engineering education. The significant improvements observed in students' scores on the Entrepreneurial Minset Learning Assessment (ESEMA) surveys indicate that these pedagogical approaches have the potential to enhance both theoretical understanding and practical skills. Despite the challenges presented by the traditional emphasis on theoretical knowledge, the integration of PBL and EML has provided students with practical skills and an entrepreneurial mindset essential for success in the field.

In reflecting on the results of this study, it becomes evident that the integration of Problem-Based Learning (PBL) and Entrepreneurial Mindset Learning (EML) holds promise for enhancing mechanical engineering education. The significant improvements observed in students' scores on the Entrepreneurial Minded Learning Assessment (ESEMA) surveys underscore the potential of these pedagogical approaches to augment both theoretical understanding and practical skills. However, the challenges encountered, such as the need for iterative prototyping and adjustments to project requirements, highlight the complexities inherent in implementing innovative teaching methods.

The implementation of Problem-Based Learning (PBL) and Entrepreneurial Mindset Learning (EML) in foundational mechanical engineering courses, specifically Statics and Dynamics, has yielded promising results. Despite the challenges presented by the traditional emphasis on theoretical knowledge, the integration of PBL and EML has provided students with practical skills and an entrepreneurial mindset essential for success in the field. Moreover, the variability in response rates and the presence of outliers in the data underscore the importance of careful data collection and analysis in educational research. While the results are promising, further investigation is needed to fully understand the impact of PBL and EML on student learning outcomes and to identify areas for improvement. Additionally, ongoing reflection and adaptation of teaching strategies based on student feedback and assessment data will be essential in optimizing the integration of PBL and EML in mechanical engineering courses.

Lessons Learned and Moving Forward

In reflecting on the Statics project, students found satisfaction in applying their CAD skills to bring their designs to life. However, in the spring semester, we missed the opportunity to test the prototypes with the designated testing setup after 3D printing. Moving forward, we plan to introduce a new variable—thickness of the truss members—to enhance the design complexity. Some teams inadvertently used very thick truss members, rendering failure testing impractical with the current setup. In future iterations, we aim to produce two bridges: one with uniformly slim members and another with reinforced members in the weakest members.

Regarding the Dynamics project, the implementation of the second part was delayed allowing the class to catch up with rigid body analysis and reassess the design equation accordingly. This delay impacted the design and construction of the prototypes. For subsequent iterations, we intend to implement iterative prototyping, enabling students to address challenges in constructing the supports, pivot, and hockey stick. Given that these components involve moving parts, students will need to calculate and test tolerances before finalizing the prototype. This iterative process will also provide time for students to catch up with the rigid body analysis portion of the course and gain insights into how factors such as height, mass, and coefficient of restitution influence the hockey stick's performance.

In terms of the ESEMA survey, we recognize the importance of ensuring its completion for both pre- and post-surveys. To mitigate potential issues, we plan to offer incentives for survey completion in class and provide timely announcements to maximize student participation.

Looking forward, our next step involves collecting data from further 2~3 cycles in both courses and developing a longitudinal study on students' entrepreneurial mindset development in the first two years of engineering education. We aim to review if other factors seem to change or if the ones that change have a larger impact on the overall entrepreneurial mindset development. This longitudinal study will provide valuable insights into the trajectory of students' entrepreneurial mindset over time and help us better understand the factors that contribute to its development.

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