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Teaching Entrepreneurial Mindset in a First-Year Introduction to Engineering Course

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Abstract

With a mission to graduate engineers who can create personal, economic, and societal value through a lifetime of meaningful work, KEEN (Kern Entrepreneurial Engineering Network) started a movement of fostering an entrepreneurial mindset in young engineers. This paper will discuss the experience and evaluation of incorporating entrepreneurial mindset learning in a freshman Introduction to Engineering course.

Introduction to Engineering is a one-semester 2-credit hour freshman lecture and lab course focusing on teaching engineering design process, with students completing a half-semester long multi-disciplinary design project. In addition, technical concepts such as engineering drawing, MATLAB and basic disciplinary knowledge are taught along with the introduction of "soft skills" such as communication, teamwork and project management. This paper will discuss how KEEN's 3Cs framework, i.e., curiosity, connections and creating values, was incorporated into the existing course content centered on an open-ended design project. The impact of this addition will be evaluated through student surveys on their awareness of entrepreneurial mindset concepts.

Introduction

Arizona State University is a partner institution of the KEEN network with the mission to transform engineering education by fostering an entrepreneurial mindset in young engineers [1]. The freshman Introduction to Engineering course was revamped to expose entrepreneurial mindset concepts to students during their first-semester at the university.

Introduction to Engineering is a one-semester long 2-credit hour freshman lecture and lab course focusing on teaching engineering design process, with students completing a half-semester long multi-disciplinary design project. In addition, technical concepts such as engineering drawing, MATLAB and basic disciplinary knowledge are taught along with the introduction of "soft skills" such as communication, teamwork and project management. The course is required for students majoring in mechanical, aerospace, electrical and chemical engineering.

This paper will discuss the experience and evaluation of incorporating entrepreneurial mindset learning in the Introduction to Engineering course. Specifically, it will discuss how KEEN's 3Cs framework [2], i.e., curiosity, connections and creating values, was incorporated into the existing course content centered on an open-ended design project. The impact of this addition will be evaluated through pre and post student surveys on their awareness of the entrepreneurial mindset concepts.

The rest of the paper is organized as follows. First, the existing work on fostering entrepreneurial mindset in the freshman engineering curriculum is reviewed in the background section. Design and implementation of incorporating KEEN's 3Cs framework in the Introduction to Engineering course is described next, followed by the assessment and results. Lessons learned and recommendation for future improvement is presented next, followed by conclusion.

Background

Existing work on incorporating entrepreneurial mindset materials into the freshman engineering curriculum have taken different approaches, ranging from online modules to a full-fledged design course.

Lightweight e-learning modules [3] were developed in a one-credit standalone course, one per semester for the first and second years, to introduce four key elements of entrepreneurial mindset including technical fundamentals, business acumen, customer awareness and societal values.

In [4], entrepreneurial contents were incorporated in the entire first year through a one-lecture introduction to entrepreneurship in the first quarter, a team-based exercise emphasizing creativity in the second quarter and a team project designing a poverty-alleviating device in the final quarter.

A module consisting of three to five lectures were incorporated into an existing freshman course [5] that used case studies to teach product development lifecycle including customer need identification, concept generation, concept development, scope expansion, and business plan. The assignment for students was to develop an abstract idea into a one-page product concept and enter into an idea to product competition.

A freshman introduction to engineering course [6] spreading over two semesters incorporated KEEN learning outcomes into multiple well-defined design/build/test team projects, individual homework assignments, active collaborative learning modules, and presentations.

Entrepreneurially minded learning was introduced in a two-course sequence spanning the entire first year [7]. During the first semester, artificial budget requirements were built into robotic design projects. While in the second semester, entrepreneurial mindset materials was incorporated in a smart design project emphasizing seeking opportunities using brainstorming, accessing market interest, accessing technical feasibility, designing for manufacturability, and providing a cost analysis of an eventual finalized product.

A semester-long freshman engineering design course [8] was developed from scratch to cover the entrepreneurial topics including opportunity recognition and value proposition, understanding intellectual property, ideation and concept generation, customer discovery, pro-forma financials; manufacturing considerations in product design, technology roadmapping, understanding return on investment and venture creation within and outside of corporations.

The work presented in this paper borrowed ideas on opportunity identification and market research from the Opportunity Thinktank [9], a set of seven modules that help undergraduate engineering students establish an entrepreneurial mindset through opportunity identification. Different from their work, this paper emphasizes on how to integrate entrepreneurial mindset concepts in the teaching of entire engineering design process.

Design and Implementation

In contrast to the existing work, entrepreneurial mindset materials were incorporated in a first-semester freshman Introduction to Engineering course, tightly integrated in an open-ended design project. The entrepreneurial materials on opportunity identification, market research, and value creation through customer involvement, which are the focus of the KEEN's 3Cs framework, were intertwined with the discussion of engineering design process, which is the main thread of the Introduction to Engineering course.

The Introduction to Engineering course is a 2-credit 15-week lecture and lab course consisting of 50-minute lecture and 2-hour 50-min lab each week. The course covers the topics of engineering design process, engineering model and drawing, MATLAB, teamwork, technical communication and project management. In addition, basic disciplinary knowledge is introduced to help student with their multidisciplinary design project. Students work in multidisciplinary teams in both lecture and lab throughout the semester.

Entrepreneurial mindset materials were incorporated in the course, centered on an open-ended design project. The design project was intended for students to practice the steps of the engineering design process [22]. The project schedule is shown in Table 1 with the topics for each week highlighted. How entrepreneurial mindset concepts were integrated into the discussion of engineering design process in each week's topics will be explained in details next.

Table 1. Project Schedule

Project Week	Engineering Design Process	Lecture	Lab
Preparation	Overview	Design Process and EM	
1	Recognize the Need; Gather Information	Pain Point Investigation	Market Research and Opportunity Identification
2	Define the Problem; Generate Alternative Concepts	Information Synthesis and Problem Definition	Ideation and Rapid Prototyping
3	Evaluate the Alternatives; Select the Most Promising Concept; Plan the Project	Project Management	Decision Making and Project Planning
4	Communicate the Design	Technical Communications	Proposal Presentation
5	Implement the Design	Unit Economics	Construction & Testing
6-9	Implement the Design	---	Construction & Testing
10		---	Project Demonstration

Preparation

A brief introduction to entrepreneurial mindset was incorporated into the lecture explaining engineering design process. Entrepreneurial mindset was introduced through the video

illustrating the difference between entrepreneurial engineering vs. traditional engineering [10], as well as through the concepts of 3C's, i.e., curiosity, connections and creating values [2]. Specifically, "curiosity" was focused on as students learn about the need identification step in the engineering design process. Customer needs and paint points were emphasized through a video clip from the ABC's television show "Shark Tank" [11]. Next students learned how to use the five whys method [12] in root cause analysis to identify costumer pain points. Finally students learned to use the Point Of View (P.O.V.) Madlib [13] to write a proper need statement, which is a part of the need-objective-requirements problem definition [14].

Project Week 1

Before the pain point investigation lecture, the students were assigned a homework to each come up with a list of twelve bugs, i.e. pain points that either bother themselves or bother other people. They were encouraged to read news, interview friends and family. During the lecture, students worked in teams of four. They first wrote down their pain points on post-it notes. As a team, they worked together to combine and group bugs, and then voted the top four bugs. For each of the four bugs, they applied five whys analysis and wrote a need statement using the P.O.V. Madlib.

During the lab that week, students worked on "information gathering" step in the engineering design process. "Connections" from the 3C's was emphasized to collect and integrate information from many sources to gain insight. Specifically, students were taught how to conduct formal secondary research using on- and off-line published resources. Useful websites for conducting market research were shared with students [15-20]. For each of their top four chosen bugs, they had to answer the following three questions [9]:

1) Who is my end user/customer with the problem?
2) What are the current solutions and current state of technology for solving the problem?
3) What trends affect the user and their problems?

After collecting the information, they used the decision matrix in Table 2 (adapted from [9]) to help them choose the bug they would like to work on for their project. Students scored each bug with respect to each criteria using a chosen scale (1 through 5 for example). For the criteria of number of current solutions, more current solutions mean less market opportunity, and should receive lower score. Then students added up the scores, and the bug with the highest sum would be their best opportunity based on their decision matrix.

Table 2. Decision Matrix to Help Students Identify Opportunity

Criteria	**Bug 1**	**Bug 2**	**Bug 3**	**Bug 4**
Societal Importance				
General Interest				
Market Need				
Engineering Related Problem				
# of Current Solutions				
Solution Benefit				

Ability to Create a Solution				
SUM				

After students picked their opportunity, they organized the current solutions using a 2x2 matrix [13] to further investigate the competitive landscape. They were asked to plot the current solutions on a 2x2 matrix as shown in Figure 1 along two axes: cost (low to high) and difficulty (easy to hard) [9]. An empty quadrant, i.e., a white space, could signal a market opportunity. Students were encouraged to pick different axes to explore different aspects of the solution space. This exercise was aimed to help them position their own solution based on market need.

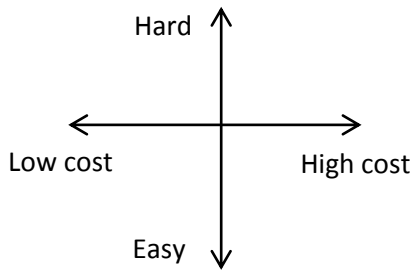

Figure 1. A 2x2 matrix

Before the end of the lab, students were given a primer on interview preparation [13] and how to conduct interview [13]. They then worked with their team to come up with a list of interview questions. Their homework was to each conduct an interview outside of class with a potential customer who experienced the pain point and record their findings.

Project Week 2

During the information synthesis and problem definition lecture, students were first asked to share their interview findings with their team. They then worked together to refine their P.O.V. using the critical reading checklist [13]. It is a good tool to help students think through the P.O.V. and evaluate if it is valid, insightful, actionable, unique, narrow, meaningful and exciting. After the evaluation, students went a step further to expand their P.O.V. into a story describing how a semi-fictional character experienced the pain point, his/her frustration, and the big insight. Finally, they synthesized their findings into a complete problem statement with need, objective and requirements.

With the carefully thought out problem statement, students moved on to the step of generating alternative concepts in the design process. They started the lab that week developing "How Might We" questions [13]. These are short seed questions to help launch brainstorms. Specifically, they were asked to break down the larger problem into smaller actionable pieces and come up with "How Might We" questions to prompt solution to the individual pieces. With the list of questions, they went through a 20-minute brainstorm session aiming to come up with 50 solutions to their problem statement. They were asked to emphasize quantity, not quality, and that they should not criticize each other's ideas. After brainstorming, students worked with their teammates to evaluate the ideas and pick the top three. Then they were given one hour to build

three prototypes for these top three ideas using cardboard, post-its and sharpie. Once they finished their prototypes, they presented their prototypes to another team who acted as their customer and received feedback. Then they exchanged role with the other team. Students were asked to use the constructive feedback template "I like …, I wish…, What if/I wonder/How to …" [13], in which "I like" was what they liked about the prototype, "I wish" was their desired features, and "What if/I wonder/How to" was their suggestion for improvement.

Project Week 3

Project management was taught during the lecture this week. Students were introduced with the concept of Gantt chart and critical path. They then went through a meal planning exercise [21] to practice creating a Gantt chart and identifying critical path in a project.

For the lab, they went through the design process of evaluating alternatives and selecting the most promising concept. They first summarized the feedback they received for their prototypes from the previous lab. Afterwards, they chose a list of criteria to evaluate their prototypes and constructed a decision matrix to pick their top design solution. They then focused on project planning step of the design process by creating a bill of materials and developing a Gantt chart for their top chosen design. Risk management was briefly introduced, which is part of "connections" in 3Cs. Students were asked to identify three "high-threat" potential problems for their upcoming project. For each problem, they discussed how this problem could be prevented, and proposed an action to be taken if the problem did occur that would mitigate its effect and bring the project back on track.

Project Week 4

In the technical communication lecture, the topic of how to create a professional looking technical report was supplemented with ideas on how to make an effective pitch. Students were shown a couple of video clips from the ABC's television show "Shark Tank". They then worked in teams to come up with tips on giving an effective elevator pitch and shared with the class. After the discussion, the NABC pitch template [23] was introduced to the students at the end of the lecture.

During the lab that week, each team was asked to give a proposal presentation, the communicating design step of the design process. "Creating values" from the 3C's was emphasized here. Students had to think hard how their solutions were different from the competitors and how their solutions would create values for the customers.

In their presentation, they had to address each letter in the NABC template:

- Need (N): Who is the potential customer? What is the market need?
- Approach (A): What is the unique approach for addressing this need?
- Benefits per costs (B): What are the specific benefits per costs that result from this approach?
- Competition (C): How are these benefits per costs superior to the current solutions and alternatives?

They were given tips on how to answer these questions. For example, use the story they wrote to describe the need and potential market; use photos, mockups, diagrams, work-flows, etc. to quickly and clearly illustrate their innovation; use the 2x2 matrix they constructed and a simple competitive analysis table to show 3-4 key features/benefits of their proposed solution out-matches 3-4 current solutions.

Project Week 5

An important aspect wasn't addressed in the project planning phase was whether or not the proposed solution would be economically viable and sustainable, i.e., if the product would create economical value. The economic aspect of a product was covered in this week's lecture. First, common business models were introduced. Then the concept of unit economics was explained. Specifically, examples were given on how to compute the customer lifetime value (LTV) [24], i.e., how much net profit a single customer can generate in his/her entire relationship with the business. It was emphasized that to make a business profitable and sustainable, the LTV has to be much larger than the sales and marketing cost to acquire a new customer. During the lab this week, students started with their project construction, the design implementation step of the design process.

Project Week 6-9

These were project construction and testing weeks. Lectures topics were not related to entrepreneurial mindset and design process. Students worked on their project construction during lab time. Customer involvement was emphasized during these weeks. Students submitted a progress memo during week 7. Besides summarizing the progress they made on their project, they had to interview customers and get customer feedback on their design features.

Project Week 10

Project demonstration and presentation was during this week, which was the last week of class. Each team had to pre-record a 2-min video in the form of a sales pitch. Again students were asked to address all letters of the NABC template in the video. After the video, each team then gave a live demonstration of their project prototype.

A final project report was required of each team. It was the manifestation of the 3C's entrepreneurial mindset concepts they learned throughout this course. In the report, they demonstrated their curiosity by identifying a customer need through story telling. They then had to describe in details of their market analysis, i.e., their potential customers and existing competitions. They made connections through this market research and interviews of potential customers which resulted in proposing their own solution. Then they had to explain how their solution was different and how their design would add value in an economic, environmental, or societal sense such as reducing costs, increasing speed, expanding reach, eliminating inefficiency, increasing effectiveness, or whatever value they could think of. Customer involvement was emphasized throughout the project, and students had to reflect on how customer feedback influenced their design.

Assessment and Results

The entrepreneurial mindset materials were administered to four Introduction to Engineering sections of about 40 students each in the Fall semester of 2016. The evaluation of entrepreneurial awareness was done through comparison of pre and post surveys given to the students [9]. Table 3 shows the list of questions in the two identical pre/post surveys, which are the desired engineering skillset in the KEEN framework [2]. Students filled out the survey by circling an integer between 0 (low) and 4 (high) for each question with the exception of Q18 which students gave free form answer.

Table 3: Pre/Post Entrepreneurial Mindset Survey

Please circle your current level of knowledge/ability regarding: 0 (low) 1 2 3 4 (high)	
Q1	Identifying an opportunity.
Q2	Investigating a market.
Q3	Creating a preliminary business model.
Q4	Examining technical feasibility, customer value, societal benefits and economic viability.
Q5	Customer engagement.
Q6	Assessing policy and regulatory issues.
Q7	Determining design requirements.
Q8	Performing technical design.
Q9	Analyzing design solutions.
Q10	Creating models and prototypes.
Q11	Validating designs.
Q12	Communicating engineering solutions in economic terms.
Q13	Communicating engineering solutions in terms of societal benefits.
Q14	Validating market interest.
Q15	Developing partnerships and building a team.
Q16	Identifying supply chains and distribution methods.
Q17	Protecting intellectual property.
Q18	Please add any comments you may have regarding your experience with entrepreneurial mindset.

There were 80 students in total who consented to participate in the research study and responded both the pre and post surveys. The average score for each question in the pre/post survey is shown in Figure 2.

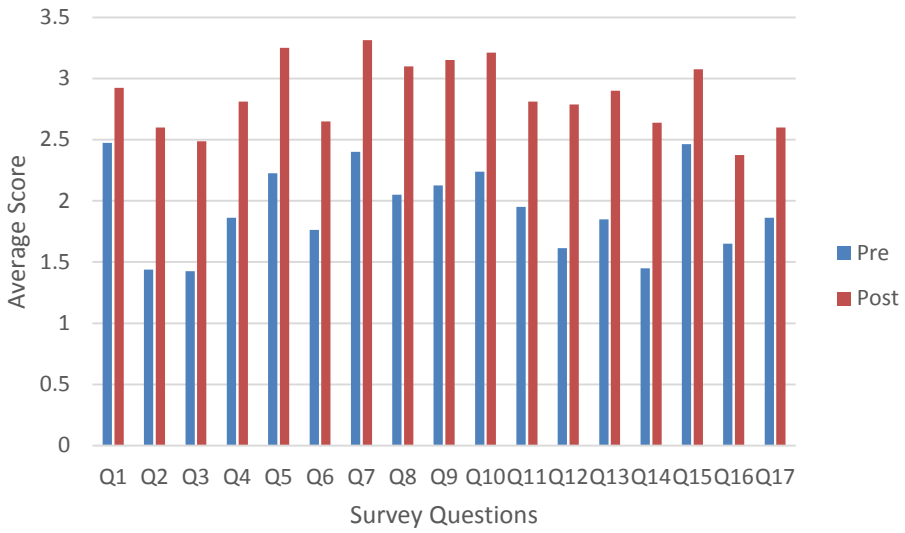

Figure 2. Pre/Post Survey Results

The net gain between pre and post survey is shown in Figure 3. It can be seen from both figures that there is consistent improvement across all questions. The highest gains are from Q2, Q12 and Q14. “Investigating a market”, “Communicating engineering solutions in economic terms” and “Validating market interest”. This is most likely the result of emphasizing market research, effective pitch using NABC, and customer involvement throughout the design project.

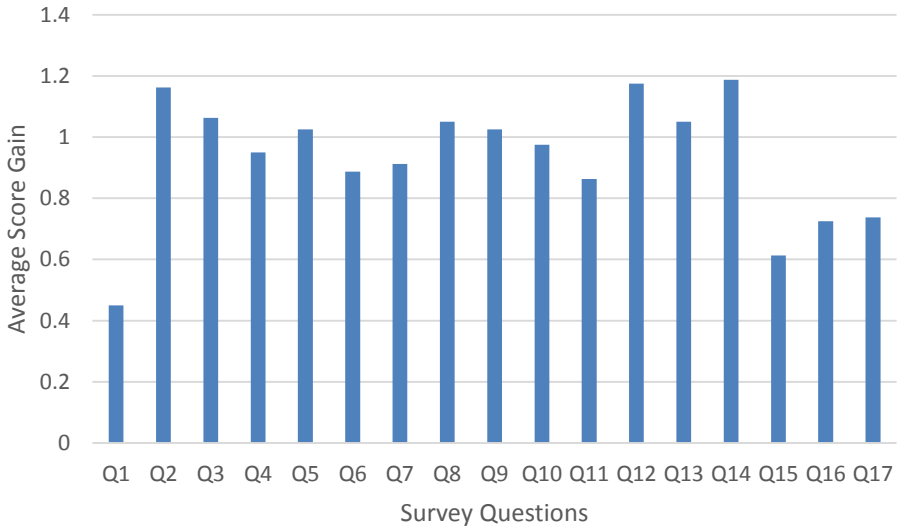

Figure 3. Pre/Post Survey Score Gain

Lessons Learned and Future Work

Incorporating entrepreneurial mindset materials in the freshman Introduction to Engineering course showed positive outcome based on pre/post survey results. However, feedback from students was mixed. On one hand, there were students really enjoyed the entrepreneurial aspect

of the course. One student commented, “I have no entrepreneurial experience however I’m quite interested in such things and I believe the class is an effective fundamental class.” There was another student who said he joined an entrepreneurial business because of this class. On the other hand, there was student complaining “I was not very enthusiastic about the entrepreneurial side of this specific class. The ideas were intriguing, but I didn't take this course to learn that, I would rather have had that as a separate class.” One possible way to address this dilemma is to put more emphasis on engineering design process, which is the main thread of the Introduction to Engineering course, and introduce entrepreneurial mindset concepts as techniques to help design a better product which customers actually want.

In terms of letting students identify pain point and define their own project, there were pros and cons to it. There were students who raved about the freedom of choice for their design project: “I like that my group was given the ability to construct our own problem and we were able to solve our problem with the complete support and approval of the professor.” They thought “the creative opportunity that was provided with this course was refreshing”, and “(it) promoted creative thinking and use of skills that I wouldn't normally think to use”. On the other hand, there were issues related to open-ended design project. First, sometimes students were unsure what project to choose and they were afraid of failing and “worrying about the grading for the final project”. Another issue was student proposed projects had different complexities. For example, there was one team who designed an earbud wrapper using CAD and 3D printing. In contrast, another team designed from scratch a full-fledged remote control toy bulldozer to let kids have fun picking up dog waste in the backyard. The two projects obviously required different time commitment from the students. The first project albeit comparably simple did evolve through four versions based on customer feedback exemplifying the entrepreneurial mindset. Due to this variation in difficulty levels, there were students complaining the project wasn’t “challenging” and it didn’t “expand dramatically their skill set”. On the other hand, there was complaint such as “The entrepreneurial mindset was interesting, but I would have preferred for the project to be a more traditional one as this was pretty intense for a 100 level class.” Possible solution to this problem could involve restructuring the course to have two projects instead of one. One project would be a well-defined one and emphasize on “technical” competencies. The other project could be open-ended and a disruptive technologies type promoting creativity and entrepreneurial mindset. Also it should made clear to the students the grading criteria of the project. Going through the design process is more important than the final outcome, therefore failing is acceptable. Persisting through and learning from failure is part of the value creation process.

Conclusion

Entrepreneurial mindset was taught in a semester-long freshman Introduction to Engineering course. It was tightly integrated in an open-ended design project and intertwined with the discussion of engineering design process. Curiosity, connections and creating values, the KEEN’s 3Cs framework, were emphasized in the design project through pain point identification, market research, and value creation with customer involvement. Comparison of pre and post survey showed increased student awareness of entrepreneurial mindset concepts. Future work includes continuous improvement of entrepreneurial mindset materials and potential course restructuring.

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