A Pedagogical Approach for Developing an Entrepreneurial Mindset in Engineering Students

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Introduction

Today's modern technology-centric world faces unique challenges that need forward-looking and transformational solutions, rather than incremental ones. Solving these challenges requires training a new generation of engineering students who are innovative and risk-takers and who think beyond traditional engineering approaches. In fact, many institutions of higher education offer courses and programs that are specifically designed with this goal in mind. While initially the main objective of entrepreneurship education was encouraging students to create new ventures, more recently there has been a shift in focus to a broader concept which emphasizes entrepreneurship as a way of thinking and behaving [1]. A student with this mentality would not only be successful in developing startups and ventures but can also take the creativity and self-confidence to any other job in industry or academia.

Developing an entrepreneurial mindset and building self-confidence can (and should) become an integral part of most, if not all, engineering courses at the graduate and junior/senior undergraduate levels. This can be achieved by facilitating learning by thinking, collaborating, and doing (as opposed to the traditional subject-based learning) through carefully designed activities, projects and case studies. Further, the students can be trained to develop a risk-management strategy to undertake an idea or concept and turn it into a business.

Developing an entrepreneurial mindset requires changing from the traditional subject-based learning to more interactive and collaborative approaches such as problem-based learning (PBL) as well as case and scenario-based learning (CBL). In PBL, learning starts by exposing the students to a given problem, and results from the process of working towards the understanding or resolution of that problem [2]. Learning process in CBL follows a similar path; however, here students learn by playing a role in an evolving storyline [3], which to maximize effectiveness, should also contain a certain degree of ambiguity and uncertainty. Once the scenario is dissected and explored in detail by the instructor, the students can compare their thought process with the way an experienced engineer would have approached the scenario. This can significantly help them relate the theoretical content with real-world situations and examples, which can further assist with retention of the subject matter.

At the same time, self-confidence in undertaking a venture can be built by carefully designing venture development projects. Here, the students are asked to generate a business idea and would need to conduct all the necessary investigation and evaluation involved in generating a realistic venture concept and taking it through to the point of commencement of operations [4]. Since many of these investigation and evaluation tasks are relatively new for the students, certain training materials should be provided by the instructor. However, this should not be to the extent that the process be dominated by input from the instructor. Instead, the students should be given room to explore, make mistakes, learn from those mistakes and try something new. Another important aspect here is to ensure that the overall goal is not lost. It is not reasonable to expect the students to develop a new business idea and undertake the venture during just one semester. As such, the focus should be on what the students learn, rather than what they produce. Shifting focus to the process instead of the output also affects what is graded, e.g. instead of grading the business plan, the process should be graded [5].

The goal of this paper is to present pedagogical approaches to help with the above objectives. The case studies presented here have been designed with junior/senior electrical engineering students in mind, but can be applied to other disciplines or levels with proper modifications.

Project Approach

The pedagogical approaches proposed here are intended to help students achieve an entrepreneurial mindset and to train them on how they should conduct an innovative concept from inception to full development. This is done through customized course projects that have been developed for two undergraduate courses: “introduction to linear feedback systems” and “data science for electrical engineering.”

In the first case study, a problem scenario is presented that is ambiguous and not-well-defined. The students are hence encouraged to look for subtle clues in the problem statement and make connections between those and the technical concepts they learn in class. In the second case study, a full-scale entrepreneurial course project is designed to help the students learn how to pitch their ideas, craft a value proposition, seek and incorporate input from beneficiaries, develop a prototype and finally, build a proper business model that can help them put the associated risk factors into a proper framework.

Case Study 1: Developing an Entrepreneurial Mindset

This exercise was conducted at a junior/senior-level undergraduate course titled “Introduction to Linear Feedback Systems.” This is a core course for electrical and mechanical engineering students that helps familiarize them with the fundamentals of modeling, analyzing and controlling linear dynamic systems. A course project counts towards 25% of the overall grade and is presented to the class after the completion of lectures that cover time response as well as the steady-state response of dynamic systems. Historically, the project has been designed with two preliminary submissions and one final submission. During the first submission (which is the focus of this work), the students choose a system from a list of given systems (e.g. vehicle cruise control system, drone height control system, etc.), analyze it in open-loop, and identify proper design criteria based on the type of application. These could be requirements on step response rise time, settling time, and overshoot, steady-state reference tracking, steady-state disturbance rejection, or stability margins. In their preliminary report, the students are expected to choose a subset of 3 out of the design criteria listed above and justify their choices. A shortened sample description of the original problem statement is provided below (before intervention)[1]:

> In this project, we will consider a commercially available quadcopter. To control the height of the quadcopter, consider the ideal element description below, where F_r is the upward force generated by the four rotors and F_g is the downward force due to gravity. Damping due to air resistance is represented with a damping coefficient *b* (Fig. 1). As the first step, clearly articulate what the system input and output are, and explain in simple terms what you want your system output signal to achieve. […] In addition, you should now define three total specifications consistent with your control goals. Of these three specifications, you must select one each from at least two of these three categories: (*a*) transient response specifications (e.g., rise time, settling time, percent overshoot), (*b*) steady state specifications (e.g., final value, steady state error, disturbance rejection, sinusoidal steady state gain/phase), or (*c*) stability margins (gain margin, phase margin). Justify the specifications you have adopted.

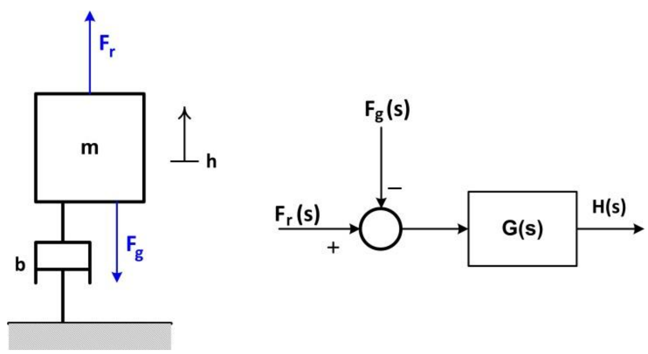

Fig. 1. Schematic diagram of the plant (first assignment – before intervention)

While this has been an engaging and effective exercise, the students do it after relevant discussions and examples in class. As a result, most teams quickly identify the crucial design criteria with no difficulty and most groups converge to the same answers. There is no ambiguity in the problem statement and the students can clearly assess the problem within the framework covered in the lectures.

As part of this pedagogical intervention, another preliminary assignment was added to the course project, with a due date prior to the discussion of transient and steady-state behaviors of systems in class. In other words, the students are provided with the problem statement before they know about metrics to quantify the behavior of dynamic systems. The goal was to provide the students with an ambiguous problem statement for which they were not specifically trained and to force them to try to decipher a given real-life situation in terms of engineering concepts. The preliminary assignment added as an intervention is as follows:

[1] The original project has been developed by Tyrone Vincent and Kathryn Johnson, at Colorado School of Mines.

> Read through the problem statement below. Then, articulate the problem in simple terms and explain why you think control engineering will be helpful in solving it.
>
> You and your friends have started a business to deliver pizza by drones. You have purchased a few commercially available drones and have programmed them so they can go to a specified location (with given coordinates), land, and safely release the pizza box. You have managed to convince the owner of a local Papa Jim's pizzeria to test your system for delivering pizza to their customers on campus. You planned to have the pilot test during the finals week, since this is the time you suspect many students on campus will be ordering pizzas when studying for their exams. The outcome however is a disaster! Papa Jim's receives 15 complaints the first day alone, ranging from pizza slices on top of one another, peperoni pieces stuck to the box lid, damaged boxes, to pizza dropped on the roof. The restaurant owner is furious. Your team calls for an emergency meeting to investigate the problem. You test the release latch of the drones and they all seem to be working fine. What do you suspect the problem is then?
>
> As part of your initial report (no more than one page), describe in simple terms what you suspect the problem is (Hint: go through the list of complaints above and think about the way the drones may have been navigated along the desired trajectory). Be as specific as possible. Discuss what evidence in the problem statement has led you to these conclusions.

The issues listed above are related to realistic behavior problems associated with the movement of the drones, e.g. moving up or landing too fast (i.e. rise time too small), releasing the pizza box too soon (i.e. non-zero steady-state error), experiencing too many oscillations (i.e. too much overshoot), not being able to reject disturbances such as wind, not having sufficient stability margins, etc. These topics are then discussed in class after the submission due date of the first assignment. During each lecture, appropriate reference can be made to the project to help the students connect the new concepts they learned to the project problem statement.

Case Study 2: Project-Based Training for Venture Development

This exercise was conducted at a senior-level undergraduate technical elective course titled "Data Science for Electrical Engineering." This is an introductory course to data science, with specific focus on electrical engineering, where the students learn the basics of data pre-processing and statistical decision making, along with fundamentals of descriptive and predictive analytics using regression, classification and clustering techniques. A group-based project was designed to walk the students through various steps of developing a business concept and presenting it, conducting initial market studies, developing a business model (cost, revenue, target customers, etc.), building multiple prototypes, and finally, presenting their developed concept to a group of advisers from industry. The objective behind this exercise was to teach the students a systematic way through which they can assess and manage risks associated with developing a new business idea/concept.

The course project required the students to complete the following steps (in a 17-week semester). Mini lectures (10-15 minutes each) were given in advance in order to teach the students about the requirements of each of these steps.

- Form teams, develop an idea and give an elevator pitch (week 4, 10 points)
- Develop and submit a business model using business model canvas (week 6, 10 points)
- Present their "pretotype" (week 8, 15 points)
- Submit five beneficiary interviews (week 10, 15 points)
- Present their updated business model pitch based on the feedback received from instructor as well as beneficiary interviews (week 13, 10 points)
- Present their updated prototypes (week 16, 30 points)
- Final pitches to a group of industry advisers (week 17, 10 points)

Elevator Pitch

During a practice mini lecture, the students were trained on giving a proper elevator pitch (up to 3 minutes long). It was emphasized that the goal of the pitch is to convince the audience that: the problem you are addressing is important, you offer value beyond what there is in the market, and you are the man/woman for this job. Examples were provided to underline the importance of an interesting and relatable "hook statement" to help engage the attention of the audience. The anatomy of a good pitch (see Fig. 2) was discussed both as a model as well as a rubric for how the pitches would be graded.

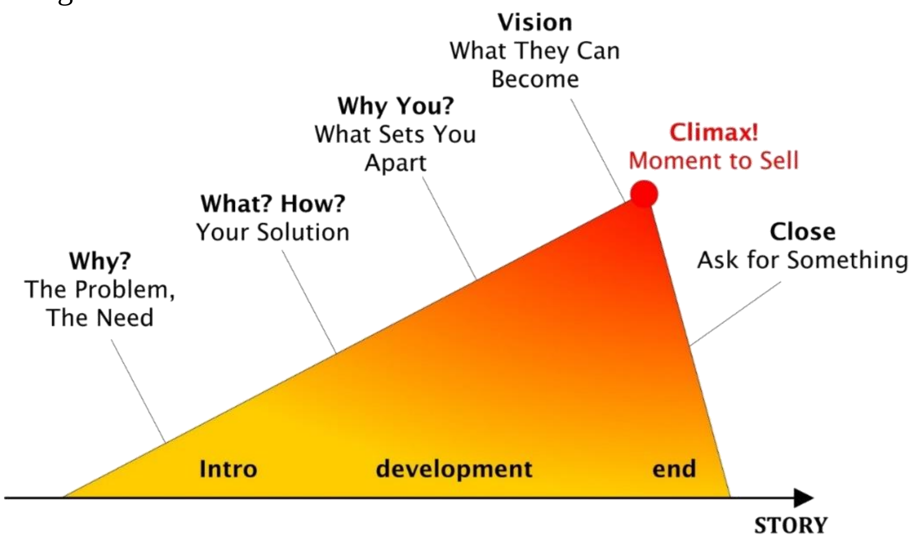

Figure 2. Anatomy of a good elevator pitch

The guidelines provided to the students were as follows:

- State the Problem: make it personal so that anyone can relate to it
- Explain the Need and Value: make it clear why the problem you are trying to address deserves attention
- Customer Value Proposition: talk about your solution, your team, your expertise, and the unique things you can offer
- Set a Vision: clarify to your audience what they can become/achieve by using your product/solution

- Close the Sale: do not leave the pitch open-ended. Always ask for something, which could be as simple as a follow up discussion over coffee or a more specific ask.

Business Model Canvas

The students were then trained on how to develop a business model. The objective here is to develop a model that clarifies their value proposition, and details how they will offer it, the general costs, and the potential revenue stream. To develop a successful business model, the teams were asked to give special attention to the following:

- Who is your target customer? What value will you be offering them?
- How and through what channels will you offer them this value?
- What types of activities/resources will you need to execute your value proposition?
- Do you envision that you will need to partner with anyone else?
- What are your operational costs? How about your revenue stream?
- What are your impacts on the environment and/or the society?

To do this, the teams were asked to use the business model canvas. This is a well-known tool that allows them to prepare for the above questions. Students were encouraged to print out the canvas on a large poster-size piece of paper and use post-it notes to share ideas in a collaborative way. During this brainstorming phase, they were also encouraged to meet with the instructor to fine tune some of their ideas. Figure 3 illustrates the schematic diagram of the business model canvas.

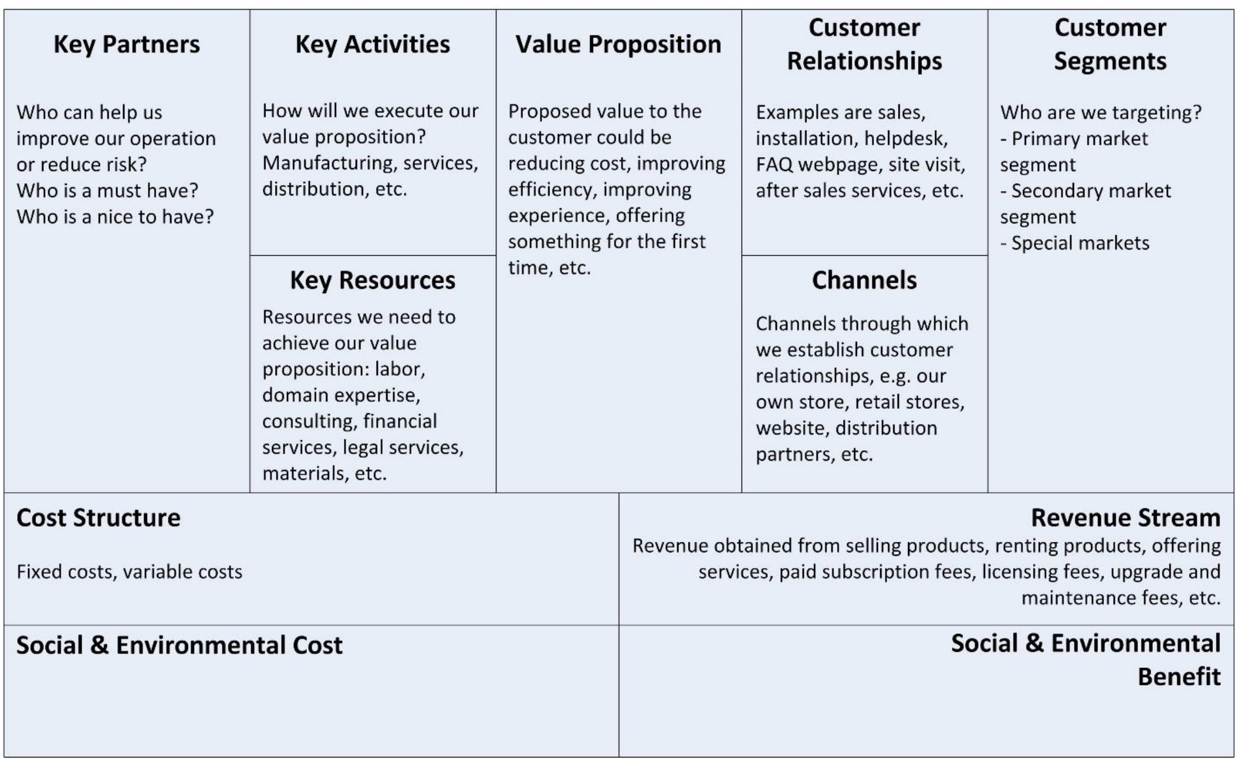

Figure 3. Business model canvas

Developing Pretotypes

The idea of “pretotyping” was developed by Alberto Savoia. It is a practice intended to solve a common problem faced by many startup companies [6]:

> Most people invest too much too soon to develop a first version of the product with too many features and too much functionality. They presume they know what people want and assume that if they build it right, people will want it. Pretotyping is testing an idea quickly and inexpensively by creating extremely simplified, mocked or virtual versions of the product to help validate the premise that “if we build it, they will use it.”

Using pretotyping allows companies (or student teams in this case study) to fake it and test it before they make it. Once they receive positive feedback on their “fake” version of the product, they will know that it is the right product to make and can then dedicate resources to building it.

Examples were provided to the students in order to provide them with ideas on how they can pretotype their product. Some examples from [6] that are discussed in class:

- Mechanical Turk: ideal for situations where you can replace costly, complex or yet-to-be-developed technology with a hidden human being performing the functions, e.g. IBM’s speech-to-text experiment
- Pinocchio: suited for when size, shape, weight, portability, etc. are important and one’s imagination can be used to fill in the blanks, e.g. Jeff Hawkins’ wood block Palm Pilot
- Minimum Viable Product: a working prototype with bare minimum features
- Provincial: suited when major costs are associated with scaling, not functionality. Therefore, the scope can be limited to a small subset of the ultimate target market, e.g. testing a restaurant app in a city first before taking it national
- Fake Door: As an example, in developing a web product, one can pretend a feature exists in order to see if anyone clicks on it, e.g. before writing a book, advertise it in forums with a link saying “for more information click here”

An important ethical point was made to make sure the students are aware of the fine line between pretotyping and fraud, and the importance of making truthful claims about their products and understanding the fact that at some point in the future, their pretotypes are expected to become fully working products. Discussions were held in class to emphasize that it is acceptable for the teams to start with a limited functionality pretotype, as long as their claims about what the final product can do are scientifically sound and achievable, e.g. one cannot make a mock pretotype of a time machine, since the science behind it is not proven. The importance of this aspect was underlined especially for situations where money is raised, along with the fact that the investors must be aware of where in the process the company (team) is and the timeline for full productization.

As the expectations from functionality of a pretotype are minimal, the pretotypes were graded in a binary fashion, i.e. teams received full marks if they presented a pretotype.

Beneficiary Interviews

With their pretotypes ready, the teams were asked to interview at least five potential customers (beneficiaries). This timeline was intentional to make sure that teams do not spend too much time or other resources on a product that may not have reasonable market appeal. Teams were given the following guidelines for conducting their interviews:

- Your goal is to understand the problem and relate to the potential customer,
- If possible, go for the main target who is the decision-maker (for buying/adopting or not buying/adopting your product), not someone close to them,
- Interview people individually. Interviewing several people at the same time creates a focus group that could lead to anchoring,
- Do not discuss your solution. Try not to sound like a salesman/woman,
- Let them talk. Ask them what their needs are and why meeting those needs is important to them.

To help them collect relevant data, a modified version of an empathy map was provided to the teams (Fig. 4), along with a list of possible questions to ask:

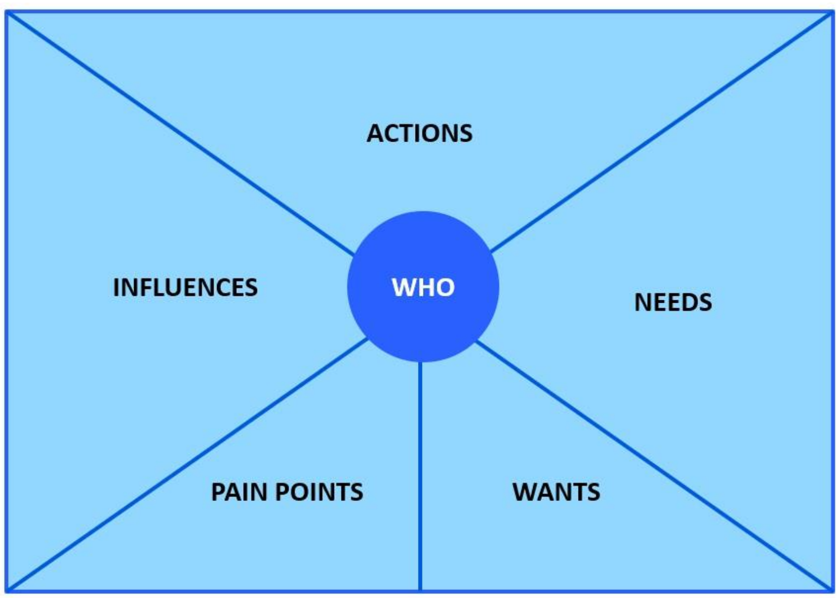

Figure 4. Template for empathy map

- Who: Who is the person we are interviewing? What is their role? What level of power do they have in terms of decision making?
- Actions: What do they do today? What can we imagine them doing in the future?
- Pain Points: What are their fears? What frustrates them about their current situation?
- Wants: What are their wishes and wants? What are they trying to achieve?
- Influences: What do they see/read/hear about how others are approaching the similar problem? What people or factors influence their actions?

- Needs: What do they need to do differently? How do they/we know if they have been successful?

Based on the outcome of the beneficiary interviews, the teams were then asked to update their business models if necessary, e.g. change their value proposition, their cost/revenue streams, etc. Also, they were encouraged to use the information obtained through these interviews when they develop their partially working prototypes. The prototypes did not have to be full functionality models, but the teams were expected to show features in their prototypes that utilized data science related concepts they had learned in class.

Results and Discussion

Case Study 1

This case study was implemented in the junior/senior-level undergraduate course "Introduction to Linear Feedback Systems" in fall 2019. A total of 40 students, divided into 12 groups, submitted the preliminary project assignment. The groups picked different evidences listed in the problem statement to brainstorm the possible root causes. Although the concepts of stability, time response (rise time, settling time, overshoot) and steady state response (steady state error, disturbance rejection) had not been discussed in class, most groups identified issues such as drones flying too "erratically", not being able to handle turbulence, accelerating or decelerating too fast, etc. During post-test (i.e. follow up project reports submitted after the discussion of above topics in class), groups were asked to revisit their preliminary reports and connect the issues they had identified to topics covered in class. All groups correctly completed this assignment and accurately identified issues related to stability, transient behavior and steady state behavior.

Table 1. Student responses in case study 1

Evidence Considered	Possible Root Causes (Related to Control Theory)	Root Causes Identified by the Groups*	No. Groups Identifying the Issue
Pizza slices on top of each other	Poor stability Rise time too short Overshoot too high Lack of disturbance rejection	Lack of stability/flying too erratically (5) Drones fly too fast with high acceleration when ascending/descending (2) Impact of turbulence (2) Drones are turning too abruptly (1)	9
Peperoni stuck on the pizza box lid	Overshoot too high Landing rise time too short Lack of disturbance rejection	Lack of stability (1) Poor stability in landing (1) Drones hitting objects Impact of turbulence (1) Landing too fast (4)	7
Pizza boxes dropped on rooftops	Steady state error in height control	Flying altitude too low (1) Inaccurate GPS data (6) Pizza holding device not maintaining proper force/not releasing at the right time (1) Drone running into objects (2)	9

		Drones having problems navigating in inclement weather (1)	
Pizza boxes being damaged	Poor stability Overshoot during landing	Poor stability in landing (2) Drones hitting surrounding objects (5) Impact of turbulence (1) Pizza dropped off too close to the building (1) Pizza dropped off at high altitude (1)	9

*Number in parenthesis indicates the number of teams that listed the root cause

Overall, the exercise was successful in forcing the groups to interpret a given event in terms of engineering systems. Compared to previous semesters (without the intervention proposed), the students showed more interest in classroom discussions when covering the relevant lectures.

Case Study 2

This case study was implemented in the undergraduate course "Data Science for Electrical Engineering" in spring 2019. The course is a technical elective, mainly enrolled by senior undergraduate and graduate students. A total of 13 students enrolled in the class and formed 5 project groups. During the initial round of elevator pitches in week 4, teams proposed ideas related to energy management in smart homes, automated control of appliances and loads in a smart home, a smart system for controlling traffic with autonomous vehicles, an app to assist a golfer with her/his shots, and a software for identifying faults in an oil pipeline. During week 8, all teams presented their pretotypes, which included very limited or no functionality models of what they had envisioned. The "pretotypes" consisted of two webpages with inactive buttons and links, an Arduino controller which was not connected to any devices, a computer app with no features (i.e. mainly a screenshot), and a Microsoft Excel file.

In week 10, teams submitted their beneficiary interview forms. Some groups had had an easier time finding the right "potential customers" and had conducted more interviews, e.g. the groups working on smart home related solutions or the golf app. On the other hand, some groups had faced challenges finding the right beneficiaries, e.g. the group working on the traffic control solution. The outcome of the beneficiary interviews was reassuring for most groups and convinced them that they were on the right track. The only exception was the group working on the traffic control solution, who decided to change their project completely. Part of this decision was low initial level of interest obtained through the beneficiary interviews. They changed their product to a smart alarm clock instead. This was a significant lesson learned for the entire class and further underlined the importance of building a "pretotype" followed by beneficiary interviews, so that the team can receive feedback early, before spending too much time, energy and/or capital on developing a product that may not receive significant interest in the market.

During the first run of the elevator pitches, the "asks" by the teams were generally arbitrary and not justified, i.e. most asked for large sums of money as initial investment without justifying the need. By the time teams had developed and pitched their business models, the requests were noticeably more reasonable and justified.

Finally, during week 16, teams presented their prototypes. These were still limited functionality models; however, the teams had been asked to make sure they implement one or more data analytics models and algorithms. As a result, various regression, clustering, classification and deep learning algorithms had been adopted and implemented by the teams. For proof-of-concept purposes, and due to lack of access to real-life data, teams were allowed to simulate data for training and testing purposes. This was necessary to ensure that the projects can be completed and tested within the given 17-week timeframe.

The last lecture was dedicated to the students presenting their expanded business model pitch (that covered their initial elevator pitch as well as the highlights of their developed business models) to a select group of advisers and investors from industry. The overall feedback was positive with some initial conversations about potential investments; although, no firm commitments had been made by the end of the semester.

Overall, this exercise led to positive results and favorable feedback from the students. Although admittedly it would have been more effective to conduct the experiment over a longer period of time (i.e. more than one semester) in order to provide the students with more time to finish the tasks. While interactions with the students during and after the class indicated genuine interest in this exercise, no student team decided to pursue their project/idea after the semester ended.

The final remark about this exercise is related to grading. Since the focus of the project was for the students to learn how to undertake a venture project and how to assess and manage the associated risks, their submissions were graded based on how closely they had followed the process, rather than the actual output they had produced.

Concluding Remarks

The case studies presented in this paper are intended to help develop an entrepreneurial mindset in engineering students and build their self-confidence so they can undertake a venture. Naturally, these exercises cannot necessarily lead to creativity and innovativeness, but can help develop and encourage thinking outside-the-box. Despite having novel and interesting ideas ready to be taken to the next level, many students are often discouraged or intimidated by what they see as a daunting road ahead. Getting proper training may not reduce the risks associated with an entrepreneurial endeavor, but it can certainly change the way the students assess and manage those risks. The goal is for the students to understand that there is a difference between being blindly adventurous and taking calculated risks. The latter is what an entrepreneur does through a series of steps. The venture development training presented in this paper tried to put this into a concrete multi-step framework.

Acknowledgment

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