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Strategies to Promote Entrepreneurial Learning in Engineering Capstone Courses*

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Capstone courses offer opportunities for students to apply their knowledge and skills directly by working on teams and solving real problems within external constraints and limited time frames. As such, capstone courses offer unique opportunities to acquire and apply entrepreneurial skills in the context of the design process. This article examines what is distinctive about an entrepreneurial approach to capstone design and describes strategies used by faculty to promote entrepreneurial learning within the context of the senior capstone design experience. Implications of these different approaches for engineering students' acquisition of entrepreneurial skills and experiences are addressed.

Keywords: capstone; entrepreneurship; innovation

1. Introduction

Traditionally, the capstone course is a culmination of the engineering major that allows students to apply their technical knowledge and skills to solve a real-world problem, while developing professional skills such as communication, teamwork, project management, and leadership. The capstone course offers an ideal environment in which to learn and apply entrepreneurial skills in the context of the design process. Several empirical studies have examined engineering capstone courses [1–3] and have identified specific educational practices, such as the role of industry sponsors, the assessment of student projects, and how capstone practices have evolved over time [2].

Though the capstone structure offers an ideal setting for the integration of entrepreneurial learning with the engineering design process, these studies show that traditional capstone courses are an end-point and typically focus on preparing students to become employees of existing companies, rather than preparing them to create their own products or business opportunities. While most engineering graduates will end up working in industry, current business trends make it highly likely that they will work in a younger, smaller firm or even a start-up rather than the larger firms that have traditionally employed the majority of engineers. They are also more likely than in the past to be part of the founding team of a start up or spinout company.

Providing students with hands-on entrepreneurial experience in the context of their engineering design work builds valuable professional skills and increases their value to future employers. Regardless of where they work, they will be able to identify market opportunities, design solutions that can address them, and more importantly, know how to ensure that their ideas become reality through the commercialization process. This is true whether they are starting their own venture, joining an existing start-up company, licensing their technologies to a well-established company, or introducing new products as an employee of that company. This paper describes several strategies that engineering faculty have used to incorporate entrepreneurship into capstone courses.

2. Elements of the entrepreneurial capstones

Few capstone courses fall into a purely traditional or purely entrepreneurial model. In some cases, a capstone course can have both traditional and entrepreneurial projects underway at the same time. Other courses take a hybrid approach that falls in the middle of the traditional-entrepreneurial continuum, depending on course objectives, student or faculty interests, available resources, and institutional environments.

In all cases, a good capstone experience provides engineering students with opportunities to apply and integrate what they have learned in their educational careers in an experiential manner, resulting in valuable learning outcomes that demonstrate their capabilities and knowledge. Students work on a team, develop communication and project management skills, and apply their engineering skills to achieve a tangible product or solution. However, some important distinctions exist between traditional and entrepreneurial approaches. We begin by describing the key objectives for the entrepreneurial capstone experience, and then provide

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educational practices that are designed to produce entrepreneurial learning outcomes.

Below we present educational objectives and practices that have been successfully employed to incorporate entrepreneurial elements into the capstone design experience. These ideas are drawn in part from a panel discussion that took place during the Capstone Design Conference held in June 2010 (http://www.capstoneconf.org/resources/2010%20Proceedings/index.html) and were developed further with faculty who are currently teaching or designing entrepreneurial capstone courses.

2.1 Develop an entrepreneurial mindset

Most traditional capstones are designed to prepare engineers for the workplace [4]. Entrepreneurial capstones have a distinct goal of preparing students to recognize, create, and act on entrepreneurial opportunities that are related to engineering products and solutions. This may be realized most often by developing a start-up company or nonprofit, or pursuing technology transfer opportunities through licensing or open source pathways. Specific learning objectives for the capstone experience are described in Table 1.

A key learning goal for entrepreneurial capstones is to develop students' entrepreneurial mindset. This means, in part, helping students recognize opportunities to apply a technology in ways that could potentially create market value [5]. Faculty who incorporate entrepreneurship into the capstone experience do so to develop their students' ability to recognize and act on opportunity regardless of whether they embrace an entrepreneurial career path by founding a start-up. Raising student awareness helps to ensure that the phenomenon of entrepreneurship is demystified and is understood as a coherent process rather than blind luck. This better prepares students to recognize and pursue entrepreneurial opportunities they might encounter in their professional lives.

At the forefront is the ability to recognize and act on market opportunities, to place their technical solutions in the context of market demands, and eventually act on their potential to add value. Specifically, as a first step they need to learn how to assess whether a product or technology addresses a customer need. Following this they need to identify what it will take to move the technology forward; recognize, plan, and advocate for the resources needed, and effectively manage those resources so a scalable and sustainable solution can be realized. The entrepreneurial capstone provides a context in which to develop these skills.

One of the primary distinctions between traditional and entrepreneurial capstones is the relative emphasis that is placed on identifying market opportunities and developing solutions that will appeal to customers. This is quite different than in traditional capstones, where industry sponsor have

Table 1 Comparison of Traditional and Entrepreneurial Capstone Elements

Capstone Elements	Traditional	Entrepreneurial
Skills emphasized	Technology solution mindset.	Entrepreneurial mindset.
Student products	Working prototype and report.	Customer validated idea with a working prototype, project report, and a business or commercialization model.
Idea / Problem	Provided by sponsor or instructor.	Identified and refined by students based on market/customer need. Constraints and problem space defined by team.
Criteria for success	Defined by sponsor and/or instructor; grades, evaluation of project criteria.	Objective success determined by existing solutions (competition), needs of customer/end users, other non-technical factors. Grades based on evaluation of course criteria.
Project funding	Usually provided by sponsor.	Pool of funding generated from sponsors, donors, institution and student-generated funds via competitions.
Duration	One or two semesters; usually ends with the course.	Course duration; project may have been initiated prior to the course from previous work and may continue after the course, especially if launching a venture is warranted.
Intellectual property	Determined by institutional policy and constraints of sponsor terms and agreements.	Determined by institutional policy and origins of technology innovations. Team may arrange to have rights to IP or if underlying technology is generated by students, be student-owned.
Ideal educational impacts	Competent engineers who can effectively work in teams to develop technical solutions to identified problems.	Competent engineers who can recognize market opportunities and understand how to pursue the process of creating an entrepreneurial enterprise.
Commercial or societal impact of project	Limited; use of solution determined by sponsor. Broad dissemination or commercialization possible but not typical.	Potentially greater; if a venture is started, investment and jobs may result as they strive to reach the market.

often already defined the market(s), target customer(s), and criteria for the end solutions. Understanding the importance of markets and customers, and finding the best fit between the specific target market/customer and the developing product, service, or technology, are key elements that receive relatively greater emphasis in an entrepreneurial capstone.

2.2 Provide necessary curricular content and support scaffolding for entrepreneurial goals and objectives

To support entrepreneurial objectives, modifications in curriculum are appropriate. The traditional capstone typically starts with the articulation of a technical problem to be solved. In an entrepreneurial capstone, identifying and validating a viable market opportunity is the starting point; the technical problem or design specification is drawn from the market need. Some of the key differences include an emphasis on the incorporation of information such as competing products, pricing, and market distribution channels, as well as user input [6]. Bringing in outside experts to present marketing and sales topics and provide feedback for student projects is a common approach to reinforcing a different perspective. As part of the framing of the project, it is also necessary to proactively develop and incorporate a business model concurrently with the technical solution, rather than waiting until after the technical solution has been completed and creating the business model around that solution. Some of the key changes include:

- Emphasize customer validation up front during the initial stage of opportunity/need finding. This includes collecting data on competing products and solutions, gathering user input on pricing and desired features, and requiring that final presentations include this information [7].
- Modify the approach to economic analysis so it is more market- and customer-oriented (including, for example, the cost of sales and considering different distribution models in making projections).
- Provide support to develop a business model that encompasses the full scope of business activities and include it as a course deliverable.
- Format course deliverables to include a final oral presentation, including a short business pitch and technical presentation. A forum for the audience to judge and provide feedback on the business opportunity provides a means to validate the outcome of the project and in the most promising cases enables teams to connect with potential mentors who can help them take their projects forward.

2.3 Allow students to generate their own ideas

One of the key differences between traditional capstones and entrepreneurial capstones is the source of project ideas. A recent study [2] found that capstones primarily get project ideas from industry sponsors (71%) rather than students (15%). In entrepreneurial capstone courses, students are more likely to identify their own ideas for projects, in part because opportunity identification (framing the right problem) is a key design and entrepreneurial skill. Rather than solving a predefined problem for an industrial client, students working on their own projects have to understand the needs and demands of the market, identify who the customer will be, and figure out how to engage that customer's interest in their solution. With industry-sponsored projects, market validation has already been done or is beyond the scope of the students' work, so the primary focus is on building, testing, and writing reports about their design solutions.

When students have an opportunity to become 'problem finders' as well as 'problem solvers' they acquire different learning outcomes than when they pursue more closed-ended and pre-defined projects from sponsors. The open-ended process of having student teams identify opportunities, problems or needs themselves, often is based on the teams' own experiences and interests, and is validated by their own research on the market, prior patents, and existing technology, which helps them decide which solutions to pursue. This is an important aspect of the entrepreneurial process and requires a higher level of engagement and ownership over the project by the student team.

2.4 Incorporate authentic deliverables, constraints and feedback into the process

An entrepreneurial capstone may be less likely to be perceived by students as a purely educational exercise, with potential to be a more 'authentic' activity [8] when it involves creating a real product or service that can enter the market and impact people's lives. When the team has an opportunity to pursue a venture based on their project, it can enrich the learning experience as a whole. Entrepreneurial objectives create a need to learn that enriches and produces a strong educational outcome for both entrepreneurial goals and engineering design goals. Meeting a real need is key; likewise, practical constraints (particularly relevant when a project is not sponsored by industry) require that students learn basic economic realities of product development. If a product has high material costs, it will not be affordable to the consumer even if there is budget available to build a prototype in the classroom.

Real-world feedback may include questions from a panel of investors who listen to final presentations and may even be willing to mentor or invest in the best student projects. Presenting an 'elevator pitch' can be a transformational experience for engineering students. Students need to present solutions in a market context and use the appropriate language to present their ideas in persuasive ways, both as a solution to a need that meets technical requirements, and as a compelling business opportunity. To do this, they must prepare, understand, and explain the technical, market and financial details in a succinct and convincing way. For many engineering students, this means moving well beyond their zone of familiarity and comfort. Although engineering students possess the quantitative skills to readily master financial analysis, most are not prepared to evaluate and communicate an opportunity from a customer perspective. Meeting this challenge can even be transformational when students recognize that they have the ability to lead beyond the purely technical aspects of their work, and possibly even create their own jobs.

2.5 Form interdisciplinary student teams

Traditional capstones tend to be more engineering-centric, while entrepreneurial capstones are more likely to involve interdisciplinary teams beyond just engineering. In particular, business and engineering students may collaborate in entrepreneurial capstones, combining their respective expertise in market research and technology.

Interdisciplinary teams often require that groups are formed based on areas of expertise and that each team has the right set of skills to undertake the project (e.g., marketing, design, specific technical engineering expertise). Biomedical engineering teams often purposefully include members with complementary skills and expertise (e.g., mechanical, electrical, industrial design) because medical devices often require the integration of multiple technologies.

The structure of teams may differ as well. Entrepreneurial capstones have sometimes used the typical corporate structure as a metaphor for structuring teams [9, 10], including those in small start ups such as a CEO, CTO, CFO, and so on. Examples of such models include the Engineering Entrepreneurs Program at North Carolina State [11], which involves engineering students only, but enables first- and second-year students to collaborate on capstone projects with seniors. Lawrence Technological University's multidisciplinary capstone design experience associated with its Entrepreneurship Certificate program [12] allows business and engineering students to work together on projects. Other capstones have created arrangements that enable students from different disciplines and schools within the university to either cross-register for the same course or pursue their independent academic coursework through a shared project.

2.6 Allow students to engage early and to continue post-course

Traditional capstone design courses typically involve one or two semesters of work [1]. While no one has formally examined the typical length of capstone courses, ambitious entrepreneurial projects are sometimes difficult to complete within an artificial timeframe of two semesters. Both anecdotal evidence and practical realities suggest that having a longer period of time to consider market opportunities provides a better foundation for idea generation and validation. Students who have thought carefully about a potential idea prior to entering their senior year capstone can focus more deeply on the entrepreneurial aspects of their projects while keeping within the time frame of a semester or year-long course.

Structured opportunities for students to continue working on their projects, either through a student incubator or a masters-level program that provides opportunities for continued entrepreneurial or product development activities increase the likelihood students will follow through on early successes. Lehigh University's Integrated Product Development program is a model for this approach, providing sequential support programs for emerging student ventures from on-campus incubation to integration with local off-campus incubation and support programs.

2.7 Create opportunities for competition and external validation

Integrating elements of competition and real world pressure creates an environment in which students are challenged. One approach is to encourage or even require participation in external student design and innovation competitions, which brings in real-world, open-ended objectives, professional feedback and, in some cases, tangible resources to move projects forward. While some universities have their own campus opportunities, increasingly the most promising student teams are encouraged to take part in national opportunities such as ASME's iSHOW and NCIIA's BMEidea and BMEStart competitions. The BMEidea and BMEStart competition criteria were designed by a panel of BME capstone program directors to demonstrate and document achievement of ABET requirements in the required submissions. These competitions provide another context in which students can compete for resources and receive external feedback and

validation for the quality of their ideas and technologies.

Entrepreneurial capstones often do not have the same level of financial support as industry-sponsored projects that are prevalent in traditional capstones. While this could be viewed as a drawback, some feel that resource-limited environments can also inspire students to be more entrepreneurial as they try to garner resources to achieve their goals. One faculty member motivated students by agreeing to match student-generated funding dollar for dollar from departmental resources. Creating an 'artificial economy' inside the classroom is another approach that can help simulate what students will encounter in the real world [10]. Rowan University created a 'Venture Fund' that project teams could pitch for project funding on a competitive basis to students to support prototyping, materials, and other costs [9]. This raised the status of entrepreneurial projects and encouraged teams to treat their projects as opportunities to launch a product or company. Providing student opportunities to compete for real funding is another mechanism for bringing out students' entrepreneurial energy and creating a market for ideas in the allocation of program resources.

2.8 Facilitate student ownership of intellectual property

Students' rights to intellectual property (IP) developed in the course of their project and the opportunity to exploit this commercially can be a powerful motivator for students to pursue projects beyond the classroom. In entrepreneurial capstones, whether students own IP they have had a hand in creating depends on institutional policy and the sources of the technology they are using. Many institutions allow students to own the rights to IP they generate on their own through their coursework. In cases where students did not generate the IP, typically the institution has ownership, for example in applying ideas developed in grant-supported research. Regardless of the specifics of diverse institutional policies, successful programs clearly articulate those policies and include formal presentation of, or even require sign off on, the terms under which projects are carried out. Whether or not an opportunity ultimately is pursued beyond the capstone, having an entrepreneurial focus creates an important 'teachable moment' to ensure that as knowledge workers, students understand the fundamentals of intellectual property and how they apply to their own work.

3. Conclusions

The need for innovative and entrepreneurial engineers who can address societal needs in sustainable ways has never been greater. The senior design context can provide an opportunity to integrate entrepreneurial thinking, market-oriented design, and business strategy with engineering design thereby developing entrepreneurial engineering undergraduates. Pursuing substantive, entrepreneurial, open-ended projects in which there is a focus on defining and addressing a market opportunity through a compelling design solution, creates an excellent context for transformational learning that is likely to result in undergraduate engineering graduates who are well equipped for the 21st century.

An entrepreneurial capstone experience produces engineers who are prepared to lead in the business environment, can understand and communicate with financial and marketing peers, and have experience and the demonstrated ability to take ideas from inception to a demonstrated business opportunity. Producing these outcomes requires a commitment to supporting student-originated projects by providing relevant knowledge, content, and support for the financial, marketing, intellectual property, and other business dimensions of projects.

Commercial potential can be substantially improved by making the capstone an intensive, crowning experience of an integrated sequence of entrepreneurial learning opportunities, enabling the most promising teams to graduate with emergent companies. While this is a realistic expectation in only a small percentage of cases, the example they set has profound impact on the expectations and transformational potential of the programs from which they emerge.

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