

Infusing an Entrepreneurial Mindset into Multidisciplinary Capstone Curriculum: Learning Objectives, ABET Alignment, and Supporting Activities*

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In a Multidisciplinary Design Capstone course sequence, faculty have been integrating the entrepreneurial mindset into the course's learning objectives. The desire to have students identify opportunities to create value, install curiosity about the world and their impact, and connect various topics and material together is of the utmost importance in a multidisciplinary capstone course that includes practical engineering design experience. The Multidisciplinary Design Capstone course sequence focuses on authentic industry sponsored projects that students work on over a two-semester sequence. This paper describes the capstone course as well as the entrepreneurial mindset learning objectives that have been developed and incorporated into the course. These learning objectives are presented as well as their alignment to the ABET Criterion 3 (1–7). Curriculum changes and activities to align with the new learning objectives are presented as well as lessons learned from the faculty. This study looks at student and sponsor/advisor perceptions of the entrepreneurial mindset learning objectives.

Keywords: multidisciplinary; ABET; entrepreneurial mindset

1. Introduction

1.1 Background

Wanting to develop the mindset of engineering students to think beyond their technical knowledge into how their work as engineers impacts the world is an important part to a comprehensive engineering curriculum. Part of this mindset can be thought of as the entrepreneurial mindset where students are encouraged to identify opportunities to create value, be curious about the world around them, and connect ideas and topics together to form unique solutions. This Entrepreneurial Mindset (EM) has been a focus of many schools within the Kern Entrepreneurial Engineering Network (KEEN) and has been guided by a general EM framework [1]. This entrepreneurial mindset is something that can be developed [2]. At The Ohio State University, faculty have been infusing EM into courses at the first-year [3–5] and capstone level [6] since 2017. These curriculum changes have been guided by identifying learning objectives that align with EM and then associating activities to help support those learning objectives along with appropriate assessments. This paper highlights the curri-

culum changes and learning objectives in a multidisciplinary capstone course sequence to infuse and strengthen the EM content in the course.

1.2 Literature Review

Learning objectives are foundational in supporting student learning. Ambrose [7] informs of seven research-based principles for Smart Teaching used to disclose practices that provide intentional educational environments to heighten students' learning. In the article, the scholars identify a principle of *How students organize knowledge influences how they learn and apply what they know* in which the scholars describe how students make connections with pieces of information that can be accurately and meaningfully organized to increase students' likelihood of being able to retrieve and apply their knowledge effectively [7, p. 4]. This intentional consideration of how students create mental models that help them make sense of new knowledge provides a useful anchor point in achieving accurate and meaningful connections. Learning objectives serve as a vital parameter to that equation in that these often are the shared goals and shared language created with courses to guide

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students through their sense-making process. The Universal Backwards Design (UbD) framework is one common tool in course design for its support in developing accurate and meaningful learning objectives as well as informing assessment plan and learning plan decisions as they align with these learning objectives [8, 9]. Instructors can carefully position their educational goals through shared contextual based language within their courses to efficiently support students' organization of knowledge and creation of understanding [9, 10]. The opportunity also to develop learning objectives anchored in shared contexts across disciplines also becomes a vital tool not only for progressing the field through shared educational goals, but also to equip new educators with anchor points when taking on their new courseloads [11, 12].

Disciplines and fields can develop and leverage learning objectives transferable to established and emerging pedagogical needs to progress student readiness for post-graduation opportunities. In engineering, there is an established priority in reforming engineering education to support the development of sociotechnical engineers capable of extending technical skills within social realities of modern-day complex problems [13–16]. There becomes a growing need to build upon the identification of these sociotechnical skills and to develop pedagogical approaches capable to supporting student learning in these emerging pillars of engineering education [13, 16]. More specifically, with emerging pedagogical approaches comes the need to develop accurate and meaningful learning objectives to support the development of these socio-technical skills.

One emerging context with the ability to support the development of sociotechnical skills in engineering students is through *entrepreneurship* blended within engineering education. Entrepreneurial education is not simply preparing students to start a business, rather “. . . to develop to the students the knowledge, skills and competencies which will help them to engage in a more enterprising, innovative and flexible manner in the changing workplace environment from today” [17]. When centered in engineering curriculum, entrepreneurship allows for students to engage with skills such as empathy, collaboration, and creativity [18–21]. The Kern Entrepreneurial Engineering Network (KEEN) is a partnership of more than 55 colleges and universities across the United States that work to support engineering educators with tools, assessments, and resources in developing engineering student's entrepreneurial mindset [22]. More specifically, “The Entrepreneurial Mindset (EM) is a set of attitudes, dispositions, habits, and behaviors that shape a unique approach problem solving, innova-

tion and value creation” [23]. The KEEN network works to establish the research to practice cycle in engineering in informing ways in which to heighten engineering students' engagement with empathy, creativity, resiliency, flexibility, and collaborative abilities through entrepreneurial education in engineering classroom pedagogical approaches [24–26]. One notable challenge identified in the progression of engaging in entrepreneurial education through the EM approach is the limitation in the conceptualization of learning outcomes of entrepreneurship [27]. The purpose of this study uses this as a departure point in developing Entrepreneurial Mindset Learning Objectives that could be used to catalyze the use and practice of EM within a multidisciplinary, senior engineering design course.

2. Methods

2.1 Course Context – Multidisciplinary Design Capstone

The Multidisciplinary Design Capstone (MDC) course sequence at The Ohio State University is an optional capstone experience available to all engineering disciplines. This two-course sequence pairs student teams up with industry sponsors to work on an authentic industry driven project. All of Ohio State's 14 engineering disciplines have participated across the lifetime of the program (since 2009). Students who enroll elect to take this course instead of the senior capstone project in their discipline. Beyond engineering students, this course also includes non-engineering students through the Engineering Science Minor program. These non-engineering students have completed first-year engineering and must participate in an engineering capstone course in addition to ~5 additional credits of engineering courses to receive the minor. Many of these engineering science minor students are students who originally intended to get an engineering degree but transferred out of the college to another major like mathematics, psychology, or business. The engineering science minor students are expected to contribute to the project in a similar quantity to the engineering students, but the way they contribute and their expertise that is used is based on their major and the project needs. The truly multidisciplinary nature of these teams beyond just engineering disciplines adds to the richness and value that these project teams can provide the industry sponsors. While many of the elements of EM were already a natural part of the course, the infusion of EM and strengthening of components that already existed was a goal of this curriculum development initiative. The importance of including and re-emphasizing EM in the capstone course also aligned with a desired continuity

in education since students would have experienced EM in their first-year engineering classes starting with the 2017 cohort which would be in this capstone course as early as 2020 for those students on a 4-year timeline. To do this, it was important to establish specific learning objectives related to EM, but also to consider how those learning objectives complimented ABET criteria.

2.2 EM Learning Objectives Development

To create learning objectives that align with EM, a backwards design [9] approach was taken to establish a set of objectives. While other ways of operationalizing EM exist [28, 29], it was important for the faculty at Ohio State to be involved in the development of these objectives using the others' definitions as a guide. These objectives were modified and critiqued by stakeholders [30, 31] until a final set of 14 EM Learning Objectives (EMLOs) were established. While many of these learning objectives can be seen as general to engineering or design, they are a part of the framework established by KEEN as necessary for developing an Entrepreneurial Mindset and therefore they were included. The final EMLOs with descriptions are given below.

1. **Demonstrate Curiosity:** Ask and encourage questions that facilitate and inspire growth and learning.
2. **Analyze Accepted Solutions:** Explore a contrarian view of currently accepted products, processes, and services.
3. **Integrate Information through Making Connections:** Make connections between different domains of knowledge to reach new and innovative ideas and solutions.
4. **Evaluate Social, Economic, and Environmental Risks and Benefits:** Evaluate social, economic, and environmental factors when considering ideas and solutions to problems.
5. **Identify Opportunity to Create value:** Create ideas for new products, processes, or services that provide a potential social, economic, or environmental value.
6. **Learn from Failure:** Persist through and learn from failure.
7. **Define Problem:** Based upon an identified opportunity, stakeholder feedback, primary research, and secondary research, create a formal definition of a specific problem.
8. **Define User Needs:** Develop a list of needs from research and stakeholder(s) that support project objectives.
9. **Develop Concepts and Visual Representations:** Represent and refine conceptual solutions through the use of visual representations.

10. **Analyze Solutions and Develop Design Requirements:** Select a final concept solution based on user needs and develop design requirements.
11. **Perform Detailed Design:** Perform detailed design driven by the set of design requirements and taking into account usability.
12. **Test and Validate Solutions:** Develop a process to verify the solution meets the design requirements and validate results.
13. **Identify and Utilize Resources and Expertise:** Identify gaps in knowledge, resources that could fill that gap, and how those resources can be used to advance a solution.
14. **Consider How to Protect Intellectual Property:** Recommend ways in which you can protect your own intellectual property and appropriately use other's intellectual property.

Each EMLO was given three levels of potential achievement which were meant to aid in potential scaffolding of the curriculum. The beginning level was focused on introducing the students to the concept, the intermediate level was focused on using the concept to apply to a problem, and the advanced level was meant to be as close to a real-world project-based application of the EMLO as possible in a classroom context. As such it is expected that in a first-year course many of the EMLOs would be met at the beginning and intermediate level, but in a senior capstone level course these would be met at the advanced level. There were rubrics developed for each proficiency level to help differentiate for the instructional team what would be appropriate activities based on the level desired. An example of the 3 levels is given below for the EMLO "Identify Opportunity to Create value", "Define User Needs" and "Analyze Proposed Solutions and Develop Design Requirements".

5. *Identify Opportunity to Create value:*

- (Advanced) Propose an opportunity to create a product, process, or service and justify that it can be developed to create value using research from multiple sources.
- (Intermediate) Given a broad description of an opportunity, refine the opportunity based on research.
- (Beginner) Describe the features of an identified opportunity.

8. *Define User Needs:*

- (Advanced) Refine user and stakeholder needs through iterative cycles of interaction and feedback.
- (Intermediate) Develop a list of user needs using either primary or secondary research.

- (Beginner) Apply a given set of user needs as part of the design process.

10. Analyze Proposed Solutions and Develop Design Requirements:

- (Advanced) Analyze proposed concepts based on user needs and student-generated design requirements.
- (Intermediate) Select the best solution from the proposed concepts and provided design requirements.
- (Beginner) Describe the process of analyzing potential solutions and determining design requirements for the project.

2.3 EMLO Alignment to ABET

The senior capstone course is the culminating experience for most engineering disciplines, and it is an important part of the ABET assessment. Since assessment is always ongoing for ABET, alignment with EM was a logical step to take. As these EMLOs were developed the course instructors considered how they aligned with existing ABET criteria [32]. ABET criterion 3: Student Outcomes 1–7 are given below.

1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
2. An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
3. An ability to communicate effectively with a range of audiences.
4. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
5. An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environ-

ment, establish goals, plan tasks, and meet objectives.

6. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
7. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

The course instructors and EMLO developers worked together to create a relationship between the EMLOs and ABET criterion 3. These relationships were based on the definitions of the EMLOs compared to the ABET criterion student outcomes. The group identified key common terms or concepts between the two to identify correlations. For example, EMLO 5 “Identify Opportunity to Create value” was correlated with key terms from ABET criterion 3 outcomes 1, 2, 4 and 7 as shown in Table 1.

Table 2 shows the established alignment between the EMLO and ABET criteria. Any EMLO that was considered to be meeting the ABET criteria at its advanced EMLO level is shown with an X in the appropriate box. A limitation to this alignment is that there may be some variation in how EMLOs are met in various projects and therefore the alignment may not always be one to one for all EMLO activities. However, these represent the ideal alignment for advanced EMLO activities in a capstone course. As shown by Table 2, the EMLOs meet several of the ABET criteria which allow for the course developers to create assignments that meet multiple learning outcomes.

2.4 MDC Curriculum Support of EMLOs and ABET

The original MDC course sequence only included major deliverables such as four written design reports, four oral presentations, and two progress status reports. After establishing which EMLO criteria at the advanced level were going to be addressed in the MDC courses, activities were developed to help support and assess the development of these learning objectives as well as the original major deliverables. Below are three examples of activities that were included in the course to

Table 1. EMLO 5 and ABET Correlation

EMLO 5, Identify Opportunity to Create Value	ABET Criterion 3 Outcome
Create ideas for new products, processes or services	1. An ability to identify, formulate, and solve complex engineering problems
Provide a potential social, economic, or environmental value	2. Specified needs with consideration of . . . global, cultural, social, environmental and economic factors
Create ideas . . . that provide a potential social, economic, or environmental value	4. Ethical and professional responsibilities . . . consider the impact of engineering solutions in global, economic, environmental, and societal contexts
Create ideas for new products, processes or services	7. An ability to acquire and apply new knowledge as needed

Table 2. EMLO and ABET Criteria Alignment

EMLO	ABET Criterion 3						
	1	2	3	4	5	6	7
1. Demonstrate Curiosity	x		x		x		x
2. Analyze Accepted Solutions	x	x				x	x
3. Integrate Information through Making Connections	x	x		x		x	x
4. Evaluate Social, Economic and Environmental Risks and Benefits		x		x		x	
5. Identify Opportunity to Create Value	x	x		x			x
6. Learn from Failure				x	x		x
7. Define Problem	x	x	x		x		
8. Define User Needs		x	x		x		x
9. Develop Concepts and Visual Representations	x		x				
10. Analyze Solutions and Develop Design Requirements	x	x				x	
11. Perform Detailed Design	x	x					
12. Test and Validate Solutions		x				x	
13. Identify and Utilize Resources and Expertise	x			x	x		x
14. Consider How to Protect Intellectual Property				x			x

support these EM objectives. These activities cover EMLO 5, 8 and 10 as these were three topics that the instructors felt needed to be strengthened in the student deliverables and design process. Students completed these activities in class as a team to help them scaffold their work towards their major capstone project milestones.

The first example (Fig. 1) is a user needs and market analysis assignment. This assignment aligns with EMLO 5 “Identify Opportunity to Create Value” and EMLO 8 “Define User Needs”. This activity is helpful in students being reflective about

users as well as the current market space which supports the development of ABET Criteria 3: Student Learning Outcomes #1, 2, 3, 4, 5 and 7. As these projects are scoped and identified by the industry sponsors, it is important for the student teams to still consider the users and market for the project to develop an impactful solution even if the industry sponsors already considered that in the project scoping.

The next activity (Fig. 2) is a value proposition statement. A value proposition statement aids in the communication to stakeholders of the purpose

Activity Title: *User Needs, Status Quo and Markets*

Purpose: To identify stakeholders’ needs and the current status and potential market of the project or product.

Prompts:

1. Define the User Needs for your project:
 - a. Who is your user or users?
 - b. What are their top 3-5 needs?
2. Define Status Quo and the Primary Market for your project:
 - a. What is currently being done (or not done)?
 - b. What are the pros and cons of the status quo?
 - c. Who could potentially be affected by changes in the status quo? (e.g. Who is the primary and secondary markets?)

Fig. 1. Activity 1 – User Needs, Status Quo and Markets.

Activity Title: *Value Proposition*

Purpose: To develop a value statement that addresses the specific problem to communicate to stakeholders.

Prompts:

Submit your first version of a value proposition. Start with these 3 key items:

1. Identify a specific problem being dealt with by a specific audience.
2. Articulate how the product/service being sold or solves this specific problem.
3. Communicate the audience-specific intangible and quantifiable benefits of the solution.

Then, work to refine and simplify into a phrase.

Fig. 2. Activity 2 – Value Proposition.

Activity Title: <i>Design Requirements</i> Purpose: To develop specific design requirements and specifications that address user needs for a value-added solution to be created. Prompts: 1. Work with your team to review your User Needs. 2. Build a table in Excel with a column for User Needs and associated columns for all Design Requirement details.
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Fig. 3. Activity 3 – Design Requirements.

and goal of the project solution. This activity aligns with EMLO 5 “Identify Opportunity to Create Value” as well as ABET Criteria 3: Student Learning Outcomes #1, 2, 4 and 7. Again, this is a crucial step in the Entrepreneurial Mindset and an important component to creating an impact.

This last activity (Fig. 3) is about considering the design requirements which aligns with EMLO 10 “Analyze Solutions and Develop Design Requirements” and ABET Criteria 3: Student Learning Outcomes #1, 2 and 6. This activity directly relates design requirements to specific user needs that support the creation and development of a value-added solution. These activities were incorporated into the major project deliverables. The first activity was included as a section of the first major deliverable, Problem Identification report. EMLO 8 was used as part of the rubric to assess the student deliverable. Activities 2 and 3 were incorporated in the second major deliverable, Systems Design report which EMLOs 5 and 10 were used to assess the students’ submissions. The careful consideration for the course iteration to include these EMLOs provided useful insights when implemented in the Multidisciplinary Capstone Course sequence. These changes to the curriculum were made in the 2022–2023 academic year and continued in the 2023–2024 academic year. However, throughout the implementation the instructors quickly identified a misalignment between the perceived value of embedding EMLOs between the instructional staff and the students. In addition to anecdotal data and observations, data was collected throughout the course both before and after the implementation to gauge students self-reported perceptions of preparedness. While self-reported perceptions may not be reliable measures of learning gains, in this case the goal is to develop a mindset around these characteristics and thus the perceptions likely are linked to that mindset development. This data collection and analysis is the focus of this project with the aim to support and identify additional course improvements.

2.5 Survey Methods

To help identify the impact on student learning of these three EMLOs (number 5, 8 and 10), students

were given a survey at the beginning and end of project for students to self-identify their perceptions of preparedness for each of the 14 EMLOs (Likert scale 1 to 5, with 1 – not prepared at all, 2 – minimally prepared, 3 – somewhat prepared, 4 – adequately prepared, to 5 – very prepared. The language used for the EMLO survey was the description of the top overall objective rather than a specific level. This survey was given in both Autumn and Spring Semesters in 2021–2022 (N = 63), 2022–2023 (N = 67), and 2023–2024 (N = 68) academic years. In addition, in 2022–2023 (N = 23) and 2023–2024 (N = 15) the project sponsors and faculty advisors were given the same survey at the end of the project to compare their perceptions of student’s preparedness as well. Only the results from students who completed both the pre- and the post-test were included in this dataset.

3. Results

The results from the Spring post-test are given in Table 3. Because of the small number of sponsors and faculty advisors, the two cohorts of participants were averaged together. Using a Kruskal-Wallis nonparametric test, the results from the three years of students were compared and many of the differences were not statistically significant. The two items that were statistically significant from 2021–2022 to 2023–2024 were “Learn from Failure” and “Consider How to Protect Intellectual Property”. These were not EMLOs that were explicitly focused on in the course revisions related to the EMLOs but it is interesting that the “Learn from Failure” decreased across the cohorts and the “Consider How to Protect Intellectual Property” increased. Additionally, the student responses were compared to the sponsors & advisor responses using a non-parametric Mann Whitney U-Test and found that there were no statistically significant differences between the sponsor and advisor perception of the student preparedness and the students’ self-perceptions.

While there were not many statistically significant results comparing the student’s self-perception of preparedness by year, there were significant comparisons from the pre-test to the post-test in all individual years and when considering the total

Table 3. Spring post-test means of EMLO preparedness across three cohorts of student responses and responses from sponsors and advisors. (*statistically significant differences)

EMLO	2021–2022	2022–2023	2023–2024	Sponsors Advisors
1. Demonstrate Curiosity	4.43	4.37	4.35	4.37
2. Analyze Accepted Solutions	4.38	4.30	4.32	4.37
3. Integrate Information through Making Connections	4.38	4.30	4.29	4.24
4. Evaluate Social, Economic and Environmental Risks and Benefits	4.02	4.06	4.00	4.03
5. Identify Opportunity to Create Value	4.25	4.25	4.29	4.18
6. Learn from Failure	4.63*	4.52	4.35*	4.55
7. Define Problem	4.35	4.31	4.26	4.37
8. Define User Needs	4.40	4.39	4.31	4.34
9. Develop Concepts and Visual Representations	4.33	4.36	4.26	4.34
10. Analyze Solutions and Develop Design Requirements	4.38	4.42	4.32	4.37
11. Perform Detailed Design	4.25	4.27	4.24	4.32
12. Test and Validate Solutions	4.32	4.21	4.12	4.18
13. Identify and Utilize Resources and Expertise	4.33	4.16	4.21	4.26
14. Consider How to Protect Intellectual Property	3.54*	3.76	4.10*	4.11

Table 4. Autumn pre-test and Spring post-test means of EMLO preparedness across three cohorts of student responses

EMLO	Autumn – Pre-Test				Spring – Post-Test			
	2021– 2022	2022– 2023	2023– 2024	Total Avg	2021– 2022	2022– 2023	2023– 2024	Total Avg
1. Demonstrate Curiosity	4.05	4.21	3.82	4.03	4.43	4.37	4.35	4.38
2. Analyze Accepted Solutions	3.79	3.88	3.47	3.71	4.38	4.30	4.32	4.33
3. Integrate Information through Making Connections	3.54	3.73	3.44	3.57	4.38	4.30	4.29	4.32
4. Evaluate Social, Economic and Environmental Risks and Benefits	3.32	3.33	2.99	3.21	4.02	4.06	4.00	4.03
5. Identify Opportunity to Create Value	3.41	3.49	3.35	3.42	4.25	4.25	4.29	4.27
6. Learn from Failure	4.08	4.10	3.91	4.03	4.63	4.52	4.35	4.5
7. Define Problem	3.70	3.81	3.40	3.63	4.35	4.31	4.26	4.31
8. Define User Needs	3.68	3.64	3.49	3.60	4.40	4.39	4.31	4.36
9. Develop Concepts and Visual Representations	3.51	3.76	3.46	3.58	4.33	4.36	4.26	4.32
10. Analyze Solutions and Develop Design Requirements	3.52	3.76	3.41	3.57	4.38	4.42	4.32	4.37
11. Perform Detailed Design	3.41	3.46	3.25	3.37	4.25	4.27	4.24	4.25
12. Test and Validate Solutions	3.38	3.63	3.21	3.40	4.32	4.21	4.12	4.21
13. Identify and Utilize Resources and Expertise	3.46	3.61	3.35	3.47	4.33	4.16	4.21	4.23
14. Consider How to Protect Intellectual Property	2.49	2.96	2.96	2.81	3.54	3.76	4.10	3.81

across the three years. A non-parametric Wilcoxon Signed Ranks Sign test was used to test for significant differences across the paired samples. The means for each EMLO are given in Table 4. In all cases, each EMLO showed a statistically significant increase ($p < 0.001$) from the autumn pre-test to the spring post-test. This demonstrates that there is significant value being generated in these courses related to preparing students who are grading with respect to the EMLOs. The percentage increase for each EMLO for the total average score is shown in Fig. 4.

4. Discussion

4.1 Comparing across Cohort Years

While the additional activities implemented in

2022–2023 and 2023–2024 were intended to impact the EMLOs, specifically EMLOs 5, 8, and 10, these EMLOs had no change from the control year, 2021–2022, without the activity intervention. However, the two categories that did have changes were “Learn from Failure” and “Consider How to Protect Intellectual Property”. Considering intellectual property was not a focus of these new EMLO activities, however, the instructional team had been talking about intellectual property with increasing frequency over these three years and therefore while no extra activities were included, this additional lecture and discussion material may have had a significant impact on student learning. The decrease seen from 2021–2022 to 2023–2024 in the category of “Learn from Failure” was surprising but may be related to COVID pandemic changes in the course

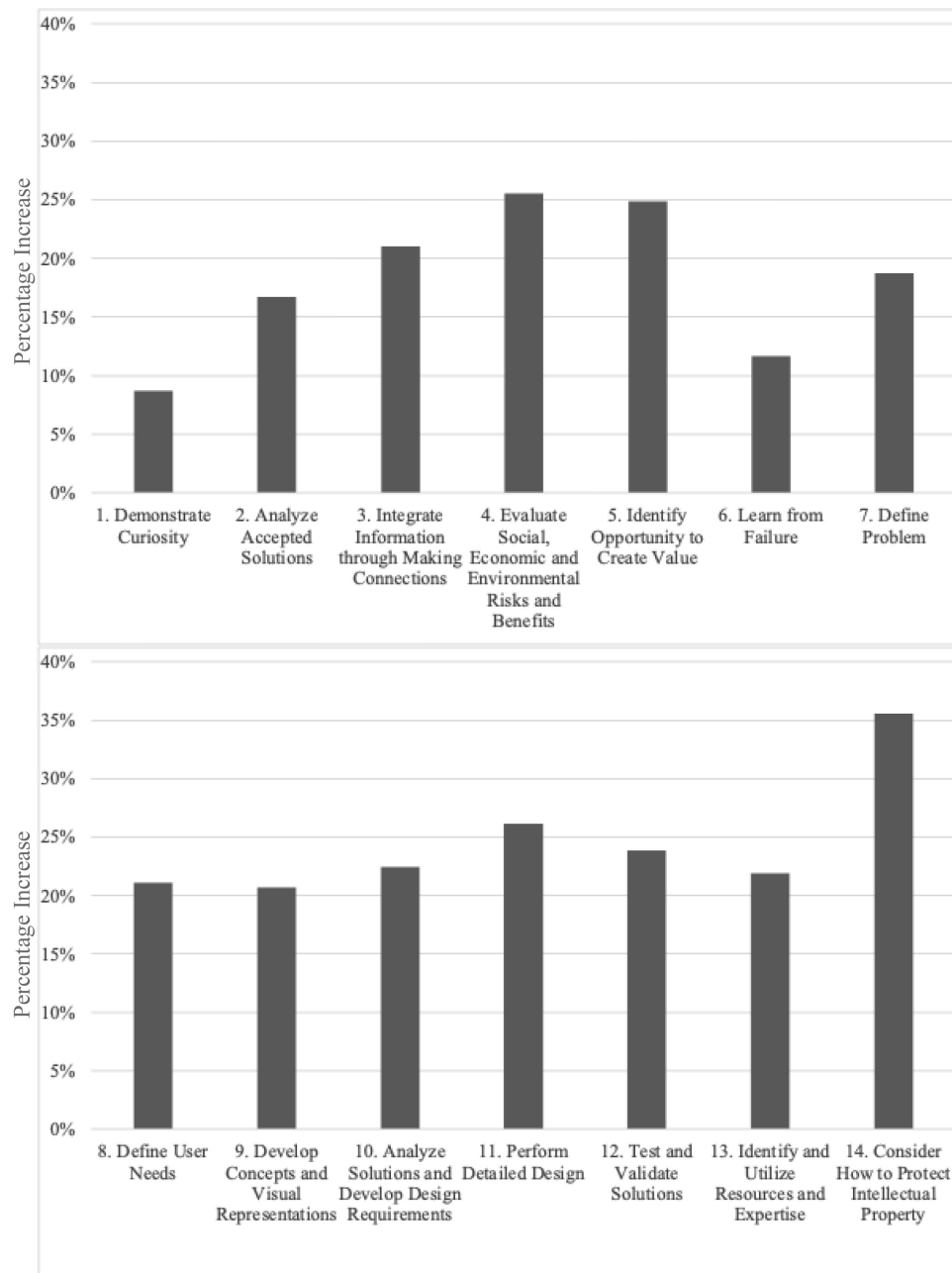


Fig. 4. Percentage Increases from pre-test to post-test for student EMLO perceptions from 2021–2024.

in 2021–2022. In 2021–2022, there were still many lingering effects from the lockdowns that impacted both the students taking the course and the industry sponsors they were working with. First in 2021–2022, there were still many virtual and hybrid components of the course and in industry connections. Additionally, there were projects from 2020–2021 that were not fully finished and therefore carried over into 2021–2022 and so students were more likely to be reading previous reports and presentations and learning from other teams' artifacts. This could have potentially impacted their experience with learning from failure.

4.2 Comparing Pre-test to Post-test

Across all years and regardless of extra activities added to the course it is evident through the student perceptions that the capstone course addresses the Entrepreneurial Mindset through all of these EMLOs and the growth seen from the pre-test to the post-test. This supports that capstone courses are natural fits for integrating the Entrepreneurial Mindset and it is what is seen in many other examples across the engineering capstone community [33–42]. Because EM is not purely about entrepreneurship, this mindset is useful for a variety of capstone contexts that result in innovative solu-

tions, products, or processes. The four categories that had the highest percentage change from pre-test to post-test were “Evaluate Social, Economic, and Environmental Risks and Benefits”, “Identify Opportunity to Create Value”, “Perform Detailed Design” and “Consider How to Protect Intellectual Property” with each of these increasing by more than ~25% from the pre-test to the post-test. The category with the lowest growth was “Demonstrate Curiosity” and this provides an opportunity for improvement in the future.

4.3 Additional Instructional Team Observations

When implementing these activities, the MDC instructors identified a misalignment when these activities became student-facing. More specifically, the value of these activities that incorporate EMLOs into their design were not viewed initially by students as meaningful as it relates to the capstone project progression. Students felt the activities were just busy work or non-relevant to the project, and they struggled with making the connection between the activity and how it progresses the project. After observing this, the instructors have adjusted the introduction of the activities by clearly stating the connection between the activity, learning outcomes and project progress as well as introducing EM on its own earlier in the course. Another observation included the progression of student understanding of the EMLOs and the mindset associated with them as a critical part of engineering. At the beginning of the course sequence, students saw the EMLOs as just another set of learning outcomes that instructors included in the syllabus. By the end of the course sequence, the students expressed a better understanding of what the EMLOs meant, and their purpose related to their project success.

5. Conclusions

From the data analysis presented here, it is evident that this capstone course does increase students' perceptions of preparedness with respect to the EMLOs. Additionally, the faculty advisors and sponsors also had similar perceptions of student preparedness at the end of the project. This provides valuable insight into the course itself. However, the lack of strong impact from the assignments that were intended to impact EMLOs warrants further investigation or further curriculum design.

There are some additional investigations and studies that could be completed in the future to further support this effort of infusing EM in this capstone. One promising investigation would be to integrate direct and indirect assessments [43, 44] to measure Curiosity, Connections, and Creating Value which are key components of EM. These assessments would provide additional data to support the results shown here. Additionally, there were rubrics developed to assess each of these EMLOs [45] and there is an opportunity to use these rubrics to examine the student project reports that were submitted across these three years to see if the direct assessment of these EMLOs align with the student perception of their preparedness. Additionally, there is an opportunity to regularly assess the status of a specific EMLO across the year as students turn in elements of their project using these rubrics. These additional assessment techniques could provide rich data to support further curriculum development in EM. Capstone courses are well positioned to integrate EM learning objectives and further development of these skills is important to graduating students with this crucial mindset.

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