Generating Start-up Relevance in Capstone Projects

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1. Introduction

Accreditation Board for Engineering and Technology (ABET) requires students to complete a capstone design experience that prepares them for engineering practice through team-based projects incorporating the knowledge and skills acquired in earlier course work [1]- [4].

While capstone course pedagogy differs widely from one program to another, in all cases, students are expected, through the process of completing the capstone project, to understand design constraints, such as economic factors, safety, reliability, ethics, and social impact. In addition, students are expected to learn about design process and methodology, team building and project management, as well as, formulation of design problems and alternative solution.

Over the past two decades engineering programs nationwide have developed several different approaches to satisfying these ABET objectives [11]. The authors in [5], for example, explore the various impacts of single versus multi-semester long capstone projects. Multidisciplinary teams and projects develop communication, teamwork, and project management skills, in addition to engineering skills [6]-[7]. Service-learning pedagogy in the capstone course has gained considerable popularity over the past decade and focuses student teams on solving societal problems in partnership with a non-profit organization [8]-[10]. Campus Compact lists several programs in its service-learning resources for engineering [9].

Many larger engineering programs have developed partnerships with industry or have created start-up programs that provide the real-world problems, the resources, and the lab environment for students to learn through real-world experience. These programs emphasize industry-sponsored capstone projects, which place students in the position of having to solve a problem for a client, often using resources provided by the client. For example, over the last twenty years, the Learning Factory at Penn State has become one of the largest college-wide, industry-sponsored capstone design programs in the nation [12]. At the University of North Texas with over 350 engineering students graduating each year, corporate partners play an important role in supporting capstone projects through providing funding and mentorship [14]. And a fourth pedagogy in recent years is to foster the spirit of entrepreneurship and innovative product development [13]-[15]. For example, since 2007 twenty private colleges and universities with ABET-accredited engineering programs have been funded by the Kern Family Foundation to participate in the Kern Entrepreneurship Education Network (KEEN) [12].

At the Electrical Engineering Department of Sonoma State University, our challenge is that we are located in an environment without the rich pool of companies necessary for such opportunities and we do not have the funding for realistic lab or start-up ventures across multiple projects. Therefore, the above approaches are difficult for many small departments, including ours, that are unable to find sufficient corporate or non-profit partners for each capstone project or the funding to support start-ups.

In this work we describe an alternative practical approach for small engineering programs to fulfilling the ABET required capstone design experience that (1) takes advantage of techniques taught to start-ups to generate ideas relevant to customers while (2) working with limited equipment and resources. Therefore, our contribution in this work is to develop an approach that exposes students to the challenges of product development within the types of realistic economic, societal, and sustainable situations of the above approaches but that does not depend upon the resources available to larger universities with greater industry presence and support.

Similar to industry-sponsored and entrepreneurship-oriented programs, we emphasize on a number of needs, including the following: (1) the need to generate a product that is relevant to both a user and the economy rather than just interesting to the student team; (2) the importance of commercial viability; (3) the need for our students to come up with relevant ideas on their own. In order to achieve these goals with limited resources we draw on *entrepreneurship education* to develop four entrepreneurial *processes* (ideation, customer discovery, client validation, and commercial viability) that teach the above concepts. Furthermore, we draw on pedagogical research in experiential learning [26] and scaffolding [18] to "package" the processes to support student learning with a minimum of resources.[1] It should be noted that n our approach as each of the processes can be implemented independently, different programs can choose to implement only those that fit best with their program's logistics and goals.

We emphasize that the four entrepreneurial processes we have developed and integrated into our capstone curriculum are designed to familiarize our students with an *early product development* phase of a *start-up*, where limited resources both in terms of the team and the facilities are available. We believe, offering such realistic experience offers two key educational advantages: (1) turning our resource constraints into an advantage by creating a relevant experiential learning environment with its own set of challenges for the students to solve; (2) imbuing our students with attributes that are highly desired by employers, while meeting ABET requirements (see Appendix B).

Furthermore, in our approach we take advantage of *entrepreneurship education* to teach students to transform their engineering knowledge into economically relevant engineering practice. The entrepreneurship education is explicitly designed to emphasize the interaction between design techniques and techniques to incorporate the types of economic constraints engineers must address. For example, in our four entrepreneurial processes, the Creative Idea (ideation) Process develops student abilities in both generating creative ideas to solve real-world problems and team building. The Customer Discovery Process [16] and the Client Validation Process guide the student in how to solicit and incorporate feedback from users and customers through the design and prototype phases respectively. The Commercial Viability Process shows students what they need to know to determine whether a product can make an economic contribution to the company and to society.

The rest of this paper is organized as follow. In Section 2 we discuss the change in the capstone course structure. In Section 3 we elaborate upon the integration of the entrepreneurial processes and the pedagogical scaffolding techniques used. Section 4 reports the outcomes, Section 5 describes ongoing challenges along with proposed improvements, and Section 6 concludes.

2. Capstone Course Structure

As required by ABET, the capstone project is a mandatory course for all students seeking an Electrical Engineering (EE) degree at Sonoma State University. In the past, the EE capstone project used to be a 4-unit single-semester course with an assigned course instructor. The class

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[1] The templates used to provide the scaffolding are available from the authors.

would meet on Fridays for three hours each week to discuss general student concerns, questions, and design issues. In addition, all the students were expected to meet with the course instructor for 30-45 minutes at least once every week to discuss their progress and submit their individual assignments. On Friday classes the course instructor would provide structured lectures and assist all 12-20 enrolled students to create teams, find project ideas, and establish project plans. Under such course structure, each student team was expected to submit a detailed project proposal by Week 5 of the semester. The students were asked to submit a detailed system design report by Week 9, and finalize their prototype and documentations, including the final presentation, during Week 16.

This approach proved to be very challenging for various reasons, including the following: (1) the coordinating faculty did not necessarily have the required expertise in all the areas covered by selected student projects; (2) having only four months to complete the senior design project, from idea to product, was not sufficient for students to produce a quality work, prepare the required documentations, and demonstrate their understanding of engineering knowledge and apply it to practical problems; (3) in many cases, due to lack of time the students had to choose a project from the existing project pool rather than generating an innovative project idea of their own.

As the result, the Department decided to change the capstone course structure and split it into two consecutive courses. The first part of the capstone course (ES 492) is a one-unit planning course in Fall where students are expected to define a problem statement and a product idea, create a team, specify their customer base, and detail their development plans. Following a formal presentation at the end of the semester, successful teams can enroll in the second part of the capstone course (ES 493) in Spring. In the 3-unit ES 493 course the students are expected to complete their working prototype, fully test and analyze it, estimate the manufacturing cost, and examine its market potential. We note that the focus of our capstone course is to build prototypes to solve real-world problems with the ideas initiated by students and supervised by an industry mentor and a faculty. Therefore, students interested in research, simulations, modeling, or theoretical study are encouraged to take a different course specifically designed for such activities. The rest of this section describes the timing and logistics of the new capstone course structure.

2.1. First Part of the Capstone Course

Appendix A shows the general weekly activities and assignments for ES 492. The course will meet once a week for three hours and all students are required to participate. In each weekly class, the instructor provides a brief lecture, followed by some hands-on activities, or a talk by a guest speaker regarding potential project ideas in various areas, such as wearable, biomedical, or personal communication technologies. The guest speakers are often faculty members throughout the School of Science and Technology at Sonoma State University, technical professionals from the local industry, members of the campus community, such as library or police department, or individuals from the local community with specific technical needs, such as non-profit organizations.

The course covers general topics such as defining problem statements, engineering and customer requirements, mastering presentation techniques, building a successful team, understanding project management and identifying the milestones, learning about product qualification techniques, understanding customer discovery, and preparing a successful proposal. A faculty from the School of Business and Economics generally delivers the lectures relating to the customer discovery and importance of team building. During the final two weeks of the course, as indicated in Appendix A, we primarily focus on preparing the students for the end of the semester final Project Proposals. Each project team is expected to have a client to validate the project idea and its impact in the relevant industry, a faculty advisor, and an industry mentor.

Student teams are responsible to select their own client and industry mentor. The client is not a client in the typical sense but rather acts as an individual who may be interested in purchasing or simply using the product who can give the student team relevant feedback as they build the prototype. This allows students to experience the interaction required to ensure that any necessary changes still meet "customer" needs. We note that under the current two-semester capstone course structure, the students, and not the client, initiate the project idea.

The course grading is based on individual effort and team performance in class assignments, final documentation, and quality of team's final presentation. For the final presentation, all teams present in front of faculty members and members of the Advisory Board, who collectively decide on the quality of each presentation.

2.2. Second Part of the Capstone Course

The second part of the capstone course begins in Spring. The course mainly focuses on prototyping development, testing, and product validation. As such, there are fewer structured assignments than in the first semester. Instead, teams must meet the milestones shown in Table 1. In particular, during this semester each student team must meet with its faculty advisor on a weekly basis; minimum of ten meetings with formal minutes are requires. The students are also expected to meet periodically with their industry mentor and client. Other than the final presentation, the students meet as a class three times, as indicated in Table 1. The course instructor in ES 492 will be in charge of organizing these meetings.

Table 1: Capstone second semester activities.

Week	Activity
1	Course agenda review *
2	Meet with client (complete Key Features template)**
4 & 7	Meet with client (Client Validation & Revenue Validation templates) and industry mentor (Revenue Validation template)**
8	Midterm design review – submit project & budget update *
9 & 13	Business Lab (Commercial Viability Process) with business faculty partner *
12	Meet with industry mentor (Market Potential template)**
15	Final project demonstration and poster presentation *
16	Submit all your documents
* All teams must be present. ** Minimum of 4 documented meetings with the client and industry mentor are required.	

The course grading will be based on the following:

- Individual performance defined by the faculty advisor (30%);
- Team meetings with the industry mentor/client (10%);
- Quality of the final team report (20%) assigned by one or two faculty members;
- Quality of the final presentation and prototype demonstration (30%) assigned by faculty members and members of the Industry Advisory team.

At the end of the semester all students are required to complete a mandatory short survey and submit the Exit Interview questions in order to receive their final grade. The following subsection identifies the components that incorporate the entrepreneurial approach and the pedagogical techniques used to implement them.

Below, we list examples of capstone projects that students have completed. In each case students were directed by a faculty advisor, mentored by an industry advisor and continuously consulted their client.

Project	Web Page	Details
SenCell	https://sites.google.com/site/sencellssu/	Designing a solar powered, cellular enabled, and modular system that can monitor conditions of its surrounding environment and relay that data to an end user.
WIRD	WIRDssu.wix.com/WIRD	Integrating a smart smoke detector with a WiFi repeater to improve WiFi connectivity and notify users of a incident over the internet.
Passive Wireless Pavement Sensor	https://sites.google.com/site/passivewirelesspavementsensor/	Analyzing road pavement quality through nodes that have Geophone sensors. Data will be send wireless and save in a SD card that could be analyze through Matlab and Google maps.
SOMO	http://www.somossu.wix.com/home	A Solar Generator Control Unit, which monitors the outside environment and allows the generator to respond accordingly.

3. Entrepreneurial Integration

We take advantage of entrepreneurship education to teach students to transform their engineering knowledge into economically relevant engineering practice. While a startup goes through the same product development stages as does an established company - Ideation; Customer Discovery; Customer Validation; and Customer Creation [16] - its success is often more dependent on customer acceptance of a single product. Thus entrepreneurship education is explicitly designed to emphasize the interaction between design techniques and techniques to incorporate the types of economic constraints engineers must address. Specifically, we integrate four entrepreneurial processes across the two-semester capstone to capture the four key features found at the core of the various schools of thought in entrepreneurship education: (1) creative ideation, (2) team development, (3) meeting customer needs, and (4) commercial viability [16], [17]. Table 2 lists the four processes as well as how they fit within the structure of the capstone and the learning outcomes they deliver. The Creative Idea Process addresses both creative ideation and team development. The Customer Discovery Process and the Client Validation Process address meeting customer needs at different stages of product development. Commercial viability is addressed in the process of the same name.

Experiential learning has four phases: the concept, the application expectations, the experience, and reflection on the three prior phases [26]. We designed the implementation of each process to satisfy pedagogical scaffolding that supports these phases of experiential learning without taking significant time or resources away from the pure engineering needs of the course. Pedagogical scaffolding requires that each entrepreneurial process include mechanisms that ensure (1) a shared understanding of the purpose among participants, (2) a method for ongoing diagnosis of learning, and (3) a way to provide assistance tailored to the student's current need that fades until it is no longer needed [18]. Incorporating mechanisms for both (2) and (3) into the design of each process as described below provides sufficient support for the student to learn while making sure that the student leaves the process able to perform the task without the scaffolding.

The remainder of this section walks through each entrepreneurial process to explain the mechanisms that create the scaffolding and to elaborate on the importance and delivery of the learning outcomes.

3.1. Creative Idea Process

We designed the Creative Idea Process to deliver the learning outcomes associated with both creative ideation and team building. As indicated in Table 2, this process is made up of three cycles of the same set of activities. It is the act of experiencing multiple cycles that provides the learning. In the first cycle the faculty member models the process to provide the shared understanding necessary for scaffolding. The repetition in the next two cycles along with faculty monitoring provides the opportunity for ongoing diagnosis and for the necessary student-specific assistance which fades as the student asks fewer and fewer questions. By the time students complete the third cycle the faculty member has worked to ensure students achieve the five learning outcomes, thus providing them with the foundations for generating creative ideas and for effective teamwork. Below we briefly articulate the need for each learning outcome and indicate how the process delivers it.

Learning Outcome (1): Generate lots of ideas before choosing. Research in design thinking [17] and entrepreneurship [19]-[21] shows that brainstorming to generate many ideas before choosing one results in more creative and innovative ideas. Therefore, the process gives students practice generating ideas by requiring them to come up with three ideas each week. In our approach, by the time students finish the three cycles, they have generated nine ideas. Further, the requirement that each student provide feedback on the ideas generated by others allows them to experience many ideas and the different ways ideas approach similar problems.

Learning Outcome (2): Consider concepts that aren't usually associated. Research and experience in innovation [20] show that many innovative ideas occur at the intersection of two fields that previously had not been connected. The three cycles of the process expose students to many fields in a short period of time due to the different fields reflected in their own and other groups' ideas. This ensures that each student consciously considers multiple fields. making it more likely that connections across fields will become apparent.

Learning Outcome (3): Learn the importance of feedback. Obtaining and incorporating feedback early in the idea generation process is critical to creating a relevant product [16]. However, the fear of being ridiculed or failing is one of the biggest inhibitors to generating creative ideas [21], [22]. In the Creative Idea Process students experience the value of feedback from both sides. Because they are receiving feedback at the same time that they are giving it, they learn to provide feedback in a way that is more constructive and less negative. Consequently, they will be in a better position to recognize the value of the feedback they've received. Additionally, the practice of receiving feedback helps the students to embrace feedback rather fearing it.

Learning Outcome (*4*)*: Obtain different perspectives.* Another key to generating creative ideas is to consider the problem from many different perspectives [17], [19]. The process provides students with this experience in four ways: (1) it requires them to work in a team so that they must consider the perspectives of the team members, (2) it randomly assigns students to different teams each week so they learn to work with three sets of differing perspectives, (3) as givers of feedback they see the ideas generated by the perspectives of the other teams, and (4) as receivers of feedback they see what the perspectives of non-team members add to their idea.

Learning Outcome (5): Identify the characteristics of an effective team. There is no such thing as the "right way" to build a team but effective teams are able to communicate, have compatible skill sets (both technical and organizational), share a common vision or goal, and are built on trust [23]. The Creative Idea Process provides a basis for team formation through the random and changing group assignments. The random groupings offer students the opportunity to work with many of their classmates and, thus, allow them to identify the classmates with common project interests, compatible work and communication styles, and with whom they can build trust.

Table 2: Integration of Entrepreneurial Processes

Stage 1: Ideation – semester 1, weeks 5-8	
Creative Idea Process (1 Cycle = 2 class periods, Process = 3 cycles)	**Learning Outcomes**
Class period 1 (weeks 5, 6, 7) 1. Create "new" random teams 2. Generate ideas to solve a real problem Class period 2 (weeks 6, 7, 8) 3. Provide feedback on all ideas the next week	1. Generate lots of ideas before choosing 2. Consider concepts that aren't usually associated 3. Learn the importance of feedback 4. Obtain different perspectives 5. Identify characteristics of an effective team
Stage 2: Design Development – semester 1, weeks 9-15	
Customer Discovery Process	**Learning Outcomes**
In-class Peer exercise (week 9) 1. Using Customer Discovery template, create survey on problem idea addresses 2. Survey peers 3. Compile implications of peer feedback 4. Revise survey per implications Survey 10 potential customers (weeks 10-13) 1. Using Customer Discovery template, survey customers 2. Compile data and implications 3. Revise idea per implications	1. Align idea & design with actual customer needs
Stage 3: Prototype Development – semester 2, weeks 1-15	
Client Validation Process	**Learning Outcomes**
1. Meet with client week 2 to complete Key Features template 2. Meet with client week 4 or 7 to complete Client Validation template	1. Align necessary changes with client needs
Commercial Viability Process	**Learning Outcomes**
1. Meet with client week 2 to complete Client Revenue Validation template 2. Meet with industry adviser week 4 or 7 to complete Industry Revenue Validation and Cost Validation templates 3. In-class Profit Projection template & Research product market week 9 4. Meet with industry adviser week 12 to complete Market Potential template 5. In-class Profit Projection template final week 13	1. Update the prototype budget for realism (realistic revenue model and actual costs of prototype) 2. Identify a realistic projected market share 3. Identify the cost assumptions key to scaling

3.2. Customer Discovery Process

In our approach, students use the Customer Discovery Process to align their design with the needs of a specific customer base to ensure the economic relevance of their product. Throughout weeks 10-13, they survey at least 10 potential customers for feedback on the design. The scaffolding for this process uses two mechanisms. The first mechanism is the Customer Discovery template which has three parts: (1) a survey to elicit input from the customer on the problem as seen through their eyes, (2) a spreadsheet to compile the appropriate data from that input, and (3) a questionnaire to translate the implications of the survey into a revised statement of the idea and the customer need it solves [16], [24]. Each part of the template guides the student by prompting them for the information that is required. Even so, students often have trouble converting the way they think in terms of engineering technology into the description of problem that it solves from the customer's perspective that they should enter into the survey template.[2] The second scaffolding mechanism is the In-Class Peer exercise which provides them with insights on how to think like the customer.

During the week 9 class period the faculty member introduces the In-Class Peer exercise by walking through all three parts of the template (mentioned above) using a hypothetical example. This brings students to a shared understanding of the process and how it interacts with the customer. Subsequently, with the faculty member providing ongoing diagnosis and assistance as needed student teams create their own survey and take turns as surveyors and customers. The faculty member then facilitates a discussion where students identify what they've learned and how it will help them create their final surveys. Students come out of this peer exercise with an understanding of how the customer's perspective differs from their own, giving them an understanding of why they need to complete the Customer Discovery Process which they do by surveying 10 potential customers.

Customer Discovery Process Learning Outcome: Align idea & design with actual customer needs. Current thinking in design development incorporates customer (or user) feedback at the earliest development stage to avoid spending time and resources designing something that no one wants [16], [17], [25]. Through the Customer Discovery Process students gather customer feedback so that they can use it to make design decisions they know align with customer needs.

3.3. Client Validation Process

The Client Validation Process is an abbreviated customer discovery process to ensure ongoing production decisions continue to meet customer needs. Again, the scaffolding occurs through two mechanisms. (1) We ensure a shared understanding between student team and the client through two templates designed to prompt students for the relevant information. (2) We brief the client to perform an ongoing diagnosis as they assist the student team so that the assistance fades as the team learns. The Key Features template prompts the team to identify the 3-5 key features in the design that the client considers critical to meeting their needs. The Client Validation template prompts the team to indicate any changes they need to make to those key features and to agree with the client on acceptable options.

Client Validation Process Learning Outcome: Align necessary design changes with customer needs. The changes that occur during the build process to accommodate what is technically feasible or financially reasonable can render a product unappealing by changing features the customer considered critical [16], [26]. The Client Validation Process requires students to find out what the client considers the 3-5 key features of the design and to work with the client should

[2] For example, students might see the ability to use a new technology for remote data collection while the customer, will only be excited if this allows them to collect data from a remote area in a way that is better for their purposes than what was previously available.

changes need to be made to those features. This causes students to recognize the potential impact of any changes they need to make without putting too severe a constraint on what can be done within the parameters of a course.

3.4. Commercial Viability Process

The Commercial Viability Process brings the team to an awareness of whether their final product is profitably scalable through the three learning outcomes discussed below. The scaffolding for the first learning outcome (update the prototype budget for realism) is done by having the teams meet with the client and the industry mentor to complete three templates that prompt the teams to focus and report on the appropriate issues during those meetings (the Client Revenue Validation, Industry Revenue Validation, and Cost Validation templates).

The scaffolding for the second and third learning outcomes (identifying a realistic projected market share and identifying the cost assumptions key to scalability, respectively), is done through two mechanisms. (1) We ensure a shared understanding using two templates, the Profit Projection and Market Potential templates, which are designed to guide students through what is expected. (2) We ensure the ongoing diagnosis and student-specific assistance by having the business faculty partner available to help as needed during two business lab sessions in weeks 9 and 13, as shown in Table 2. In the first lab, students enter their budget information into the Profit Projection template and the faculty works with students to start their market potential research. A meeting with the industry mentor in week 12 provides support gathering the appropriate data. The week 13 lab provides teams any assistance needed to complete the templates so that they can draw their own conclusions about commercial viability. Below we briefly describe the need for each learning outcome and indicate how the process delivers it.

Learning Outcome (1): Update the prototype budget for realism. For a product to be commercially viable, the revenue generated must come from a revenue model that makes sense to the customer and that covers all costs of building the product [16], [26]. The Commercial Viability Process requires students to confirm the acceptability of the revenue model with their client (Client Revenue Validation template) and to confirm the realism of both the revenue model and their final cost estimated with the industry mentor (Industry Revenue Validation and Cost Validation templates).

Learning Outcome (2): Identify a realistic projected market share. For a product to have commercial potential it must capture a sufficient share of the overall market to make it worthwhile financially [16]. The Commercial Viability Process requires students to estimate and justify the total market relevant to their product and the share they predict that their product will capture to give them a sense of the scale of operations it would be reasonable to expect.

Learning Outcome (3): Identify the cost assumptions key to scalability. In addition to capturing a reasonable share of the market, the revenue from that share must cover all of the costs of building, marketing, and delivering that amount of product [16]. Through the Commercial Viability Process students enter their updated budget information and their market potential projections into the Profit Projection template which turns the information into a basic 5-year profit or loss projection. A projected profit indicates that the product can be scaled to their predicted market share in a commercially viable way.

4. Outcomes

Over the past two years, a total of 38 EE majors enrolled in the senior design project course were asked to complete two mandatory surveys: (1) a survey for the course; and (2) an exit survey. Both surveys were primarily based on quantitative questions with a few questions asking for student comments and suggestions. Below, we elaborate on the results of each survey.

The purpose of the mandatory short **course survey** was to evaluate how students felt about the overall process, their progress, learning outcomes, achievements, interactions with their industry mentor and client, and their own team dynamics. Table 3 summarizes student responses over the past two years (2013-2014 and 2014-2015).

Table 3: Responses of students to the survey.

Questions	4. Very Much	3. For the most part	2. Almost / Not Sure	1. Not Really
Overall Capstone feedback				
I feel through the senior design project I have gained sufficient skills to formulate relevant engineering problems and solve them independently	80%	10%	10%	0%
I feel through the senior design project I have gained sufficient ability to use software, simulation and computer aided design tools necessary for engineering practice	90%	10%	0%	0%
I feel through the senior design project I have gained sufficient ability to create and identify milestones and develop a working project plan	94%	6%	0%	0%
I am very satisfied with the time my team and I spent on our Capstone Project	84%	10%	3%	3%
Entrepreneurial Process feedback				
The ideation phase helped me to formulate the right project idea	82%	18%	0%	0%
Overall, I am very happy with our team dynamic and I felt we worked great as a team	80%	10%	7%	3%
I feel through the senior design project I have gained sufficient understanding to identify the customer base	85%	10%	5%	0%
The customer discovery part assisted me to learn about the importance of end-user feedback	84%	6%	10%	0%
Overall, it was very educational to interact with our industry mentor/client	70%	10%	11%	9%
I feel through the senior design project I have gained sufficient ability to incorporate disciplines outside EE*	75%	15%	5%	0%

*The primary non-EE discipline incorporated is the business of commercial viability, however, student projects have also incorporated other disciplines such as kinesiology and chemistry.

Based on the feedback received from our students for the past few year, the majority of our graduates have been satisfied with their Capstone experience, in spite of its intense workload. Most students seemed to be satisfied with their team and faculty advisor. However, as mentioned in the next section, in some cases the teams expressed difficulty getting in touch with their industry advisors due to their unavailability. Moving forward, we will compile more data to ensure that our activities have been effectively and successfully implementing ABET outcomes taught and assessed in the capstone course.

When students were asked about the most challenging aspect of the process, majority of them expressed that finding the ideal project was a toughest task. Most students felt that the ideation stage helped them tremendously to formulate a practical problem and determine alternative solutions. Furthermore, many students found the customer discovery stage very rewarding and helpful in terms of receiving meaningful feedback.

In addition, at the end of each semester, all student team members were asked to complete a mandatory **exit survey**. The survey contained 12 questions designed to gather feedback with respect to the way the senior design experience delivered on specific ABET student outcomes (e.g., outcomes c,g,h,i,j,k, and n – see Appendix B for the description of each student outcome). Faculty advisors were also asked to evaluate each student based on similar questions. In the table below, we list the overall average of responses received from both the 38 students and their faculty advisors for the two years since initiating the modified capstone project. We compare these results with the overall average of responses received from students (total of 12) and faculty from 2011 to 2013 before initiating the modifications. The results generally demonstrate that both the students and faculty feel that the new approach better delivers the specified outcomes.

Student Outcome✧	Students ✢		Faculty ✢	
	Old*	New**	Old	New
c	3.8	4.4	3.2	4.0
g	4.1	4.2	3.4	4.2
h	3.9	4.1	3.1	4.1
i	NA	4.3	NA	4.2
j	3.8	4.4	3.2	4.2
k	NA	4.2	NA	3.9
n	NA	4.3	NA	3.9

[5]=Extremely Capable; [4]=Very Capable; [3]=Capable; [2]=Almost Capable; [1]=Not so capable
✧ ABET Requirement
* Indicates the old capstone approach – one-semester senior design project
** Indicates the new capstone approach – two-semester senior design project
NA=Not Available
✢ = See Appendix B for calculation details.

It must be noted that we did not include the industry advisors and clients to evaluate each individual student's learning outcomes. However, we asked them to evaluate each project based on the four entrepreneurial processes that we had identified and discusses. The sample results of such evaluation for the aforementioned projects in Section 1.2 are shown in the table below. In general, the available results indicate that while the advisors and clients believe students have grasped a good understanding on the *early product development* in a start-up environment, more work is necessary to assist the students to learn about Commercial Viability process of their product and determining whether their product can make an economic contribution to the organization (their start-up company) and to the society.

Project Example	Ideation	Customer Discovery	Client Validation	Commercial Viability	Overall understanding of *early product development* in a start-up environment
SenCell	4.5	3.5	4.0	3.0	4.0
WIRD	4.0	4.0	3.5	3.5	4.5
Passive Wireless Pavement Sensor	4.0	4.0	3.0	3.0	3.0
SOMO	4.5	4.5	4.0	3.0	4.5

5. Ongoing Challenges

While modifying the capstone project proved to address a number of key shortcomings, it also introduced several expected challenges both from faculty and student point of views. Table 4 summarizes many of these challenges and what we are doing to mitigate their impact.

Table 4: Capstone challenges.

Challenges	Response
Students	
Not well-connected	We are partnering with a local incubator to allow students without professional connections to meet potential clients and mentors at the monthly meetup.
Unavailability of the industry mentor or client	Finding time to meet can be difficult with busy professionals. We encourage advanced planning by the students and make sure community members are clear about time expectations before they agree.
Getting funding	Great ideas may not receive funding simply because the students are unable to clearly express their project idea and motivation. Next fall we will require teams to have their proposals reviewed by our Writing Center to refine their writing skills.
Difficulty understanding the challenges involved in product development	Less proficient students may incorporate features that they later find extremely challenging to achieve. We try to identify these cases early so that we can mentor them towards features consistent with their skill level.
Faculty	
Faculty expertise and lack of product development knowledge	Lack of expertise in managing product development teams increases the burden on our faculty as they take on the advisor role. Thus we have revisited how participating faculty should be compensated to reflect this burden.
Available manpower and faculty compensation	As the number of enrolled EE students grows, managing so many student teams demands more time from participating faculty members. This is also considered when determining how participating faculty should be compensated.
Handling students who are out of synch	We make special arrangements for students whose progress requires them to have a spring semester start of the capstone.
Availability of the Business faculty	We require that our Business faculty partner meet with the engineering students at least 6 times across the two semesters and must work closely with them to make it work for both departments.

6. Conclusions

In this paper we described how we rearranged the focus of our capstone course to emphasize an entrepreneurial pedagogy. We elaborated on how we achieved the integration of the entrepreneurial processes and the pedagogical scaffolding techniques, laying out each process and its learning outcomes so that other engineering departments can implement any or all of them as fits with their program's goals. We also listed our challenges, including faculty entrepreneurial and industry experience, and adhering to ABET standards, as well as community support and institutional limitations, and the challenges perceived by our graduates. Ways to address such challenges were also discussed in this paper. Survey feedback from the past few years is consistent with the majority of our graduates benefiting from integration of the entrepreneurial processes. In addition, the majority of graduates indicate satisfaction with their capstone experience, in spite of its intense workload. To build upon these favorable results we plan to develop long-term data to more thoroughly evaluate whether ABET outcomes taught and assessed in the capstone course have been successfully met.

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Appendix A

Class activities and student assignments during the first semester

Week	Lecture / Class Activity	Assignment
1	Capstone structure	Review the syllabus / Students given information, options, guidelines, and timelines about the capstone experience.
2 & 3	Lecture: Defining Problem Statement	One-page description of your interests – what technologies are you more interested to learn (e.g., wireless / optics / embedded systems / programing languages) [Individual]
4	Lectures: Project Requirements – Engineering vs. customer requirements Talk: Faculty-Professional Guest Speaker	Identify your specific problem statement [Individual]
5	Lectures: Presentation Techniques Talk: Faculty-Professional Guest Speaker	A. Identify engineering & customer requirements for specific examples [Individual] B. Creative Ideas Process-Cycle 1: Identify three specific real-world problems and provide your solution [Random Groups]
6	Lectures: The importance of team building and its dynamics (*) Talk: Faculty-Professional Guest Speaker	A- Creative Ideas Process-Cycle 1: Respond to three project ideas and provide feedback via Piazza [Individual] B- Identify your strengths and weaknesses – what type of team environment do you like to work in? [Individual] C- Creative Ideas Process-Cycle 2: Identify three specific real-word problems and provide your solution [Random Groups]
7	Lecture: Project Management and project scheduling – Creating Gant Chart Talk: Student Short Presentations	A- Creative Ideas Process-Cycle 2: Respond to three project ideas and provide feedback via Piazza [Individual] B- Creative Ideas Process-Cycle 3: Identify three specific real-word problems and provide your solution [Random Groups]
8	Lecture: Product Qualification and Testing Talk: Faculty-Professional Guest Speaker	A- Creative Ideas Process-Cycle 3: Respond to three project ideas and provide feedback via Piazza[3] [Individual] B- Select a team
	End of Ideation Stage	
9	Lecture: Importance of Customer Discovery (*) Talk: Student Short Presentations	A- Prepare your first draft of the document: project goal, problem statement, engineering and customer requirements B- Customer Discovery Process-In-class Peer exercise [Team]
10	Lecture: How to prepare a successful project proposal; learning about available resources[4] Talk: Student Short Presentations	Customer Discovery Process- survey 10 potential users/ customers by end of week 13 and incorporate implications into design using Customer Discovery template [Team]
11	Lecture: Identifying your design subsystems and challenges Talk: Student Short Presentations	A- Prepare a five-page project proposal to be submitted as student research project proposal for funding [Team][5] B- Identify your faculty and industry advisors
12 & 13	Talk: Student Short Presentations – getting ready for Project Proposal Presentations	Specify and submit the details of your design: part-list / Gantt Chart / subsystems and the individual in charge / Specify tasks requiring extra assistance
14 & 15	Talk: Student Short Presentations – getting ready for Project Proposal Presentations	Present some test results
	End- of design Development State - Project Proposal Presentations (funding and design development)	

[3] Piazza is an online gathering place for students where the instructor can post and address questions http://piazza.com/
(*) Conducted by a Business Faculty expert in entrepreneurship.
[4] Available resources include library resources, online tools, sites such as https://www.kickstarter.com/
[5] This serves as the first project draft.

Appendix B

ABET Students Outcomes

a. an ability to apply knowledge of mathematics, science, and engineering
b. an ability to design and conduct experiments, as well as to analyze and interpret data
c. an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
d. an ability to function on multidisciplinary teams
e. an ability to identify, formulate, and solve engineering problems
f. an understanding of professional and ethical responsibility
g. an ability to communicate effectively
h. the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
i. a recognition of the need for, and an ability to engage in life-long learning
j. a knowledge of contemporary issues
k. an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

Program Specific Criteria

l. a knowledge of probability and statistics, including applications appropriate to Electrical Engineering program.
m. a knowledge of advanced mathematics through differential and integral calculus, linear algebra, complex variables, and discrete mathematics.
n. a knowledge of basic sciences, computer science, and engineering sciences necessary to analyze and design complex electrical and electronic devices, software, and systems containing hardware and software components, as appropriate to Electrical Engineering program

Ns=Total Number of Students
Nf=Total Number of Faculty
Snj=Student Response For Outcome i [0-5], n=[1-Ns]
Fni=Faculty Response For Outcome i [0-5] for Student j,
i=Specified Student Outcome: [c,g,h,i,j,k, n]
SA(i)=Overall Average Response for Outcome i by Students
FA(i)=Overall Average Response for Outcome i for each student j by Faculty j=[1-Ns]

$$SA(i) = \frac{\sum_{1}^{Ns} S_{ni}}{N_s}$$

$$FA(i) = \frac{\sum_{n=1}^{Nf} \sum_{j=1}^{Ns} F_{nij}}{N_f N_s}$$