Cultivating an Entrepreneurial Mindset in an Undergraduate Engineering Statistics Course Using Project-based Learning

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Abstract— **There is resurging interest in the engineering education community in entrepreneurial activities and the development of an entrepreneurial mindset (EM). According to the KERN Entrepreneurship Education Network, facets of an EM include curiosity, an emphasis on creating value, and the ability to make connections. While extracurricular activities are the primary mechanism by which this topic has been introduced to engineering students in the past, it is beginning to show up in more formal ways. The literature includes examples many of how to promote entrepreneurship and an EM in traditional project-based courses engineering students take (senior design, etc.); but there are fewer examples and best practices for cultivating an EM in a fundamental engineering course--namely engineering statistics. Project-based learning (PBL) is a pedagogical approach that involves active learning directed at investigating and solving complex, real-world problems-- and it is an approach that is underutilized in math-intensive engineering courses. The purpose of this study is to demonstrate how PBL can be integrated into an undergraduate engineering statistics course to promote an entrepreneurial mindset and investigate its impact on student learning. Six teams of engineering students in a 200-level engineering statistics courses responded to the challenge of presenting "A World Without Statistics". Teams were given liberty to choose any topic of interest and received funding to support their idea. The resulting projects creatively conveyed what the world would be like without statistics using a myriad of topics: sports, resilient infrastructure, online data, robotics, artificial intelligence, and manufacturing. Evidence suggest that curiosity, an emphasis on understanding the value of statistics, and the ability to make connections were critical to each team's success. This paper provides an overview of the assignment, and examples of students' work. Such insights have the potential to not only influence the way we cultivate an entrepreneurial mindset in fundamental engineering courses, but also shed light on innovative ways to integrate other multi-faceted topics in engineering education.**

Keywords— ***entrepreneurial mindset, engineering statistics, project-based learning***

I. Introduction

Today's social and technological challenges call for a new type of engineer, and various stakeholders have outlined a myriad of outcomes they expect the engineering graduate to possess. For example, ABET has outline 11 student outcomes that include attributes which speak to technical competence, design thinking, and an understanding of the non-technical implications of design [1]. On the other hand, the National Academy of Engineering's widely-revered *Engineer of 2020* report [2] includes outcomes that overlap with ABET's expectations, but also mentions others that are distinct (e.g., leadership, resilience, flexibility). Moreover, industry is calling for a T-shaped engineer– an engineer with a depth of technical expertise and a breadth of knowledge in other areas [3]. At a local level, each engineering program –oftentimes with the input of an advisory board and alumni— sets a vision of the kind of engineer they want to graduate from their program; this translates to a unique set of outcomes as well. These are four examples of four stakeholders that have a seat at this proverbial "table". All of these stakeholders play an important role in the engineering ecosystem, and their perspective on what tomorrow's engineer should look like matters.

In an ideal world, all engineering curriculum would address all key stakeholders' expectations throughout the curriculum AND balance this with students' expectations to receive a high-quality education with an efficient use of resources. However, this convergence of expectations presents a highly-constrained design challenge for engineering educators. As with all design challenges, however, there are multiple solutions. While some programs might opt to cherry-pick which stakeholder's view to prioritize and ignore others' expectations, another option is to get creative about how to design learning experiences that optimize the number of outcomes it satisfies. Some might even explore ways to cultivate the attitudes and perspectives – or mindset—that undergirds the collective set of outcomes and strive to weave that mindset throughout the curriculum. Thus, by designing a series of learning experiences that cultivate a particular mindset, we inadvertently promote the development of a myriad of learning outcomes. This sounds like an optimal solution!

The KERN Family Foundation's "3 Cs" [4] of the entrepreneurial mindset –curiosity, creation of value, and connections—are the tenets of a mindset that would be useful for engineering graduates to possess and can be woven throughout the curriculum to promote the attainment of many learning outcomes. In a typical engineering curriculum, the development of technical expertise is oftentimes associated with certain types of courses while the development professional skills are the primary focus of others—and rarely do the two meet in a single course. However, it is reasonable to suggest that designing a course in a way that embeds the entrepreneurial mindset (EM) into it will lead to better attainment of the desired learning outcomes. Unfortunately, there is a lack of models or best practices for performing such an integration. This project serves as a case study on how to approach this integration.

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II. Historical Context and Examples of EM Integration in Engineering Education

The current emphasis among members of the engineering education community on entrepreneurship and associated ways of thinking is not new. Broadly speaking, engineers design artifacts, objects, and systems that benefit humanity. As Ferguson [5] describes in *Engineering and the Mind's Eye,* this type of work not only involves science, but also design, creativity and communication. He offers Leonardo Da Vinci as a paragon for engineers. When applying for a position, he "described his ability as a military engineer and a designer of siege apparatus.… [and in] times of peace, he could be an architect, sculptor" (p. 71). Based on this description and our modern conception of professions, Da Vinci would be called an engineer and much more. He had a well-rounded skillset that allowed him to be successful in a variety of contexts. He had a way of thinking that enabled him to excel at addressing a variety of societal needs. A similar way of thinking and way of being is what we expect of 21st century engineering graduates.

Engineering education has made great progress in supporting student learning in innovative ways over the last 100 years. One of the marks in the path of progress includes the shift from a hand-on/practical emphasis, to an emphasis on engineering science, to the current focus on an outcomes-based education. With an emphasis on outcomes (rather than particular skills or discrete knowledge) comes a focus on the broader attributes that we would like for engineering graduates to posse [6]. It is in this context that entrepreneurial thinking and entrepreneurship is situated.

There are a myriad of ways engineering programs promote entrepreneurship and cultivate an EM within students. For example, EM has been integrated into first-year engineering projects through hands-on activities and projects [7][8][9]; fundamental engineering courses (e.g., thermodynamics, programming) [10][11]; electives; and extracurricular activities [12][13]. There are a variety of ways EM get integrated into the courses. Some of the ways include asking students to solve a problem for a fictitious customer [14][15], designing learning experiences that require students to consider the business aspects of an innovation (e.g., market potential, business plan) [16][17]. In some courses, students identify the problem they will focus on, and/or interact with real customers as they work through the design process [11][14]. In summary, the value of EM among engineering students has been widely accepted among undergraduate educators; insights on how to imbed EM into engineering courses is an attractive next step for research directions related to this topic.

III. Purpose and Research Questions

The purpose of this study is to present a case study on cultivating an EM among engineering students via project-based learning in an undergraduate statistics course. Thus, the research question guiding this work is: *How can project-based learning be used to cultivate the entrepreneurial mindset among engineering student taking an undergraduate statistics course?*

IV. Conceptual Underpinnings

Two constructs undergird this study: insights on an entrepreneurial mindset and project-based learning. An entrepreneurial mindset can be directed to nearly any interest, idea or audience. Both of these ideas will be discussed individually before presenting connections between them.

The KERN Family Foundation is an organization that is dedicated to supporting a range of activities and initiatives that promote the development of an EM. KERN posits that an EM is characterized by "3Cs" -- *Curiosity, Connections,* and *Creating Value.* According to KERN, *curiosity* happens with students are empowered to constantly investigate the rapidly changing world to avoid the obsolescence of existing solutions [4]. C*onnections* focuses on teaching students "to habitually pursue knowledge and integrate it with their own discoveries to reveal innovative solutions" [4]. Lastly, *creating value* focuses on training students "to persistently anticipate and meet the needs of a changing world" as part of generating meaningful solutions [4].

On the other hand, project-based learning (PBL) is a pedagogical approach that involves active learning directed at investigating and solving complex, real-world problems. During the experience, students function as self-directed learners and work in teams to collaborate on solutions to open-ended challenges [18][19]. The use of PBL can increase students' motivation to learn, promote the development of creative skills and critical thinking, and can help them transfer the knowledge learned in the classroom to broader application scenarios. Moreover, the potential outcomes of PBL align with the 3-Cs of the entrepreneurial mindset. For example, students who must operate as self-directed learners have to be ***curious.*** Students who work on problems that have an authentic context are learning to keep a stakeholder's needs in mind when developing an innovative solution; this is a guiding element of ***creation of value.*** Lastly, students who know how to effectively leverage the expertise and insights of the team while working toward a common, and open-ended goal in PBL understand the value of making ***connections.*** Based on these conceptual ties between the two, we would argue that the inherent characteristics of PBL naturally lend themselves to the development of an entrepreneurial mindset (as it is outlined by the 3 Cs) regardless of the specific project objective(s).

Despite its well-documented benefits, PBL is rarely used in math-intensive undergraduate courses. One of the main critiques of of PBL is that instructors are not able to *cover* as much content as would be possible in the traditional lecture. However, if we assumed that the coverage of materials *is not the goal* of course, but instead that facilitating students' attainment of the course learning outcomes *is the goal*, it is reasonable to assume that there must be effective ways to integrate PBL to a math-intensive course without sacrificing the extent to which student attain the learning outcomes. In fact, because PBL can increase students' motivation to learn, PBL might be the underutilized vehicle for keeping students engaged throughout the process of learning a myriad of learning outcomes. The next section describes how PBL was used in this study to cultivate an EM in an undergraduate engineering statistics course.

V. Assignment Overview

Four mini-projects were added to an undergraduate engineering statistics course within an engineering program at a large southwestern institution. All four of the mini-projects were associated with the same learning objective: *By the end of this* *course, students should be able to articulate and defend the role of statistics in their engineering discipline, anticipated career, and the world.* During the ***first project***, students were required to re-write their admissions essay to answer the questions: Why Me? Why Here? Why Now? As part of the ***second project***, students worked in teams of 2-3 people to create a YouTube video that creatively expresses the role of statistics in their engineering discipline and/or anticipated career, and show how their discipline was linked to one of the 14 NAE Grand Challenges for Engineering. As part of the ***third project***, students had to design an experiment (around a paper airplane, catapult, or chewing gum) to evaluate the influence of varying factors a metric of interest (e.g., distance, flavor lasting time). As part of the ***fourth project***, students worked in teams of 3-4 to creatively convey a response to the theme "A World Without Statistics"; they presented their projects at the end-of-semester Innovation Showcase. While all of the projects include an emphasis on the 3Cs to varying degrees, the fourth project provided the greatest opportunity for students to showcase their wide-ranging interest in a variety of things (i.e., curiosity), make connections across ideas (i.e., connections), and defend the importance of statistics in some aspect of the world (i.e., reveal its value). Each of project submissions were evaluated using a rubric developed by the instructor. The next section provides six examples of how teams responded to the prompt, "A World Without Statistics". Each team presented their creative expressions at an annual event called the "Innovation Showcase". The *Innovation Showcase* is a campus-wide event that provides as opportunity for teams of students to showcase the projects they have worked on over the past semester and/or year. It is most common for senior design classes to participation. This half-day event is open for people on campus and in the community to attend. Oftentimes, the sponsors of students' projects and others in the community attend the event to see the outcomes of the students' efforts. It was not until this project that teams from a math-intensive course, foundational engineering course (i.e., statistics) participated in the *Innovation Showcase*.

VI. EXAMPLES OF STUDENTS' SUBMISSIONS

Sports Example: In response to the theme, "A World Without Statistics", one team of four students simulated a NBA draft that was not based on the players' past performance, but solely based on their appearances. With no information on how athletes would perform it became difficult to draft a winning team. Participants that walked up to their table during the Innovation Showcase created their team using a video game (in the absence of informaiton about past performance), and played a short game with their team. They were asked to evaluate the team's performance. Then, they were allowed to repeat the experience with informaiton about the players.

Infrastructure Example: One team decided to focus on the role of statistics in selecting materials when trying to develop reslient infractructure. To explore this idea, they team modeling and build four miniature bridges out of four types of materials; and tested the resilience of the bridges by adding various weights to see what would lead to a near-breaking point. They even went so far as to have different team members stand on strongest bridge to see if it would break; it did not. Thus, they let their curiosity run wild and saw the value of statistics when comparing the properties of the matierials and in analyzing data associated with testing the resilience of the bridges.

Robotics Example: One team showed how statistics on the size and flexibility of the average hand can inform the design of prosthetics. More specifically, they designed and 3D-printed a robotic hand. As part of doing the background research required for preparing the design, they discovered the value of having a large amount of data on typical charactertics of the human hand (e.g., dimensions, characteristics associated with its flexibility). They also learned about the data collection and analysis invovled in testing various designs of the robotic hand as part of finding the most comfortable design for those who need prosthetics.

Figure 1. 3-D Printed, Robotic Hand

Online Dating Example: Many around the world use online data websites to look for romantic partners, but few think about the role of statistics in facilitating this matchmaking. One team decided to respond to the prompt, "A World Withouth Statistics", by simulating what an online data website would be like in the absence of data to drive the recommendations the website offers. The team studied and hypothesized a program without algorithms to match and discovered that without the algorithms people were most likely to dislike their recommended match. The users had fun participating in the randomized date-matching process while also learning about the importance of data and algorithms that (should) drive the online matchmaking.

Machine Learning Example: One team used MatLab and Lego Mindstorm ® to write a program that would detect and communicate the color of the object placed in front of the sensor The program involved the use of a RGB camera which identifies the difference in Red, Green and Blue in a spectrum—and thus identifies a color of an object. The team created a graphical interface which would ask the user which setting to use to determine the color appearing in front of the camera. The program had two settings of operation:

> *Setting 1*: Use data from 2 millions data points given by a database.
>
> *Setting 2:* Use variable data created by the user. In this mode, the user gives the program the data points, thus creating a new database for the program. These data points tells the program which color it was looking at.

Users engaged with the program by creating data points and observing how different quantities of data inputs influenced the results. Needless to say, the program was detected the color more accurately more often when using the setting that involved the larger dataset. This was a meaningful insight for both the team that developed the program and the users that participated in ths experience.

Manufacturing Example: Although we use manufactured goods on a regular basis, this team wanted to highlight some of the behind the scenes work that goes into having a product meet the desired specifications. More speficially, one team's project emphasized how the tolerance –upper and lower limits around a desgn specification—is integral to the manufacturing process. They did by designing a 4 types of puzzle pieces of various shapes that looked like they would fit into a mold; printing the pieces on a CNC machine using wood; and creating a puzzle game for users to engage with. By looks alone, it appeared that the pieces would fit, but it was not until the users started playing with the pieces did they realize that many of the pieces were slightly larger that what would fit in the opening. Both the team that designed the puzzle and the users who engaged with it left with a better understanding of how statistics around the upper and lower limits of design specifications matters if you want manufactured products that meet a desired characteristic.

VII. CONCLUSION

There is a renewed interest among members of the engineering education community in developing engineers that possess an entrepreneurial mindset. One of the ways in which EM is characterized in by KERN's "3Cs"-- curiosity, connections, and creating value. This study presents a case study on an EM was integrated into an undergraduate engineering statistics course using project-based learning. The results include an overview of how six teams responded to challenge to present "A World Without Statistics". Teams were given liberty to choose any topic of interest and received funding to support their idea. The resulting projects creatively conveyed what the world would be like without statistics using a myriad of topics: sports, resilient infrastructure, online data, robotics, artificial intelligence, and manufacturing. Through the execution of the project, teams explored interest in a wide variety of ideas and came up with creative ways to communicate them. They made connections across topics that may not naturally come to mind when thinking about the importance of statistics in the world. By the end of the project, they understood the value of statistics and were able to communicate its value to others—and the EM helped them achieve this learning outcome. Anecdotal comments from teams during the Innovation Showcase included an emphasis on the importance of the 3Cs in this learning experience. These are just a sample of the projects presented in the course, and are only examples of what engineering students can come up with if given the opportunity to engage in learning experiences designed to cultivate an entrepreneurial mindset. Future work includes scaling this approach to other sections of engineering statistics and other foundational courses. Insights from this study and others like it have the potential to not only influence the way we cultivate an entrepreneurial mindset in fundamental engineering courses, but also shed light on innovative ways to integrate other multi-faceted topics in engineering education.

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