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Assessment of a Distributed Implementation of the Entrepreneurial Mindset in an Experimental Projects Capstone

Dr. Brian D. Ritchie, The Ohio State University

Dr. Ritchie is an Assistant Professor of Practice in the Department of Mechanical and Aerospace Engineering at The Ohio State University. He teaches a variety of courses in thermal and fluid sciences in addition to the introductory course and an experimental projects capstone sequence. He completed this work as part of his Engineering Unleashed Fellowship.

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Introduction

Capstone course sequences are notorious for being too much work for too little reward. That is especially true when the capstone sequence is an experimental projects capstone, requiring students to learn new knowledge in the discipline as well as learning about computer simulation and running experimental equipment. As an instructor, the goal is to have the students learn as much as possible to better prepare them for their careers as engineers. In addition to the standard knowledge and skillset that entails, another aspect that is vital to their success is their mindset.

Background

Entrepreneurial Mindset

The Kern Entrepreneurial Engineering Network (KEEN) developed a framework [1] to supplement the engineering skills already taught to students with outcomes that support the development of the entrepreneurial mindset (EM) to better prepare engineering students to be practicing engineers. This framework includes a set of educational outcomes based on the 3C's of EM (Demonstrating Curiosity, Making Connections, and Creating Value). Entrepreneurially minded learning (EML) is an evidence-based practice that improves student learning outcomes and the student experience in engineering courses. Grzybowski [2] demonstrated improved student performance in an EML-infused first-year course compared to the traditional course. Carnasciali [3] presented an assessment of EM learning outcomes achieved with the use of EML-directed modules, which helped inform the approach used here. Mynderse [4] presented results from student surveys showing growth of EM components following modifications in a Capstone design course, which inspired the use of surveys as well as showing the utility of infusing EML into a capstone course. Desing [5] suggested best practices for EML incorporation in first-year engineering, which was used as a basis for planning the approach to including EML in the capstone sequence.

Course Sequence

Aerospace Engineering 4510-11 is a required two-semester experimental projects capstone course sequence with roughly 75-90 fourth-year students in teams of four to six members. This capstone sequence involves team research projects that combine both computational and experimental aspects and are taught as single sections once per academic year. Unlike a traditional design capstone, the students learn the conceive, design, implement and operate (CDIO) process for an experimental research project. Teams have a primary faculty technical advisor, and the instructor serves as a project management advisor as well as a secondary technical advisor. A typical project would be a team of five students researching the literature on winglets for reducing induced drag, performing preliminary CFD to guide their design choices, building several test articles, wind tunnel testing their designs, and comparing their results to their full CFD results for the same designs.

Aerospace engineering is a field in which the curriculum tends to focus on the science of engineering much more than the application. The traditional design capstone sequences result in paper designs, leaving students wanting more experiential learning. This experimental projects capstone course sequence is an attempt to address that in a more engaging way for the students than a traditional senior lab course series. Due to the research focus of the capstone, EML was an obvious choice for improving the course sequence. The core concepts of the EM framework were already in the courses, so it mainly required adjusting the terminology.

Implementation

Like most capstones, AE 4510-11 already requires more work than the students wish. An important aspect of this implementation of EML was to limit any additional time demands on the students. This was achieved largely by transforming existing lectures and assignments using the language of EML. It is important to note that students were already expected to develop and demonstrate the engineering mindset in this capstone, but like many professional skills it was not being taught explicitly. A plan was developed for an explicit distributed inclusion of EML in the courses to make its importance clearer to the students. The plan involved all aspects of the course – lectures, team meetings, and assignments. Informed by the transparency in teaching learning (TILT) approach developed by Winkelmes and others [6], it was decided to be explicit about teaching EM and mentioning it everywhere it applied so students would know it was valued in the course and they were expected to always demonstrate it. Table 1 summarizes all the elements of EM infusion into the capstone sequence.

Lectures & Team Meetings

This explicit EM inclusion started in the first lecture of the first semester with discussion of EM and how it would result in a better final project for the students. It was shown how it fit with the framework of the courses, including how it could be demonstrated and evaluated. The next few weeks included brief (approximately 10 minutes) lectures covering each of the 3C's with definitions, relevant learning outcomes as defined by KEEN in the framework, and specific ways to demonstrate it within the framework of the course sequence. All of this was reinforced in weekly meetings with each team, where EM terminology was used while discussing their status and plans for the future of the project. As the teams started on their team projects, discussion of Making Connections and Creating Value was tied into them developing the basic outline for their projects. Why is the problem they are researching important and who will care about the answer? What is already known and how can they build from that knowledge? What resources are available to them and how can they best use them? Teams were repeatedly reminded to demonstrate curiosity, make connections between disparate bodies of knowledge, and focus on the value they could create. The second semester started by again discussing EM and how it aided the teams in finishing their projects well. EM was always discussed with the teams during weekly meetings, correlating it with the aspects of the project they were currently working on.

There were no more lectures until the end of the semester, so the team meetings were the only chance to include EM verbally in the second semester.

Table 1. Where, how and when EM was infused into the course sequence

Element of Instruction	How EM Was Infused	When EM Was Infused
Lectures	Replaced prior terminology with EM terminology Added brief discussions of framework & the 3C's	Weeks 1-5 of AU semester, Week 1 of SP semester
Assignments	Curiosity quiz, discussion, and MS Teams posts + Direct Assessments listed below	Weeks 2-3 of AU semester
Self-assessment	Survey on self-efficacy on 14 EM learning objectives	Beginning of AU semester, end of AU semester, end of SP semester
Meetings with teams	Framing the discussion in terms of EM and the 3C's when relevant	From week 5 of AU semester until the end of SP semester
Direct assessments	Stakeholder value table Concept map	Week 4 of AU semester, end of SP semester Week 7 of AU semester, end of SP semester
Course assessment	Survey on EM learning	End of SP semester

Assignments

There were relevant small assignments tied to each of the 3C's as they were discussed. A Curiosity type survey served as an icebreaker exercise when the teams had just formed. The teams discussed their individual results, followed by a discussion post about the mixture of curiosity types their team had and what impacts that may have on their project. The students then read and commented about the mixtures on other teams. This tied into course material on how to manage teams and the importance of diversity of all kinds in teams, reinforcing that EML was directly tied to things engineers do every day. Curiosity was also tied into the literature review they were just starting for their projects, explaining the importance of demonstrating curiosity all the time and not just for two weeks to turn in a literature review section for a report.

Making Connections was linked to a concept mapping assignment. Each student made a map of what they thought their project would encompass by the end, then the team combined those into one overall map. In addition, each team generated a map of all the questions they had about their project. This tied Making Connections to Curiosity, helping them see that the 3C's work together. At the end of the second semester, the students again generated concept maps for their project and combined them into one overall map for the team as well as reflecting on the changes from their initial map. Creating Value is also tied to an assignment done at the start of the project as well as after it ended. In this case, teams filled out a stakeholder value matrix.

In addition to the small assignments directly tied to one of the 3C's, the TILT framework was used for the major assignments (project proposal, proposal presentation, final report, final presentation) in the courses to explain how each of the 3C's should be demonstrated and how it would be evaluated. The 3C's were also added directly into the grading rubric so that students saw a point value linked to EM.

Assessment

Multiple forms of assessment were used to evaluate aspects of EML, and which parts of the course students found most helpful in enhancing their EM.

Direct Assessment

Direct assessment of Making Connections and Creating Value was done both before and after students worked on their projects. The pre-assessment of Creating Value was done using the stakeholder value matrix assignment mentioned previously. This direct assessment tool was adapted from one developed by Ita et al [7]. In this assessment, teams come up with a list of stakeholders, a list of categories of value, and then fill in the specific type of value each stakeholder may get in each of the relevant categories. Not every stakeholder will get each type of value so the matrix will have some gaps. The matrices were scored by evaluating the total number of elements in the matrix and the density of the matrix. The post-assessment of Creating Value repeated this assignment after completing the project.

Pre-assessment of Making Connections was done using the aforementioned concept map assignment of what students projected their project would entail. This direct assessment tool was adapted from one developed by West et al [8]. The concept maps were scored using the Nowak and Gowin scoring method [9] shown in Eq. 1

$$Score = NC + 5 * HH + 10 * NCL \qquad (1)$$

where *NC* is the total number of concepts listed, NCL is the number of crosslinks between concepts on different branches, and *HH* is maximum number of levels of hierarchy in any branch. The post-assessment repeated this assignment after completing the project.

Indirect Assessment

Indirect assessment of EM was done in multiple ways. Demonstrating Curiosity was indirectly assessed at the beginning of the first semester using the Curiosity type survey mentioned earlier. The survey was an Excel spreadsheet with questions answered on a 7-point Likert-type scale that calculates a score on the five dimensions of curiosity and classifies the taker in one of four categories of people (Fascinated, Problem Solvers, Empathetic, Avoider) based on their curiosity type, all based on the work of Kashdan [10]. There was no post-assessment using the Curiosity survey, so no changes in this aspect of EM were assessed. There are plans to implement a post-assessment using this survey in future years.

A second tool for indirect assessment of was an EML self-efficacy survey given to gauge where the students felt they were with EM. Prior evaluation of several sets of EM learning outcomes [11] found possible shortcomings of these sets, leading to the creation of new set of 14 Engineering Mindset Learning Objectives (EMLOs) [12] shown in Table 2. The self-assessment survey asked students to rate their ability on each of the 14 EMLOs using a 7-point Likert-type scale. The survey was given at the beginning of the first semester, at the end of the first semester, and at the end of the second semester.

Table 2. The set of 14 Engineering Mindset Learning Objectives (EMLOs)

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

The major deliverables for the capstone sequence also are graded on EM. These deliverables include the project proposal and its presentation at the end of the first semester, and the final report and its presentation at the end of the second semester. Each of the 3C's had explicit discussion in the assignment prompt of how they could be demonstrated in the assignment as well as a separate line in the grading rubric.

Course Assessment

The implementation of EM itself was also evaluated through a survey designed to assess learning gains. The survey was adapted from the Student Assessment of their Learning Gains (SALG) survey [13], which is a validated tool for assessing learning gains [14]. The survey covered the different aspects of the implementation, the student's increase in understanding of EM, their gains in EM skills, and their gains in the 3C's. The survey had 22 questions broken into five groups, with each answer given on a 5-point Likert scale. The first group asked how much particular aspects of the course helped with their EML. The second set was about how much knowledge they gained about each of the 3C's. The third set asked how much they had improved at six specific skills related to the 3C's, all of which we had discussed in class. The fourth set asked about knowledge gained about EM and each of the 3C's due to the courses. The final set asked about their gains in integrating information from various outside courses. The results from this survey were used to improve the EM implementation for future years.

Results

Direct Assessment

The average results of the direct pre- and post-assessment of Creating Value are shown in Table 3 for the 15 teams in the 2021-22 cohort (AY22), as well as post-assessment for the prior year's (AY21) cohort of 12 teams. The left side of the table shows the average rubric scores on a scale of 0-3 (0 = Inadequate, 1 = Developing, 2 = Emerging, 3 = Accomplished) for the range of stakeholders listed by the team, the range of value types listed by the team, and the density of elements in the matrix understanding that there is no reason why the matrix should be completely filled. The right side of the table shows the average number of stakeholders listed by the team, the average number of value types listed, and the average density of the matrix. There are no significant differences evident between pre- and post-assessment for the most recent cohort, which makes some sense as the teams could look back at their prior version when creating the second one. The difference between cohorts is small when looking at rubric scores but is more noticeable when considering the number of stakeholders and value types listed. This may reflect the increased emphasis on teaching EM in the most recent year, but the sample size is too small to draw any definitive conclusions.

Table 3. Average rubric scores (L) and average counts (R) of elements in stakeholder value matrix in pre- and post-assessment

	Stakeholders (0-3)	Value Types (0-3)	Density (0-3)	Total	Stakeholders (#)	Value Types (#)	Density (%)
Post (AY21)	2.58	2.42	2.50	7.50	5.00	4.50	74.5
Pre (AY22)	2.47	2.80	2.87	8.13	6.13	5.60	77.4
Post (AY22)	2.47	2.60	2.87	7.93	6.33	5.67	77.1

The average results of the direct pre- and post-assessment of Making Connections are shown in Table 4 for the 15 teams in the AY22 cohort, as well as post-assessment for the prior year's cohort of 12 teams. The left side of the table shows the average number of concepts listed by a team (*NC*), the average of the maximum number of levels of hierarchy (*HH*), the average number of crosslinks (*NCL*), and the average score using Eq. 1 which is the Nowak and Gowin method. The right side of the table shows the average rubric score on a scale of 0-3 (0 = Inadequate, 1 = Developing, 2 = Emerging, 3 = Accomplished) for the concept maps.

There are noticeable differences evident between pre- and post-assessment for the AY22 cohort in this case. Teams listed more concepts, had more levels of hierarchy and more crosslinks, resulting in a higher overall Novak and Gowin score and a higher average rubric score for the post-assessment. This is to be expected as the students should have a deeper understanding after completing their project. The difference between cohorts is even larger, with the AY22 cohort doing almost an entire rubric level better (2.87 vs 2.08). This may also reflect the increased emphasis on teaching EM in that year as was hinted at in the stakeholder value matrices. However, it is also possible that teams were simply less engaged by the end of the prior year due to the accumulated stress from being a student during the COVID pandemic and invested less effort in the assignment.

Table 4. Average sub-scores and overall scores for Novak and Gowin scoring of concept maps (L) and average rubric scores (R) in pre- and post-assessment

	Concepts (NC)	Levels (HH)	Crosslinks (NCL)	Score	Rubric (0-3)
Post (AY21)	29.9	4.92	6.25	117	2.08
Pre (AY22)	46.6	4.40	4.33	112	2.73
Post (AY22)	52.0	5.20	5.40	132	2.87

The other form of direct assessment involved rubrics for the major course deliverables, with each of the 3C's scored from 0-10. Table 5 shows the average scores for each cohort on the four major deliverables of the capstone sequence. The project proposal scores higher because the teams are saying what they plan to do, while the final reports cover what they actually do over the year. The presentation scores are generally higher because some teams focus on explaining each of the 3C's as part of the presentation. There is a trend of higher scores for the most AY23 cohort, and especially for the final report and presentation. But with 15 and 17 teams in the cohorts, the data set is not large enough to draw many conclusions. There are 5-6 months between sets of deliverables, and the mood of the grader is not constant over that period. The granular data shows that the scores vary for teams even between their reports and presentations, so it is unclear what to take away from this data so far.

Table 5. Average rubric scores for each of the 3C's on major course deliverables

	Curiosity	Making Connections	Creating Value
Proposal (AY22)	9.50	9.63	9.70
Proposal Presentation (AY22)	9.87	9.93	9.53
Final Report (AY22)	8.53	8.53	9.00
Final Presentation (AY22)	8.87	8.87	9.13
Proposal (AY23)	9.71	9.94	9.71
Proposal Presentation (AY23)	10	10	10
Final Report (AY23)	9.47	9.41	9.88
Final Presentation (AY23)	9.71	9.12	9.82

Indirect Assessment

The Curiosity type survey is primarily intended as an icebreaker, but an interesting trend showed in the results shown in Table 6. The students show a definite tendency to be the Fascinated curiosity type. Many students expressed surprise that there were not more Problem Solver types in a class of engineering students, making the survey better serve its role as an icebreaking activity. Not much should be read into these results, but the Fascinated type should serve the teams well in a research project. The lack of Problem Solvers could explain some of the difficulties teams have with design and manufacturing of test articles and may be indicative of the aerospace engineering curriculum being more focused on the science of engineering than its application.

Table 6. Curiosity types by cohort and overall

	Fascinated	Problem Solver	Empathizer	Avoider	Total
AY21	44	6	18	6	74
AY22	29	16	17	7	69
AY23	53	18	17	5	93
Total	126	40	52	18	236
Total %	53.4	16.9	22.0	7.6	

The EML self-efficacy survey shows the perceived growth in students' EM over the course of their capstone sequence. The results for the most recent cohort of 74 students are shown in Figure 1. The students rated themselves on how well each EMLO (see Table 2) described their current behavior or knowledge on a 7-point Likert-type scale centered on 0 (3 = Strongly Agree, 2 = Agree, 1 = Slightly Agree, 0 = Neither Agree Nor Disagree, -1 = Slightly Disagree, -2 = Disagree, -3 = Strongly Disagree).

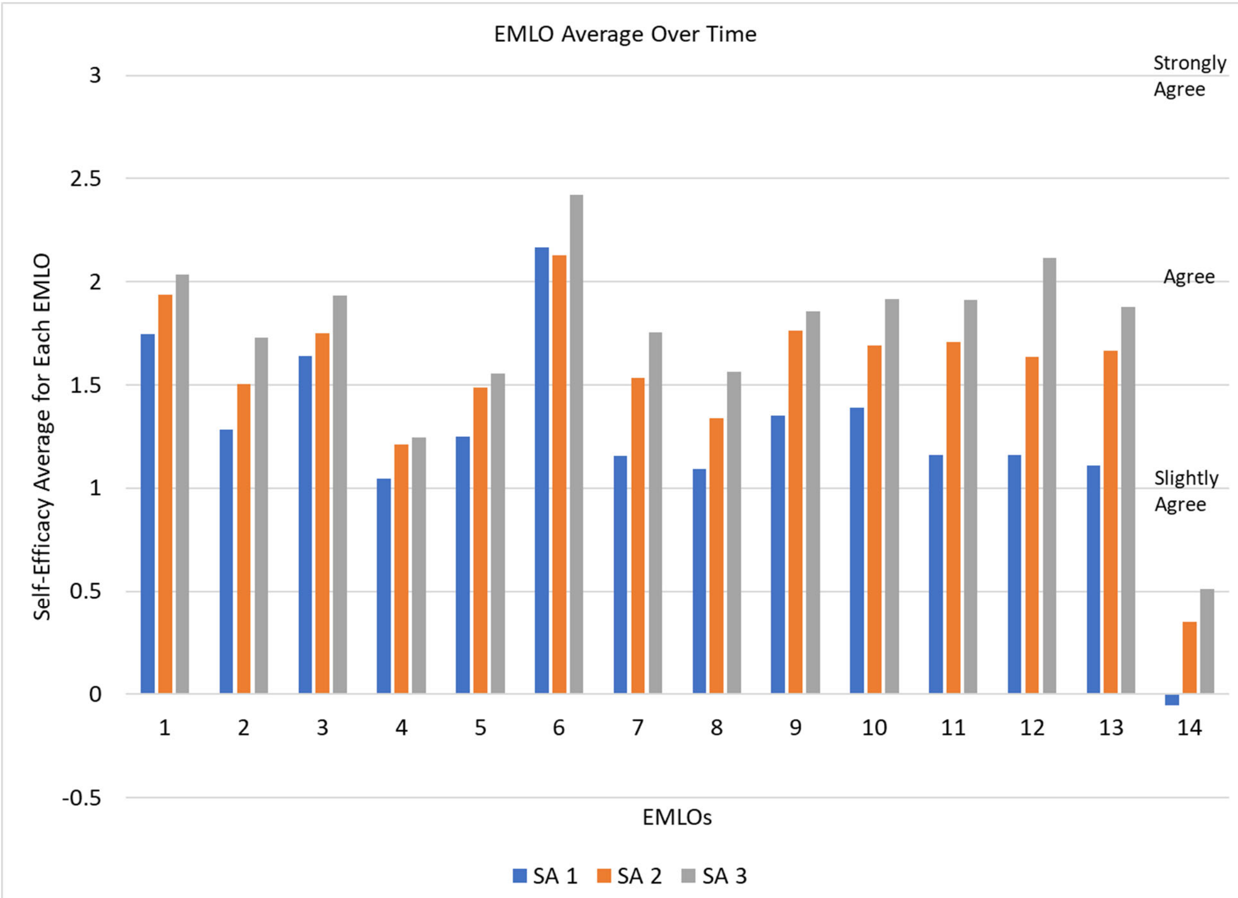

Figure 1. Average EMLO score over time, from the first self-assessment survey at the start of the capstone sequence (SA1), to the second survey at the end of the first semester (SA2), to the final survey at the end of the project (SA3)

The students begin the year with a fairly high self-efficacy in almost all EMLOs, with only #14 (Consider How to Protect Intellectual Property) registering below 1 and that is not a topic the curriculum focuses on. Over the course of the year, the students show growth in all 14 EMLOs. Some develop more in one semester than another, and the students registered some regression between the first and second surveys, or between the second and third surveys on a few of the EMLOs depending on the cohort. The first semester is largely a planning process for the project which is well covered by EMLOs 7-13, so it is not surprising to see so much growth in EM indicated as they perform those tasks. The second semester focuses on implementation and operation of the project, including all the frustrations of deciding on details and troubleshooting both experiments and simulations. Also of note is EMLO #6, *Learn from Failure*. The students come in feeling more competent in that aspect of EM than any other, which says something about the persistence that the aerospace engineering curriculum builds in students. Results from the AY21, AY22 and AY23 cohorts were quite similar (most values within 0.15 of the average value) as shown in Table 7, showing growth in all 14 EMLOs over the year and similar average values. The AY22 cohort did begin and finish with slightly lower scores. The averages of all three cohorts are presented in Figure 1.

Table 7. Average EMLO scores by survey and cohort

EMLO	AY21			AY22			AY23		
	SA1	SA2	SA3	SA1	SA2	SA3	SA1	SA2	SA3
1	1.79	1.86	2.08	1.66	1.99	2.03	1.79	1.96	2.00
2	1.34	1.28	1.78	1.16	1.62	1.66	1.34	1.61	1.75
3	1.81	1.66	2.08	1.48	1.85	1.74	1.63	1.74	1.97
4	0.98	1.15	1.28	1.08	1.21	1.12	1.07	1.28	1.34
5	1.21	1.51	1.72	1.21	1.52	1.34	1.33	1.44	1.60
6	2.26	2.08	2.50	2.00	2.15	2.47	2.24	2.15	2.30
7	1.26	1.51	1.69	0.86	1.38	1.71	1.35	1.71	1.86
8	1.24	1.18	1.57	0.93	1.38	1.44	1.11	1.45	1.68
9	1.22	1.80	1.93	1.52	1.82	1.85	1.31	1.66	1.79
10	1.47	1.61	2.04	1.25	1.86	1.73	1.46	1.60	1.98
11	1.21	1.61	1.97	1.07	1.71	1.86	1.21	1.81	1.90
12	1.12	1.51	2.17	0.95	1.88	2.10	1.42	1.52	2.09
13	1.31	1.63	1.92	0.79	1.70	1.82	1.23	1.66	1.89
14	-0.10	0.28	0.21	-0.01	0.34	0.51	-0.04	0.43	0.82
Average	1.29	1.48	1.78	1.14	1.60	1.67	1.32	1.57	1.78

Course Assessment

The course evaluation survey results have proven useful for making improvements to the course for future years, as the specific feedback identifies weaknesses in the implementation of EML in the sequence as seen in Table 8. The table shows the average scores for how helpful various aspects of the capstone sequence were for learning about EM on a scale of 0-4 (0 = Not At All, 1 = A Little, 2 = Somewhat, 3 = A Lot, 4 = A Great Deal). Of note in AY23 is the improvement of the ratings for the lectures about EM, the small EM assignments, and the CAE labs. It remains to be seen if this is a 1-year phenomenon or a trend of improvement as I have specifically made an effort to improve those course aspects and how they are presented to the students. The project itself was the most helpful part of the courses, as practical experience often is. The lectures outscored other aspects of the course. That supports the attempt to explicitly teach the material. The lower scores for the meetings and assignments suggest they can be better connected to the lectures and their projects.

Table 8. How much did the following course aspects help students in their learning about the entrepreneurial mindset?

	AY21	AY22	AY23
Lectures	1.69	1.56	2.06
Assignments	1.40	1.32	1.88
Meetings	1.44	1.42	1.87
Project	2.72	2.42	2.67
CAE Labs	1.51	1.58	1.76

The students showed higher gains in Curiosity and Making Connections than Creating Value in the first year, but improvements in instruction have remedied that as seen in Table 9. As this is a research capstone and not a design capstone, students often struggle to connect the knowledge they are generating with value. The value they were creating was often discussed and seems to have gotten through to them. The second year showed a decrease in Curiosity, likely due to the effects of COVID on the students as it bounced back this past year. It was heartening to see so many positive responses for the knowledge increase of all 3C's.

Table 9. As a result of this capstone, how much did your understanding of each of the following increase?

	AY21	AY22	AY23
How curiosity is vital in engineering	2.64	2.40	2.78
How making connections is vital in engineering	2.78	2.78	2.85
How creating value is vital in engineering	2.47	2.86	2.81

The course assessment survey also inquires about how much students have improved in specific EM-related skills due to the capstone. As seen in Table 10, the students felt they improved the most at persisting through and learning from failure, and at integrating information. Those are vital aspects of any research project and especially capstone projects, so it is not surprising to see them score much higher. But the students still felt they improved noticeably in all of the skills.

Table 10. As a result of this capstone, how much did you improve in the following skills?

	AY21	AY22	AY23
Demonstrating curiosity	2.29	2.19	2.54
Exploring contrarian views of accepted solutions	2.35	2.10	2.51
Integrating information from multiple sources to gain insight	2.78	2.58	2.96
Assessing and managing risk	2.25	2.18	2.44
Identifying opportunities to create value	2.25	2.21	2.47
Persisting through and learning from failure	3.06	2.75	3.06

In terms of gains made in EM and each of the 3C's, Making Connections slightly outscored the others as seen in Table 11. As that is the nature of capstone, it is not surprising. It is surprising that students do not feel they gained much in terms of EM overall, but rate each of the 3C's that comprise EM considerably higher. This indicates a disconnect in their thinking about and understanding of EM versus its components.

Table 11. As a result of this capstone, what gains did you make in the following?

	AY21	AY22	AY23
Entrepreneurial mindset overall	1.63	1.74	1.97
Curiosity	2.32	2.18	2.53
Making connections	2.58	2.47	2.74
Creating value	2.15	2.36	2.43

The final set of questions was about integrating information from different types of sources. The students scored all areas fairly highly as shown in Table 12, but pulling from other courses was the highest. Again, that is the point of a capstone, so it was expected to be highest. It was good to see similar scores for pulling information from experts (including people in the machine shop and other technicians as well as faculty) and from articles. They are supposed to learn from all types of sources, and talking to an expert is often more helpful than reading multiple articles when you are learning how to do something rather than seeking new facts. Students did not pull as much from their lives, but that is very project dependent. The AY22 cohort scored lower for integrating information from courses, but that is the group that was most affected by COVID in terms of online courses so they may simply not have learned course material as deeply. The most recent cohort was pushed more strongly to do design/manufacturing meetings with shop personnel before building experimental setups and test articles, and this is reflected in the higher score for integrating information from experts.

Table 12. As a result of this capstone, what gains did you make in integrating the following types of information?

	AY21	AY22	AY23
Information from various courses	2.69	2.40	2.89
Information from books and journal articles	2.35	2.45	2.76
Information from experts (on subject matter, or on technical skills)	2.49	2.51	2.85
Information from other experiences in your life	2.11	2.23	2.38

Since there is no control group available, some comparison data was sought to help evaluate the effectiveness of teaching EM in capstone. The same EM self-efficacy survey was given to a cohort of second year students in the Introduction to Aerospace Engineering course (AE 2200) at the beginning and end of the AU22 semester. This course of roughly 120 students is the first course in the major and is also heavily hands-on with a significant lab component to the course (10 labs – including designing, 3D printing, and wind tunnel testing a small airfoil segment). The first-year engineering program at The Ohio State University teaches EM, but it is not taught in AE 2200. This gives a comparison of teaching EM directly versus experiential learning alone.

Figure 2 and Table 13 show the results of the self-efficacy surveys for the second-year students versus the fourth-year students. A few things stand out immediately. The students come into AE 2200 with more confidence in their skills as engineers than the fourth-year students have when they begin capstone. But by the end of capstone, the fourth-year students have largely returned to that level of confidence. It probably indicates a bit of naïve confidence from the second-year students, as well as the difficulty of the theoretical courses in the third year of the curriculum.

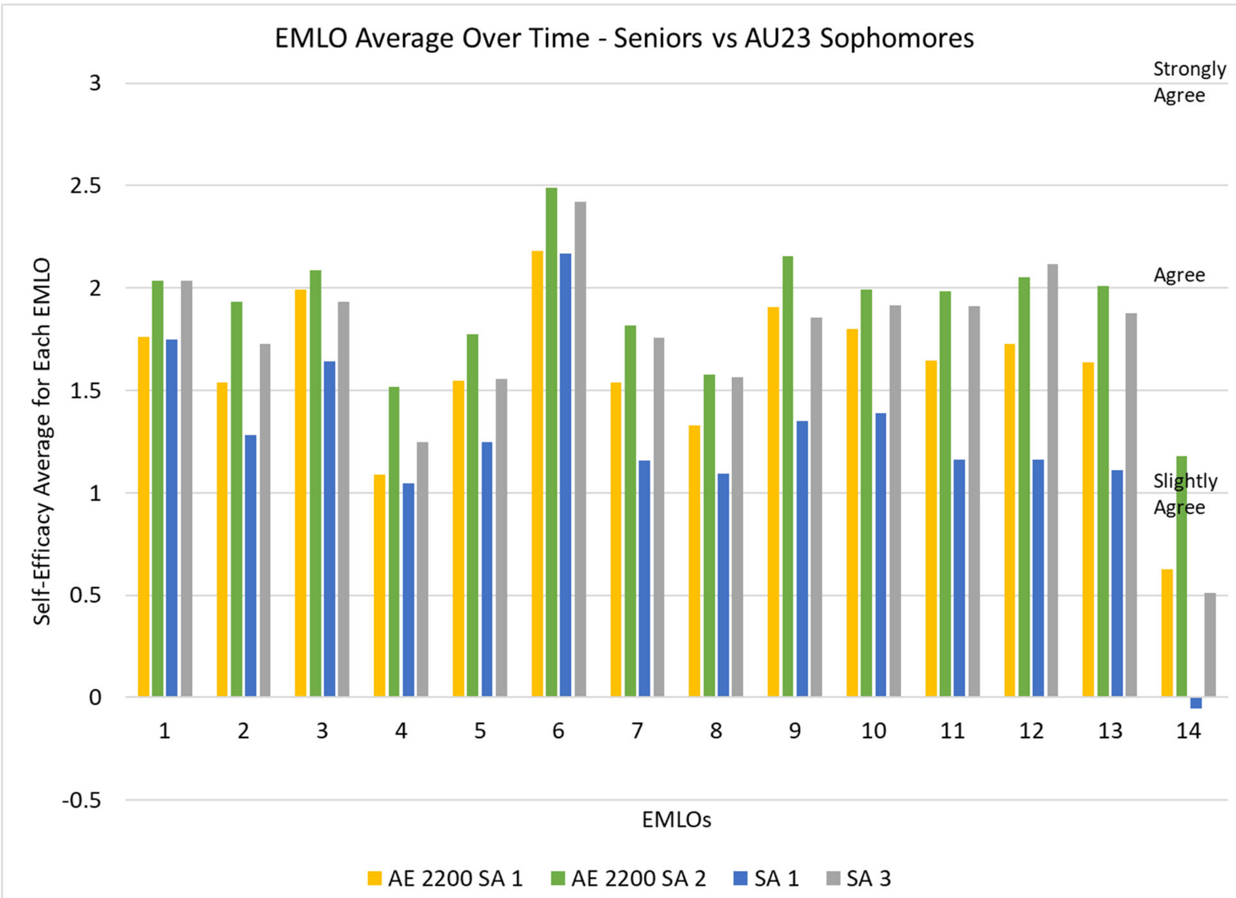

Figure 2. Average EMLO score over time comparison between second-year students in AE 2200 and fourth-year students in AE 4510-11.

As expected from the capstone project helping the most with learning EM for the fourth-year students as seen in the course assessment survey, the heavy experiential learning in the introductory course also leads to improvement in EM. But the capstone students showed greater growth, from an average of 1.25 to 1.74 (+0.49) versus introductory students improving from 1.59 to 1.90 (+0.31) though the capstone students do have twice as long to grow.

Table 13. Average EMLO scores by survey and cohort

EMLO	AE 2200		AE 4510-11		
	SA1	SA2	SA1	SA2	SA3
1	1.76	2.03	1.75	1.94	2.04
2	1.54	1.93	1.28	1.50	1.73
3	1.99	2.09	1.64	1.75	1.93
4	1.09	1.52	1.04	1.21	1.25
5	1.55	1.78	1.25	1.49	1.55
6	2.18	2.49	2.17	2.13	2.42
7	1.54	1.82	1.16	1.53	1.76
8	1.33	1.58	1.09	1.34	1.56
9	1.91	2.16	1.35	1.76	1.86
10	1.80	1.99	1.39	1.69	1.92
11	1.64	1.98	1.16	1.71	1.91
12	1.73	2.05	1.16	1.63	2.12
13	1.64	2.01	1.11	1.66	1.88
14	0.63	1.18	-0.05	0.35	0.51
Average	1.59	1.90	1.25	1.55	1.74

Conclusions

Collectively the assessment results indicate that the implementation of EML into an aerospace engineering experimental projects capstone course sequence has largely been successful. The students indicate gains across the board in the engineering mindset and indicate that specific aspects of the courses help with that. The results of direct assessments of Creating Value and Making Connections are mixed, but it is difficult to read much into data from such a small sample size working on such disparate projects. The stakeholder value matrix showed little change in Creating Value, but an experimental project is not focused on developing that. The concept mapping showed noticeable gains in Making Connections, as should be expected over the course of an experimental project. Perhaps the results from the AY23 cohort will make the trends clearer.

The course evaluation surveys provide useful feedback for improving the courses every year to maximize the student gains for the least extra effort on their part. The next steps are to continue the implementation of EML, making improvements each year as directed by the student surveys. As more longitudinal data is compiled, trends may become clearer in terms of what is working well and what is not. But as the surveys of second-year students showed, it is important to remember that doing engineering is often the best teacher. While this research was done in an aerospace engineering experimental projects capstone sequence, many design capstone sequences in other engineering majors incorporate the experiential learning component aerospace often lacks, so many of the lessons learned here should transfer well to those capstones.

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