



Growing Entrepreneurial Mindset in Interdisciplinary Student Engineers: Experiences of a Project-Based Engineering Program

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Abstract

Engineering education models have recently embraced the entrepreneurial mindset as a desired outcome of undergraduate engineering education. Interdisciplinary active learning strategies have been suggested as an effective pedagogy for engaging student engineers in undergraduate engineering education. Recent research suggests that active, social learning in context can lead to improvements in learner innovation, problem-solving, curiosity, retention and accessibility of knowledge, value-creation, and other desired learning outcomes. Much of the recent adoption of active and collaborative learning, self-directed learning, problem-based and project-based learning (PBL), peer to peer learning, and other similar learning strategies are aimed at developing innovative and entrepreneurial mindset skills, but they have been limited to Capstone Design courses. Our aim is to develop the entrepreneurial mindset much earlier in the student engineers' undergraduate education.

The Iron Range Engineering program is entrepreneurial in nature, based on continuous improvement, self-directed learning, and reflective practice. Our student engineers learn in context, by applying technical engineering knowledge in project teams working on industry-sourced projects, each of the four semesters of their junior and senior years. In addition, freshman and sophomores enrolled in pre-engineering studies in a closely aligned community college are included in the culture, many activities, and teaching staff of the upper division program.

Drawing from the Kern Family Foundation's Engineering Unleashed program and Innovating Curriculum with Entrepreneurial Mindset (ICE) workshops, faculty in the program were introduced to the entrepreneurial mindset in the summer of 2017. In the Fall, 2017 semester, they developed and piloted several entrepreneurial-minded learning (EML) modules across the curriculum of our program (approx. 95 students in lower and upper divisions), ranging from Statics in Sophomore year, to Entrepreneurship and Statistics in the Junior year, and Three-Phase and Signals and Systems for the Seniors, among others. Entrepreneurial Mindset was also reinforced in Design class and applied in project work.

This paper describes the experiences of faculty and students in the implementation of entrepreneurial mindset modules adopted in our program, as well as preliminary results of this rapid deployment in an interdisciplinary engineering program. We use a case study format to report auto-ethnographic stories from both faculty and student perspectives.

Early results are promising. After two semesters of simultaneous deployment of entrepreneurial mindset across the curriculum, faculty are engaged and working collaboratively to improve and extend this type of entrepreneurial learning even further into the program. The impact on ABET and KEEN outcomes are addressed. Student feedback is also positive. The pervasiveness of the application of entrepreneurial mindset is present in student reflections, project technical documents, design reviews, oral exams, and other student work. The entrepreneurial mindset has become part of the culture of our program in a short time, which we view as a positive outcome. The experiences of the participating faculty members are presented in the paper, as well as student reflections on the application of entrepreneurial mindset in their courses and design projects. Planned next steps are also addressed in the paper.

Introduction

Engineers are expected to create value for their clients and customers. One of the purposes of undergraduate engineering education is to prepare student engineers for this expectation in the engineering profession. An entrepreneurial mindset is one way to describe the thinking processes, attitudes, and behaviors surrounding the ability of an engineer to create value for identified customers and clients. Entrepreneurial thinking requires action to solve engineering problems, so teaching the entrepreneurial mindset to undergraduate engineers should be student-centered and should have students working through problems with a focus on customer needs and creating value for the identified customers. The thought process and the final solution are both important, and students should develop these skills in their undergraduate education. Entrepreneurial mindset learning outcomes are desired by industry and tie to both the current and proposed Accreditation Board for Engineering and Technology (ABET) outcomes [1], [2]. These include critical thinking, high-level reasoning, accurate understanding of others' perspectives, differentiated views of others, teamwork and communication skills, achievement and retention, among others. For these positive reasons, the faculty of our program decided to bring the entrepreneurial mindset to our student engineers. In Summer, 2017, an interdisciplinary team of faculty from the program attended entrepreneurship in engineering workshops through the Kern Family Foundation's Engineering Unleashed program [3]. In Fall, 2017, these faculty members introduced entrepreneurial mindset through collaborative, active pedagogies in several courses and workshops from sophomore to senior levels. This paper relates their experiences, student feedback, and planned next steps. The paper also includes discussion of the preliminary results from this collaborative effort by faculty to infuse entrepreneurial mindset simultaneously into the engineering curriculum.

Purpose of research

The purpose of this paper is to relate the experiences of faculty and students in the Iron Range Engineering (IRE) Program in implementing Entrepreneurial Minded Learning (EML) modules with undergraduate student engineers through active learning activities simultaneously throughout the program, not just in Capstone Design. The benefits of entrepreneurial mindset through active,

cooperative learning have been documented by several studies. Johnson, Johnson, and Smith [4] reviewed the evidence resulting from over 300 experimental studies and found student outcomes including achievement and retention, critical thinking and higher-level reasoning, differentiated views of others, accurate understanding of others perspectives, a liking for teachers, peers, and subject matter, and teamwork skills to be developed through cooperative learning. More recent studies have addressed various aspects of including entrepreneurial thinking in engineering education [5], teaching it via business plan development [6], case studies [7], [8], product archeology [9], and evaluating entrepreneurial knowledge in engineering students [10] and [11]. One of the stated goals from the Grand Challenges of the National Academy of Engineering is to "enhance student interest in engineering, science, and technology entrepreneurship." [12] Several recent studies suggest that when student engineers use the entrepreneurial mindset of curiosity and connections to create value, combined with the engineering skillset of opportunity, design, and impact, the resulting educational outcomes are significant. See Karl Smith's body of work [13]. In addition, the Iron Range Engineering program assesses Outcome M (Entrepreneurial Activities), as an extension of the ABET outcomes in our program, as follows:

Outcome M: An ability to engage in entrepreneurial activities.

- Assesses the potential market and likelihood of success in an industry/company/dept/team.
- Aware of the value of innovation.
- Understands the impact of risk on engineering decision making.
- Demonstrates the ability to learn through experiences of failure.
- Addresses an engineering, business, or societal problem creatively.

This research was undertaken to assess and improve the student engineers' ability to develop these skills while learning engineering in the project-based IRE program..

The Kern Engineering Education Network (KEEN) includes thirty-two partner universities from across the US [3]. The network has aggregated many entrepreneurial-minded learning (EML) modules developed by faculty from these universities on its website (www.engineeringunleashed.com). Kern Family Foundation professional faculty teach EML development as well as active and collaborative learning strategies to interested faculty members in the Innovating Curriculum with Entrepreneurial Mindset (ICE) workshops [3], held several times per year at various locations around the United States. This KEEN approach was adopted by the faculty of the Iron Range Engineering program and implemented as related in this paper.

The positive learning outcomes that can result from collaborative pedagogies and entrepreneurial mindset take time to develop in students; significantly deeper learning is thought to be achieved when the entrepreneurial mindset is introduced early in the undergraduate engineering curriculum. In a 2013 National Academy of Engineering publication, Susan Ambrose wrote that the "interconnected and interacting findings support the educational value of building curricula that provide:

- context and continual integration across time and courses that promote transfer of existing knowledge and skills to new contexts;

- early exposure to engineering and engineers to lay the foundation for future learning;
- meaningful engagement at the most auspicious time to promote deep learning;
- opportunities for reflection to connect thinking and doing;
- development of students' metacognitive abilities to foster self-directed, lifelong learning skills; and
- authentic experiential learning opportunities to put theory into practice in the real world.

She goes on to write that "students should be continually engaged in these intellectual processes throughout the curriculum — not just in their final year — and at an increasingly sophisticated level." She advocates for "the need to do all of the above concurrently and continually across the curriculum, in an intentional and coherent way, which may require a "wipe the slate clean" approach to the design of 21st century engineering education" [14].

Similarly, the University of Dayton sponsors a Kern Entrepreneurial Engineer Network (KEEN) Fellows Program for faculty to reach 100 percent of the undergraduate engineering student population by significantly expanding the number of faculty involved in the KEEN movement [15].

Faculty in the Iron Range Engineering (IRE) program did just that by simultaneously and intentionally integrating the Entrepreneurial Mindset into much of the program's curriculum. Drawing from the Kern Family Foundation's Engineering Unleashed program resources [3], four IRE faculty members attended the Innovating Curriculum with Entrepreneurial Mindset (ICE) workshop and were introduced to the entrepreneurial mindset and active and collaborative learning (ACL) strategies in the summer of 2017. A fifth faculty member did the same in January, 2018. Together, these five faculty comprise 80 percent of the instructional staff in the small program (100 enrolled students per year). When the elements of entrepreneurial mindset are incorporated into classroom pedagogies, they are called entrepreneurial minded learning (EML) modules. Basically, EMLs are starting problems with storylines and context that require student engineers to use a customer-focused approach of problem-solving. In the academic year 2017-2018, the five faculty developed several EML modules and implemented them into several courses, ranging from Statics in Sophomore year, to Entrepreneurship and Statistics in the Junior year, and Three-Phase and Signals and Systems for the Seniors. Entrepreneurial Mindset was also reinforced and applied by students in Design class and project work during the Spring, 2018 semester.

Assuming that actual retrieval and use of entrepreneurial-minded thinking in industry project work is a strong indicator of learning, our overall research question is: "Do the final project documents written by student teams include more of the entrepreneurial mindset and skillset words and phrases in the 2017-2018 academic year than they did in the prior academic year?" The research results will be used to assess whether students are using entrepreneurial mindset more after this EML infusion than they did before. While collected data is being analyzed at the time of publication, preliminary results and reflections from both faculty and students are positive and are included in this paper.

Program context

The Iron Range Engineering program is an ABET-accredited upper-level undergraduate engineering education program located in Minnesota. It is a program in the Integrated Engineering Department of Minnesota State University, Mankato. Both IRE and its sister program Twin Cities Engineering, located in Bloomington, MN, follow the project-based learning model and also use problem-based learning in courses. The programs were awarded the ABET Innovation Award in 2017. Since its inception in January 2010, 140 students have graduated from the program. Student engineers at IRE work on industry-sourced client projects in teams of three to five members every semester of their upper-division years. Each team has a project room, similar to an office. The program emphasizes continuous improvement and the development of self-regulated learning abilities, professional skills, and technical engineering knowledge, which is acquired primarily in one-credit courses called "competencies". Students learn technical content in small groups of three to twelve students with academic staff facilitating the "learning conversations", which are often flipped. Students learn the material outside of class meeting time, then use the class time to ask questions, discuss with peers, apply the new knowledge to their industry projects, and use other active and collaborative learning techniques to make the newly acquired knowledge "sticky," so it is long-lasting and retrievable in the future. The program is interdisciplinary in nature, so students in mechanical, electrical, engineering management and other focus areas of engineering learn together. Each student is required to take core competencies in each of these three areas and then selects advanced courses in emphasis content areas in order to meet degree requirements. The format is very similar to that put forth by Karl Smith [13]. Specifically, that the learning is student-centered and occurs in small groups; teachers are facilitators or guides; problems are the focus and stimulus for learning the technical content; problem-solving process skills are developed through the problem; and new information is acquired through self-directed learning. This is the "P" in Problem-based learning.

In addition to core technical competencies, students participate in a 3-credit Design course each semester, in which they complete an open-ended project, generally sourced from an industry client. Student-generated entrepreneurial projects, design challenges sponsored by engineering societies, and other types of projects are also regularly included in the Project Menu, and students select which project they are most interested in completing each semester of their junior and senior years in the program. In addition to the Design course, which is led by program faculty, and teams also spend several hours per week with their Project Facilitator, who are either faculty members or working or retired engineers from industry. Teams complete three design reviews each semester and present their work in three presentations (Scoping, Technical, and Final Solution) over the course of the semester. Students document learning goals, research, fundamental principles of engineering, idea generation and selection, experimentation, verification and validation, and prototyping efforts throughout the semester. The culmination of the project is a significant (50 - 100 pages) final technical document and presentation to the client. This is the "P" in Project-based learning.

Students also learn creativity, innovation, and overall problem-solving processes each week in Seminar workshops; they are evaluated on these skills each semester when each student completes an oral exam to demonstrate their skill and process in solving complex, open-ended

problems to a panel of evaluators.

In the technical competencies, a starting problem is often used to activate prior knowledge of the topic and to build intrinsic motivation to solve the problem. As Boud wrote in 1985 in *PBL in Perspective* [16], "the principal idea behind PBL is that the starting point for learning should be a problem, a query, or a puzzle that the learner wishes to solve." In EMLs, the starting problem provides a context, a story or scenario, for the module purpose. The next section describes EMLs in more detail.

Faculty preparation for implementation of entrepreneurial mindset

Several IRE faculty were interested in expanding the entrepreneurial mindset in the program curriculum. The five faculty involved in the new focus on entrepreneurial thinking make up approx. 80 percent of the teaching faculty in the program, so integration across much of the curriculum is possible. While the sample size is small due to the size of our program (95 - 100 enrolled students, split evenly between upper and lower divisions), the flexibility and adaptability required for rapid change are present. There are few barriers to changing the pedagogies used in the technical competencies, design class, and student workshops.

Five engineering faculty from the IRE program attended a four-day Innovating Curriculum with Entrepreneurial Mindset (ICE) workshop through KEEN [3] in 2017. The activities and presentations in the workshop focused on using active, collaborative and problem/project-based learning techniques to develop entrepreneurial mindset in our students. The 25 participants worked in content cohort groups to develop and share entrepreneurial minded learning modules throughout the following year. At the ICE workshop, the faculty experienced and learned about the three C's, which are the three components of the entrepreneurial mindset: curiosity, connections and creating value [3]. Curiosity is exploring different perspectives. Connections is thinking outside the box and place old ideas in new contexts. Creating value is identifying opportunities and determining how the design will impact stakeholders. See Figure 1.

The KEEN Framework includes entrepreneurial mindset and skillset, as shown in Figure 2.

While engineering students are accustomed to the middle column labeled "Design" in Figure 2, the entrepreneurial mindset adds skills in the "Opportunity" and "Impact" areas. Student engineers are asked to consider the needs of identified customer segments, estimate the potential market size of the design/innovation, to evaluate the feasibility of their design from many perspectives such as technical, customer value, societal benefits, and economic viability, and similar aspects of Opportunity. The expanded skillset also encompasses checking with the customer during the design phase to verify that the customer's needs are being met by the design in progress, as well as to communicate with team members, vendors, and stakeholders in economic terms. The goal is an expanded and verified value-creation design process.

Combining the entrepreneurial mindset (the three C's) with the engineering skillset can lead to positive student outcomes, as shown in Figure 3. The KEEN poster that combines these images is available at www.engineeringunleashed.org. Dr. Doug Melton has an excellent video on Mindset and Skillset [17].

ENTREPRENEURIAL MINDSET

THE 3C's



CURIOSITY

In a world of accelerating change, today's solutions are often obsolete tomorrow. Since discoveries are made by the curious, we must empower our students to investigate a rapidly changing world with an insatiable curiosity.



CONNECTIONS

Discoveries, however, are not enough. Information only yields insight when connected with other information. We must teach our students to habitually pursue knowledge and integrate it with their own discoveries to reveal innovative solutions.



CREATING VALUE

Innovative solutions are most meaningful when they create extraordinary value for others. Therefore, students must be champions of value creation. As educators, we must train students to persistently anticipate and meet the needs of a changing world.

Figure 1: Entrepreneurial Mindset 3C's Framework. [3]

| ENGINEERING SKILLSET | | |
|---|---|---|
| OPPORTUNITY | DESIGN | IMPACT |
| IDENTIFY an opportunity | DETERMINE design requirements | COMMUNICATE an engineering solution in economic terms |
| INVESTIGATE the market | PERFORM technical design | COMMUNICATE an engineering solution in terms of societal benefits |
| CREATE a preliminary business model | ANALYZE solutions | VALIDATE market interest |
| EVALUATE technical feasibility customer value societal benefits economic viability | DEVELOP new technologies (optional) | DEVELOP partnerships and build a team |
| TEST concepts quickly via customer engagement | CREATE a model or prototype | IDENTIFY supply chains distribution methods |
| ASSESS policy and regulatory issues | VALIDATE functions | PROTECT intellectual property |
| THESE SPECIFIC SKILLS REINFORCE THE DEVELOPMENT OF AN ENTREPRENEURIAL MINDSET.. | | |

Figure 2: Engineering Skillset.[3]

The KEEN Educational Outcomes have been mapped to both the current and proposed ABET Outcomes [18]. Seeking to achieve these outcomes in our student engineers, the IRE faculty developed and deployed entrepreneurial-minded learning (EML) modules in various courses. Details are included in the next section of the paper. A one-hour introduction to entrepreneurial

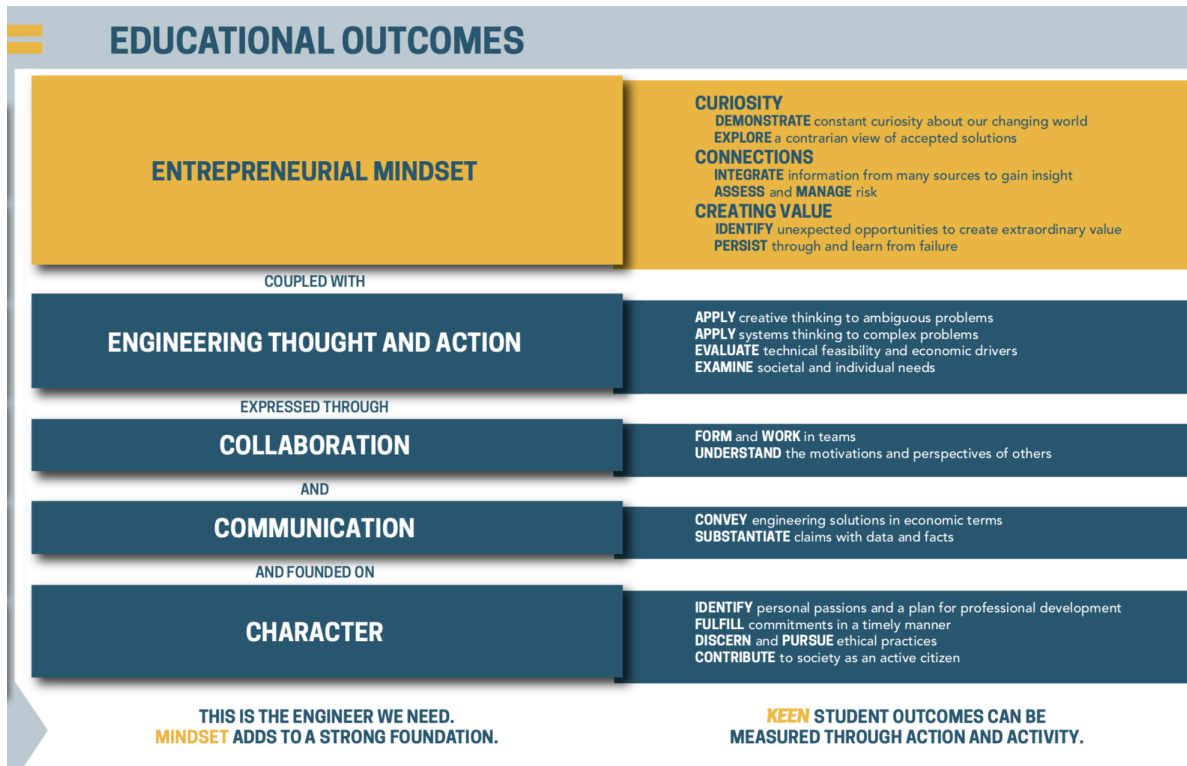


Figure 3: KEEN Entrepreneurial Mindset + Skillset = Educational Outcomes.[3]

minded learning was presented to all the students at the beginning of the semester so they would be prepared for it to appear in different courses. Approximately 80 percent of the students enrolled in IRE in 2017-2018 were introduced to EML pedagogy and entrepreneurially-minded language in their courses and in their team project work that academic year.

Methods and results in technical courses

Several faculty at IRE coordinated to simultaneously re-format some of their existing content into story-like EML scenarios in sophomore, junior, and senior year engineering courses and in integrated engineering projects for industry clients. Significant synergies have developed in our program as a result, across courses, within project teams, and in the language used by faculty and students throughout the program. The next section of the paper presents a table summarizing several EML implementations in specific technical courses, including: the module implemented, the elements of entrepreneurial mindset included, the delivery methods of the EML scenario, and evaluation methods used. Detailed descriptions of the EML implementations, faculty improvements for next time, and student comments are included in Appendix 1.

Table 1: **Integration of the Entrepreneurial Mindset into Courses**

| Course | Description of EML | Elements of Entrepreneurial Mindset Implemented | Delivery Methods | Evaluation of Elements of Entrepreneurial Mindset Implemented |
|------------------------|--|--|--|--|
| Signals and Systems | Disney Mickey Mouse hat ears interact with the attractions at Disney theme parks. Evaluate whether or not the ears should continue using infrared signaling or switch to radio frequency. | Students choose 1-2 items from each of the “opportunity” and “impact” columns in the engineering skillset to focus their solution around | Six-week independent learning activity where the final deliverable was a report detailing the solution with the reasoning behind how as it relates the chosen entrepreneurial mindset engineering skillset | Written report, faculty observation and student feedback |
| Three Phase AC Systems | “Aunt Lucinda,” was going to have the wiring in her European house switched from the current three-phase wye to wye configuration to another three-phase configuration. Verify whether the change to the system would decrease the client’s overall power usage. | Students choose 1-2 items from each of the “opportunity” and “impact” columns in the engineering skillset to focus their solution around | Six-week independent learning activity where the final deliverable was a report detailing the solution with the reasoning behind how as it relates the chosen entrepreneurial mindset engineering skillset | Written report, faculty observation and student feedback |
| Electric Machines | “Dr. Elizabeth” has a cable car in New Zealand and needed analysis of the electric machine running it to see whether to keep the cable car or replace the entire system with stairs. | Students choose 1-2 items from each of the “opportunity” and “impact” columns in the engineering skillset to focus their solution around | One week class assignment summarizing the initial scoping of the problem and proposed next steps. Students were given the option to use this as their six week independent learning activity for the course. | Written report, faculty observation and student feedback |
| Statistics | Design a safe disc-golf course by designing and carrying out an experiment on disc-golf accuracy. | Customer engagement, Value creation, Societal benefits, Economic feasibility, Build a team. | Four class periods to introduce problem and data on disc golf injuries, plan data collection strategy, and collect the data. Analyze data and communicate results. | Design of experiments plan & Data collection and analysis. Written report on proposed disc golf course design and how it improves safety for disc golf players and people and property nearby. |

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| Course | Description of EML | Elements of Entrepreneurial Mindset Implemented | Delivery Methods | Evaluation of Elements of Entrepreneurial Mindset Implemented |
|--------------------------|--|--|---|---|
| Engineering Economics | Student inherited \$50,000 and is given three options - buy a vehicle, save for baby's college fund, or pay debt. | Curiosity. Identify an opportunity. Communicate decision in economic terms. Value for self and others. | One class period to discuss the scenario and resulting opportunities. | One written reflection assignment including thought process and factors considered in making the decision. |
| Entrepreneurial Thinking | Semester-long PBL project is the scenario for many of the application activities. Also, students planned and briefly operated a small retail business. | Identify an opportunity. Write value proposition for specific customers. Connections Communication. Teamwork. Customer engagement. Validate market interest. Build a team | 8 week block, two class meetings per week. Students applied knowledge via customer discovery, wrote concept maps, market assessments, and feasibility plan for starting a small business. Communicated value and economic effects of design on client project. | Faculty observation. Written and verbal student assignments and reflections. 50-100 page final report on semester-long client project. |
| Heat Transfer | Students were tasked with insulating a pipe using materials from local hardware stores. They were to provide economic rationale for there decisions | Evaluate technical feasibility, communicate engineering solutions in economic terms | Activity was given as a homework assignment. Students were to turn in the heat transfer analysis and benefits in economic terms. | Homework assignment's analysis and student reflection portions. |
| Heat Transfer | Students designed a fondue pot for IRE graduation event. Student life director, Jim Boyd, was the "customer". | Identify an opportunity, evaluate customer value, develop partnerships and build a team | This was a deep learning activity. Students were given 4 weeks to work. Question and answer sessions were provided the last 10 minutes of each class period | Faculty observation, Deep Learning Activity report, oral exam questions, student feedback |
| Static Mechanics | Identify statics concepts and local factors that would affect the design of affordable housing in a specific country with unique social and economic scenario. | Identify an opportunity, Value creation, Societal benefits, Economic feasibility, Teamwork, Connections, Communication | Introduction and country selection. Random Team. Random Country. Research local factors and communicate results. | Presentation and Written Report |

See Appendix I for faculty and student comments on the course implementations of entrepreneurial mindset.

Methods and results in design project and open-ended problem solving activities

Engineers are expected to create value for their clients/customers; this a primary reason for integrating the entrepreneurial mindset into our student learning activities and assessing it regularly due to the program's additional outcome on Entrepreneurial activities. While the program has maintained a culture of innovation and continuous improvement since its inception, the explicit attention to entrepreneurial mindset in 2017-2018 was a significant change.

As expected, curiosity, connections, and creating value for the client have come up repeatedly in Design class deliverables and team discussions. Faculty observed greater use of entrepreneurial mindset in student's technical design documentation, students asked better questions and communicated more clearly with their industry clients, and overall considered value and customer benefits and costs to a greater degree than in previous semesters. Evidence of students meeting the Entrepreneurial performance indicators was collected in technical project documentation that now includes evidence that the teams asked the client open-ended questions (curiosity), completed Failure Modes and Effects Analysis (curiosity), creation of value (Value proposition model and Business Model canvas), improved quality of documentation and research, including interviews with subject matter experts (creating value, curiosity, and communication) and similar evidences of student engineers being aware of the customer, talking with the customer, and making design decisions based on customer feedback. Learning from failure and pivoting after soliciting feedback from minimum viable product prototypes was also evident. An example from design class follows:

In Feb. 2018, the semester just following the initial infusion of entrepreneurial mindset, student engineers at IRE had their first design review on their semester projects. Panel members (faculty and invited engineers from industry) asked each design team about the value that their team had provided to the client after the first three-week "sprint" into the project. The expectation had been set up that students were to go through the entire design process as if they only had three weeks to complete the project, rather than a 16 week semester. Teams repeat the design process in three Sprints during the semester. The design review panels asked each team "How much value does your technical document provide to the client now?" The value should be in the range of \$10,800 (assuming a 4-person team * 12 hours per week doing project work * 3 weeks * \$75 per hour). Since these are student engineers, perhaps half the rate or a total of \$5,400 is a more appropriate value target. None of the eight project teams could confidently state that their documented work had that much value at that time. The panel also posed these questions to each team:

1. How could your team have been more productive? (quality and quantity of work)
2. How could your team experience have been more enjoyable? (team interactions)
3. How could your document be better? (aesthetics, grammar, also scale and value)

4. How could your team have provided a higher value to your client? (entrepreneurial mindset)

The team's collaborative answers to these questions became the "to-do list" for the team in the next three-week sprint.

In previous semesters, students would likely have only completed a Scoping Document by Week 3. Since the entrepreneurial mindset infusion, both students and faculty noted much higher levels of value and progress toward the end of semester deliverables after each sprint. Previously, our experience was that most of the student work happened as the due date approached. Agile project management is to create value through sprints, with deliverables at end of each sprint and the opportunity for the client to provide feedback. By using three sprints during the semester, we hoped to motivate students to create more value for the client in each sprint than they would have without this schedule. Results from one academic year indicate success. Students, faculty, and industry evaluators all reported that project work got much further towards the design solution during each sprint than in prior semesters.

One student said, *"For sure, our team created a lot more value than last semester at this time."* Others communicated similar anecdotes.

Another student reflected that the sprint 1 deliverable helped the team achieve a better score: *"Facilitators usually grade lower in the first design review because its only the research phase. . . . facilitators don't feel like much value has been created. This time, the graders saw the value we created right away this semester."*

At the end of each semester, student engineers in this program complete an oral exam in which they use fundamental principles of engineering to solve an open-ended problem. They select an open-ended problem from a given set of appropriately scoped problems and have eight hours to carry out their problem-solving process that involves identifying and applying the appropriate fundamental principles of engineering, research, idea generation and selection, and a plausible solution. Faculty evaluators and industry guests indicated greater use of the entrepreneurial mindset language and skills than in previous semesters. The terms "customer", "value", "connections" and other entrepreneurial mindset terms were heard more often than in prior years. While the use of these terms was not specifically counted in 2017-2018, we plan to specifically assess the entrepreneurial mindset exemplified by students in this exam by adding items to the rubric for future use.

Another benefit observed by the faculty was that the culture and mindset changed to include more awareness of customer needs and value-driven decisions in other areas of the program. Students are using entrepreneurial mindset in written reflections, oral exams, and deep learning activities in coursework, for example. Student awareness and attention to customer value appear to be more present in learning conversations and written assignments. We are also noting more awareness of customer needs and identification of value creation in design projects. The entrepreneurial mindset has surfaced in other aspects of the program as well. Students wrote about how they now use the entrepreneurial mindset in their job search and at work. Several students related that they credit their successful internship, co-op and full-time employment interviews to their use of "customer value" phrases in interviews.

A student comment on their IRE experience from April, 2018: *"My knowledge gain for the*

engineering practice through IRE has been phenomenal, and every organization I have been a part of raves about how much more advanced I am than other entry-level engineers they have seen/worked with. I would never have done my education any other way.” (from anonymous student survey near the end of Spring 2018 semester). The use of entrepreneurial language shared by faculty and student engineers is another benefit. We also now enjoy stronger faculty cohesiveness and similarity in pedagogies as a result of this collaborative effort.

Conclusion and next steps

A majority of the faculty in this program simultaneously integrated the entrepreneurial mindset across much of the curriculum. Since our program has nearly 100 students who are now encountering active, entrepreneurially-minded learning strategies in several courses and in their design projects from sophomore year onwards, the entrepreneurial mindset is becoming part of the culture of our program and is part of the students’ tacit knowledge of engineering. There is no control group as all students in the program are experiencing this change. As reflective practitioners, we aim to use evidence-based assessment techniques to more critically evaluate learner outcomes. The KEEN assessment group has developed an Assessment Starter Kit that is intended to give faculty a set of deployable outcomes-oriented assessment tools to use in their courses and to provide a framework for discussion and dissemination of best-practices across the KEEN network, sharing and cross-pollinating assessment practices between institutions [19]. The Entrepreneurship Knowledge Inventory (EKI) [10] and the California Critical Thinking Skills Test (CCTST) [20] are additional assessment tools that provide evidence of entrepreneurship knowledge and reasoning skills. We plan to select and use these or similar assessment tools in the 2018-2019 academic year to more precisely evaluate learner outcomes.

Preliminary anecdotal results are positive, based on student, faculty, and industry feedback. Data analysis is underway to assess the change, if any, of entrepreneurial language in the teams’ final technical documents from their semester-long team projects, based on the hypothesis that if more entrepreneurial language appears in the students’ final design project documents (50 - 100 pages each), then likely they are applying entrepreneurial thinking in their project work and making decisions based on customer needs, curiosity, and value creation. This will be specifically assessed in Summer, 2018 by comparing the use of entrepreneurial mindset terms in the Fall 2017 and Spring 2018 final project technical documents to those of prior years.

The KEEN outcomes have been linked to the current and revised ABET Outcomes [17]. We plan to map our course learning objectives and our program outcomes to both the KEEN and revised ABET outcomes.

The faculty in this program will continue to develop and implement more entrepreneurial-minded modules into the curriculum, to map the EML modules to specific placement in our existing curriculum, and to assess the efficacy of these changes on student learning. We encourage faculty in other departments in our College to consider integrating entrepreneurial mindset into their programs as well.

References

- [1] No author. "C3 C5 Mapping SEC 1-13-2018," ABET, Baltimore, MD. [Online]. Available: ABET,<http://abet.org>. [Accessed Mar. 18, 2018].
- [2] N. Duval-Couetil, E. Kisenwether, J. Tranquillo, J. Wheadon, "Exploring the Intersection of Entrepreneurship Education and ABET Accreditation Criteria," *The Journal of Engineering Entrepreneurship*, vol. 6, Number 2, pp.44-57, June 2015. [Online]. Available: The Journal of Engineering Entrepreneurship, <https://doi.org/10.7814/jeenv6n2p3>. [Accessed Dec 17, 2017].
- [3] The Kern Family Foundation "Engineers with an Entrepreneurial Mindset Transform the World," [Online]. Available: <https://engineeringunleashed.com>. [Accessed: Dec 28, 2017].
- [4] D. Johnson, R. Johnson, and K. Smith, "Cooperative learning returns to college: What evidence is there that it works?" *Change*, 30(4), pp. 26-35, 1998.
- [5] T. Kriewall, K. Mekemson, "Instilling the Entrepreneurial Mindset Into Engineering Undergraduates," *The Journal of Engineering Entrepreneurship*, vol 1, Number 1, pp. 5-19, January 2009.
- [6] J. Wheadon, N. Duval-Couetil, "Business Plan Development Activities as a Pedagogical Tool in Entrepreneurship Education" *The Journal of Engineering Entrepreneurship*, vol 5, Number 1, pp. 31-48, June 2014. [Online]. Available: <https://doi.org/10.7814/jeen5v5p3wd>. [Accessed Dec. 29, 2017].
- [7] M. Schar, S. Sheppard, S. Brunhaver, M. Cuson, M. Grau, "Bending Moments to Business Models: Integrating an Entrepreneurship Case Study as Part of Core Mechanical Engineering Curriculum," *The Journal of Engineering Entrepreneurship*, vol 5, Number 1, pp. 31-48, June 2014. [Online]. Available: <https://doi.org/10.7814/jeen5v5p1ssbcg>. [Accessed Mar. 17, 2018]
- [8] J. Weaver, N. Rayess, "Developing Entrepreneurially Minded Engineers by Incorporating Technical Entrepreneurship Case Studies" *The Journal of Engineering Entrepreneurship*, vol 2, Number 1, pp. 10-27, January 2010.
- [9] J. Tranquillo, D. Ebenstein, E. Kennedy, K. Bieryla, D. Cavanagh, "Product Archaeology: Unearthing Business Decisions," *The Journal of Engineering Entrepreneurship*, vol 6, Number 1, pp. 22-36, Spring 2015. [Online]. Available: <https://doi.org/10.7814/jeenv6p3>. [Accessed Mar 17, 2018].
- [10] M. Besterfield-Sacre, N. Ozaltin, A. Robinson, L. Shuman, A. Shartrand, P. Weilerstein, "Factors Related To Entrepreneurial Knowledge in the Engineering Curriculum," *The Journal of Engineering Entrepreneurship*, vol 4, Number 1, pp. 31-38, June 2013. [Online]. Available: <https://doi.org/10.7814/jeen5v4p3borssw>. [Accessed Mar 18, 2018].
- [11] N. Duval-Couetil, T. Reed-Rhoads, S. Haghghi, "The Engineering Entrepreneurship Survey: An Assessment Instrument to Examine Engineering Student Involvement in Entrepreneurship Education," *The Journal of Engineering Entrepreneurship*, Vol 2, Number 2, pp. 35-56, Winter, 2011. [Online]. Available: <http://www.jeenonline.com/Vol2/Num2/Vol2No2P3.pdf>. [Accessed Apr. 1, 2018].
- [12] D. Pistrucci, B. Bonnstetter, C. Fry, "Creating, Educating and Assessing a New Class of Entrepreneurial Minded Engineers," *Journal of Engineering Entrepreneurship*, vol 2, Number 2, pp. 1-14, Winter 2011.
- [13] K. Smith. Personal webpage. [Online]. Available: <http://personal.cege.umn.edu/~smith/>. [Accessed Mar 19, 2017].
- [14] S. Ambrose, Undergraduate Engineering Curriculum: The Ultimate Design Challenge, The Bridge on Undergraduate Engineering Education, June 12, 2013 VOL 43 Issue 2, [Online]. Available: <https://www.nae.edu/Publications/Bridge/81221/81228.aspx>. [Accessed: Dec 28, 2017].
- [15] University of Dayton, "KEEN: Kern Entrepreneurial Engineering Network," [Online]. Available: <https://www.udayton.edu/engineering/centers/visioneering/keen-fellows-program/index.php>. [Accessed: Dec 28, 2017].

- [16] D. Boud, "PBL in perspective," *PBL in Education for the Professions*, D.J. Boud (ed), p. 13, 1985.
- [17] D. Melton, "Why Entrepreneurial Mindset Matters", Kern Family Foundation. [Online]. Available: <https://www.youtube.com/watch?v=WZHvRpuemgk&list=PLvITFYQeu1sFKecbGpVFBH44TCFnbanly&t=1s&index=1>. [Accessed Dec. 17, 2017].
- [18] P. Brackin, "KEEN and ABET". *KEEN'zine 5 The Handbook for EML*. pg 40. [Online]. Available: <https://www.engineeringunleashed.com>. [Accessed Mar. 18, 2018]
- [19] P. Singh, The KEEN Assessment Working Group. Kern Family Foundation. [Online]. Available: <https://engineeringunleashed.com/cards/cardview.aspx?CardGuid=03b4ebc6-abce-442f-b82b-2f99e2d0b7f5>. [Accessed Mar 18, 2018].
- [20] California Critical Thinking Skills Test, Insight Assessment, The California Academic Press, San Jose. CA. [Online] Available: <https://www.insightassessment.com/Products/Products-Summary/Critical-Thinking-Skills-Tests/California-Critical-Thinking-Skills-Test-CCTST>. [Accessed Apr. 27, 2018].

Appendix I

Faculty 1:

During the fall semester, I implemented the entrepreneurial mindset into three of the one credit Electrical Engineering courses I taught: Signals and Systems, Three Phase AC Systems, and Electric Machines. The EML modules ranged from a one class assignment to a six-week independent learning activity commonly known as a deep learning activity (DLA). At the start of each EML, after the problem was introduced, students were given the KEEN complementary skills chart and told to pick 1-2 items from the “opportunity” and “impact” area to focus their solution around. For the Signals & Systems EML it was a very polarizing project where the students either really liked it or didn’t. It also proved to be challenging to tie in all five fundamental principles to the project. For the next iteration of this EML, I plan to have the students only apply 1-2 fundamental principles to hopefully allow for a more in-depth technical solution. I also will add a research assignment midway through the project so students are encouraged to use a variety of peer-reviewed sources to gather information instead of just Google. For the Three-Phase AC Systems class students were initially overwhelmed at the scope of this project as they didn’t know what assumptions to make. Not as much technical work was accomplished as the instructor predicted, but the students who completed this project seemed to enjoy solving the problem since it was directly applicable to their own lives. A future EML module for this course is to use the work completed by the first group of students as a starting point to build on for a more detailed analysis. Using the student feedback and self-reflection from the Signals and Systems EML, the Electric Machines EML activity was to limit the solution to the application of only 1-2 fundamental principles and a research assignment was added midway through the project. The quality of the written reports for this EML improved and there was little student resistance to completing this activity. Also in this EML, students demonstrated the use of the KEEN complementary skills to a deeper level compared with the other two courses. Evidence of this can be seen in a group’s analysis of *“The cost to remove the cable car and install a staircase all while the value of her home depreciates is not cost effective and adds no value for her in the future. Even though Elizabeth would like to remove the cable car for personal reasons, she will likely end up re-installing a cable car or elevator in her old age which will be even more costly (especially when considering the time-value of money).”*

Student comments:

- *“The DLA (deep learning activity) was somewhat challenging because it was abstract. There was not a hands-on concrete portion which is usually how I learn best. The hypothetical situation made me think outside of the box and use my creativity a bit more than usual.”*
- *“I think the best part of the DLA that went best was the application of the fundamental principles. After we learned about each principle, I thought about how they could be used to influence the signal. This helped me see real-life applications of signals and systems that I probably wouldn’t have seen otherwise.”*
- *In the midst of the struggle, there is always learning that takes place and challenges along the way. This project was a great example of this. It challenged those involved in ways that took them outside their comfort zones and made them think. Overall this was a unique project; although, it was very challenging to find results that were completely satisfying.”*

Faculty 2:

In the fall semester, I was responsible for leading the heat transfer course. After attending the KEEN ICE workshop, I was intrigued by the idea of conducting EML modules in the courses I taught. My goals for doing so were to track the growth in the students’ ability to (1) solve open-ended problems, (2) solve open-ended problems involving heat transfer, and (3) incorporate stakeholder value in the design solution.

To begin, I administered a written reflection at the beginning of the course asking students to rate their current abilities in open-ended problem solving and their perception of the importance of stakeholder needs on design solutions.

The student’s responses seemed to depend on where they were in the program. The general results indicated that confidence in solving ill-defined problems increased as students approached graduation. However, all students seemed to understand the significance of incorporating stakeholder value.

Leading to the first EML module, students were given close-ended homework problems designed to connect heat transfer and engineering economics principles. The first module took the form of a one-day homework assignment. Students were asked to take a pipe containing a warm fluid in a cold climate and insulate it in a way to minimize heat loss. The students were constrained to using only materials that could be found at the local hardware stores. The goal was to find the best balance between material costs and fuel savings then report the solution based on economic terms (payback period, net present value, etc).

While each student was able to find cost savings, only a handful evaluated multiple options or exhibited out-of-the-box thinking. The next time I conduct this module I will frame it as a competition in which the greatest savings "wins".

The second module consisted of a design challenge. Self-selected teams (2-3 members) were tasked with designing a fondue pot to be used by "Jim" for the Iron Range Engineering graduation dinner. Students were given several constraints (heating time, safety, cost, etc) to design around. The teams were given three weeks to complete their work and submit a written report detailing the design and the engineering analysis. Each team was able to successfully meet the constraints but again didn't seem to explore opportunities to create customer value outside of the minimum. When I run this module again, I will be sure to have students add a section in the report to explicitly discuss what decisions were made to maximize customer value.

Over the semester, I had hoped to track the changes of the students in the three goal areas, but time did not allow me to conduct another written reflection. At each student's final oral exam, I asked their thoughts on the EML modules and how it affected their learning. Many of the students commented to how the modules made them think deeper about the course content by forcing them to find the shortcomings in their knowledge. Moreover, it wasn't enough for them to be able to recite the information but they had to apply it and understand how theory impacted their solutions. Others mentioned how they were more motivated to continue heat transfer studies in an attempt to answer questions brought up during the modules.

Faculty 3 (who leads a sophomore course to pre-engineering students affiliated with the upper division program):

Many of this program's core values, student outcomes, and instruction techniques are consistent across the student experience. This allows students to develop a deeper understanding of concepts from multiple interleaved exposures and helps them to recognize interactions between different technical, social, and business concepts. By introducing entrepreneurial mindset through EML modules into technical engineering courses in the first two years gives students exposure to these concepts early, and reinforces the value they bring to any design process.

During the fall semester, sophomore students in Static Mechanics participated in an EML activity consisting of a research report and presentation based on affordable housing throughout the world. Students were randomly assigned teams and countries. Each team researched their country to better understand local factors that might affect the design of affordable housing for low-income residents and what statics concepts would be involved. Local factors may include; available materials, climate, regional income levels, and social norms.

Overall, students found this real-world application thought-provoking and complex. Presentations and reports reflected valuable student engagement. The final solutions were often considerably different than if regional factors were not considered. Students found value in learning to recognize the diversity of constraints that affect a problem, and identified economic factors outside of the technical static mechanics concepts that influenced their analysis.

Faculty 4:

One EML module was implemented in each 1 credit course of Entrepreneurship, Engineering Economics and Statistics. The modules ranged from one class meeting to two-week assignments.

In Engineering Economics, the students were presented with a scenario in which they inherited fifty thousand dollars from their Great Grandpa Max and asked to answer the question "What would you do with the cash?" They were offered the options of purchasing a new vehicle, saving for their baby's college account, which is what the imagined spouse wants to do, or paying off thirty thousand dollars of student loan debt. The students received this information through a 4-slide power point, followed by group discussion. The assignment was to write a 2 page reflection paper

describing their thought process, the factors they considered, and how they used curiosity, connections and value creation in their decision on what to do with the inheritance. The instructor guided the discussion through prompting questions and connected the scenario to the fact that businesses also have to make decisions on capital spending, or deciding on the highest and best use of available funds. This happens on the first day of class with the reflection due three days later. Students related that they enjoyed the assignment, which activated prior knowledge and helped to frame the capital budgeting decision tools to be covered in the class.

A student wrote a reflection about curiosity: *“For me , curiosity was expressed in the form of wanting to learn more about how to figure out the differences in certain investment accounts and which would be the best for a college fund...Curiosity was also shown with thinking about the future and which options would set myself up to succeed but also a baby as well.”* Another student commented on the value of the activity: *”For me personally, this type of exercise is valuable. . . .it was valuable to write it all down, especially my thought process.””My biggest takeaway from this is that it’s almost always better to save for later instead of spending now.”*

I will use this EML as a starting point for Engineering Economics again; it is a good framing tool for course topics and helps students realize that their financial decisions affect others as well as themselves.

In Entrepreneurship, the KEEN framework and language is used significantly in the course resources, assignments, and learning activities. Students view several of the KEEN videos, receive the KEEN Mindset and Skill-set posters, and complete assignments tailored to help them recognize how value can be created for a specific customer segment in their engineering work overall. The EML module had students apply entrepreneurial thinking by planning and carrying out a small business activity (a smoothie shoppe, a coffee bar, a clothing flash sale). Students documented their experiences and learning via a Concept Map, reflections, assignments such as SWOT and Value Proposition Stmtns, an end-of-course paper, as well as a metacognitive memo on their learning process and outcomes.

Comments from students’ metacognitive memos from the course include:

- *“I found the KEEN learning principles of the three C’s to be extremely useful to my project...not only was I able to implement better strategies, such as utilizing a Business Charter for scoping documentation, but I was also able to identify the entrepreneurial skills that I was already applying to my project.”*
- *“I identified stakeholders and formed connections to create a successful partnership between community, educational, and industry groups. . . .Curiosity was key to understanding the vision of my client...my experience as project manager was greatly enriched because I was able to identify these key components and recognize their value.”*
- *“I’m extremely happy I took this class. . . .the three C’s were incorporated greatly throughout this course. . . .the best part about curiosity is that it’s a never-ending tool.”*
- *“Throughout the design process, we created a set of connections. In this case, my team connected with the student engineers, faculty, clothing companies, and each other.”*
- *“I personally enjoyed the learning activities of this class. They were engaging, not too complicated, and fun!”*
- *“Any and all principles, ideas, and analysis for businesses that we learned in this class I could apply to my team’s business. That is, I believe, the best way to learn, by application.”*
- *“I just wanted to make sure I took the time to thank you, I’m now an engineer who has an entrepreneurial mindset.”*