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Integrating Entrepreneurship into Capstone design: An Analysis of Faculty Practices & Perceptions*

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Capstone design courses have traditionally provided students with a culminating, project-based experience that fosters the integration of prior academic learning, a connection with industry, and by nature of that connection with industry, preparation for employment. However, in today's competitive global economy, where organizations gain value from the innovativeness of their employees, capstone design courses that integrate innovation and entrepreneurship might better prepare students for employment. There are multiple examples of capstone courses that integrate innovation and entrepreneurship, but it is unclear how and to what degree most capstone instructors integrate different entrepreneurial elements into capstone design. To better understand how and to what degree entrepreneurial elements are integrated, an explanatory multiphase mixed methods design was used, involving the collection and analysis of quantitative survey data, qualitative survey data, and post-survey interview data. One hundred and thirty-eight capstone design faculty were surveyed with an instrument designed using the entrepreneurial capstone practices described by Shartrand and Weilerstein. The quantitative and qualitative data illustrate the extent to which faculty incorporate different entrepreneurial practices in their capstone design courses, how important faculty believe it is to increase different entrepreneurial practices in capstone design, the challenges (perceived and actual) to implementing entrepreneurially focused Capstones, and how faculty members' understanding and experience of entrepreneurship impacts their integration of entrepreneurial elements into capstone courses. These findings are useful for faculty and administrators interested in integrating entrepreneurial elements.

Keywords: capstone design; entrepreneurship; innovation; curriculum

1. Introduction and background

For today's engineering students, the capstone design experience and the connection to industry that it fosters is de rigueur; however, prior to the 1980s, such culminating design experiences were offered by a limited number undergraduate engineering programs [1]. The evolution of both engineering as a profession and engineering education provides insights into why that is the case, and how capstone design is continuing to evolve.

During the nineteenth century, the engineering profession was a trade, in which engineers contributed to the rapid growth of infrastructure and mechanization. Engineering education was hands-on, preparing students for that type of role. During the second half of twentieth century, the influence and role of science and math in the profession increased, as engineers strove to understand and overcome barriers to the various projects they were undertaking. To accommodate this shift, and in part due to the release of the Grinter Report, engineering education began to emphasize science and math theory over practice [2, 3].

During the 1980s, ABET expressed concerns about this focus on theory and the paucity of hands-on design experiences in engineering education. ABET subsequently required that institutions offer a culminating design experience to provide students with a hands-on opportunity to apply their prior engineering learning. For many institutions, this marked the start of capstone design as we know it [1].

Since that time, capstone design has evolved. Faculty practices became responsive not just to ABET standards, but also to the needs of Industry. Faculty practices also reflected the desire to provide real-world experience for students, to better prepare them to enter the workforce [4]. For many institutions, having industry provide sponsored design projects for students and engage in the teaching process further solidified this connection [5]. Professional skills were increasingly emphasized in capstone design, including teamwork, written and oral communication, project planning and engineering ethics [5, 6]. In its 2004–2005 accreditation standards, ABET underscored the importance of such practices by stipulating that capstone design serve as a bridge to engineering practice and create "industry-ready engineers" [7, 8].

Engineering education and capstone design are on the cusp of yet another change. We live in a

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competitive global economy where companies are able to inexpensively outsource even high-skilled creation [3]. Organizations of today create value through the innovativeness of their workers; similarly workers will be valued for their innovativeness rather than their ability to create [9]. Engineering graduates can be better prepared to contribute to this competitive, global economy through the integration of innovation and entrepreneurship into engineering education [3].

Entrepreneurship education provides students with skills that are highly sought by employers including effective communication, problem solving, the ability to apply knowledge, multidisciplinary teamwork, the ability to understand contexts and constraints, and the ability to innovate [10–12]. Students exposed to entrepreneurship educational experiences learn how ". . . to be flexible, resilient, creative, empathetic, and have the ability to recognize and seize opportunities." [13, p. 1] They are better prepared to be innovative and entrepreneurial. These skills, along with the ability to see the big picture and understand business and market implications for a project, have been found to improve job prospects and optimize students' performance in the workplace [12]. In addition to aligning engineering education with workforce needs, the integration of entrepreneurship can prepare students to start their own companies based on their own innovations, which represents a compelling and "potent economic" outcome [14, 15].

Entrepreneurship is best taught using experiential methods [16]. Experiential learning maximizes student self-efficacy, boosts critical thinking, and increases retention of information and persistence with the major [14, 16, 17]. The level of self-efficacy and engagement with the material is further enhanced when students are able to be creative and build a project around a topic that appeals to them. When students follow their passions, the passions of their teammates, or work on a topic that, for them, will make a difference in the world, their intrinsic motivation increases [18, 19]. Experimentation and iteration in the context of the project and reflecting (in a safe environment) on the failures that ensue completes what Neck et al. refer to as a "virtuous cycle," that equips students with confidence and knowledge that they can apply next time [18, 19].

Ohland et al. found that the integration of entrepreneurship into engineering boosts retention. Their longitudinal study revealed that those engineering students that participated in entrepreneurship education were more likely to be retained (70% versus 51%) and claimed they were more confident in their decision to pursue an engineering degree [20]. Ohland et al's analysis of entrepreneurship programs revealed that programs differed, but had several features in common. Programs were generally available to seniors and were project based. Programs incorporated teams of students, sometimes across disciplines, working on projects supplied by industry or by the students themselves. Project outcomes typically included working prototypes and business plans. Industry, practitioners, and experienced entrepreneurs were often integrated as guest speakers, mentors, or providers of projects and internship experiences [20]. These common features are also found in many capstone design classes. Also, as Zappe explains, "Engineering capstone design and certain entrepreneurship courses have some similarities in terms of student outcomes, course structure, and instructional methods. Both types of courses have the tendency to be less structured than traditional courses and utilize teaching methods such as problem-based or project-based learning. The role of the teacher in both areas is less likely to be a lecturer, but rather serve as a coach or a guide that assists students in completing a longer-term project." [21, p. 1]

The benefits associated with entrepreneurship education make the integration of entrepreneurship into capstone design compelling. Additionally, the similarities between entrepreneurship education and capstone design may make the integration of entrepreneurship into capstone design relatively simple. The 2015 capstone design Decennial Survey of Capstone Practices demonstrates institutions are increasingly adopting approaches that might be described as entrepreneurial such as integrating students from other disciplines, and concept generation. The survey also noted a sharp increase student-driven, entrepreneurially-focused projects [22]. Papers have also been written that describe entrepreneurially-focused capstones. For example, Archibald et al describe a capstone design course at Grove City College that focuses on teaching entrepreneurial skills to engineering students in a hands-on product development environment that mimicked the real world [23]. Ochs et al. also provided a case study illustrating how entrepreneurship can be integrated into capstone design while also exceeding ABET standards [24].

2. Purpose and research questions

While the literature documents examples of entrepreneurially focused Capstones, it is unclear how prevalent these courses are at U.S. institutions and to what extent they integrate different entrepreneurial education practices. The purpose of this research is to examine the prevalence of different entrepreneurially focused curricular practices of engineering capstone design faculty. The three primary research questions for this study are:

Research Question 1 (RQ1): To what extent do faculty incorporate different entrepreneurial practices in their capstone design courses?

Research Question 2 (RQ2): How important is it for faculty to increase different entrepreneurial practices in their capstone design courses?

Research Question 3 (RQ3): How and why do faculty incorporate different entrepreneurial practices in their capstone design courses?

3. Methods

An explanatory, mixed methods multiphase design was used for this study [25]. This process involves the collection and analysis of quantitative data, concurrent with and then followed by the collection and/or analysis of qualitative data. The rationale for combining and integrating quantitative and qualitative data is that neither is sufficient on its own to capture the information necessary to answer the research questions.

3.1 Data

This study consisted of the collection of quantitative and qualitative data via an online survey and follow-up interviews. In Phase 1 of this mixed methods study, quantitative data was collected via close-ended responses to a novel *Current Capstone Practices and Entrepreneurship* survey instrument. Phase 2 of the study involved the analysis of responses to survey open-ended items and follow-up interviews with select interviewees. Phase 3 combined the quantitative and qualitative results. Quantitative data indicated the extent to which respondents had integrated entrepreneurship into their capstone design courses (RQ1), and the degree to which they felt it was important to increase entrepreneurship in capstone design (RQ2). Qualitative data came from two sources: (1) a single open-ended survey item, which asked respondents to "share any other thoughts about integrating entrepreneurship into engineering capstone design courses", and (2) a series of post-survey interviews. These data were used to understand how and why faculty incorporate different entrepreneurial practices into their capstone design courses (RQ3).

3.2 Survey design and administration

The *Current Capstone Practices and Entrepreneurship* survey was designed to capture entrepreneurially focused Capstone practices identified by Shartrand and Weilerstein [26, 27]. The survey also drew from the "importance" versus "practice" framework used in the National Survey of Engineering Faculty Committees, Department Chairs, and Deans described in ASEE's Innovation with Impact report [28]. The survey was composed of closed and open-ended survey items, and took approximately 15 minutes to complete. Entrepreneurial practices are defined as the extent to which faculty integrate entrepreneurial elements in their Capstone courses. Entrepreneurial importance is defined as the degree to which faculty thought it was important to integrate entrepreneurial elements.

Survey participants were recruited via email. The email invitation included a brief description of the study and served as the consent form. Participants who agreed to participate followed a link to the online survey. The survey was emailed to faculty through the following recruitment strategies: (1) the email addresses for all faculty on the on mailing list of the bi-annual Capstone Design Conference (last held June 2–4, 2014 in Columbus, Ohio) were located and email invitations to participate in the survey were sent to them (161 faculty); (2) email invitations were sent to the PIs that applied, during the last five years, for VentureWell Course and Program grants to develop more entrepreneurially focused Capstone courses (57 faculty); (3) an email request was also sent to Epicenter Pathways to Innovation teams to help identify faculty who taught engineering Capstone design (52 faculty). Epicenter Pathways to Innovation teams are teams of faculty that are part of the NSF funded Epicenter Pathways to Innovation program who are actively working to integrate entrepreneurship and innovation into undergraduate engineering education.

Survey recipients were placed into four groups listed in Table 1; each group received a custom email invitation that closely reflected their affiliations and interests. This list was de-duplicated in the order in which each contact was entered, resulting in a list of 252 faculty members. Email invitations were sent in January 2015 and participants received a maximum of four reminders over a two-week fielding period.

3.3 Interview protocol design and administration

Potential interviewees were identified by selecting cases at the extremes of the practice and importance dimensions via stratified purposeful sampling. 18 potential interviewees were identified and were emailed requesting they participate in a follow up interview. A total of 10 interviewees consented to be interviewed and were interviewed (see Table 6). Follow-on interviews to the *Current Capstone Practices and Entrepreneurship* survey were designed to explain survey participants' unique close-ended responses based on where they fell along the importance versus practice matrix. Interviews lasted no

Table 1. Survey Population

Group 1	Faculty on the Capstone design mailing list who are also either (i) VentureWell members, (ii) VentureWell conference attendees.	Distributed to 107 62 responses 58% response rate
Group 2	Capstone design mailing list faculty with no VentureWell affiliation	Distributed to 47 29 responses 62% response rate
Group 3	VentureWell grant applicants	Distributed to 56 17 responses 30%, response rate
Group 4	Pathways faculty and referrals	Distributed to 42 30 responses 69% response rate
Total	–	Distributed to 252 138 responses 54% overall response rate

more than 45 minutes and consisted of no more than 8 questions. The purpose of the interview was to obtain greater detail around how and/or why faculty integrate entrepreneurship practices into Engineering capstone design, by identifying the common challenges faced and/or the successful strategies used with the integration process. Interviews were conducted virtually using web conferencing software by a two-person research team. One member of the team led the interview-questioning process while the other took detailed notes. At the conclusion of each interview, the two-person interview team debriefed to review notes and key takeaways prior to analysis. Additional sampling protocol details are described in section 4.3.

4. Analysis and results

Most survey respondents were male (80%, n = 87) and were in the field of engineering (93%, n = 103). The most popular engineering sub-discipline was mechanical engineering (50%, n = 51). Analysis of the survey results and post-event interview results were performed in three phases. In the sections below, each analytical phase is presented with quantitative and/or qualitative results as appropriate.

4.1 Phase 1: quantitative analysis and results

The quantitative survey data were used to answer research questions 1 and 2. All quantitative data were analyzed using descriptive statistics in SPSS. Excel was also used to aggregate data and create descriptive charts and tables. The results below illustrate the most common practices across our respondent population.

Research Question 1: To what extent do faculty incorporate different entrepreneurial practices into their capstone design courses?

4.1.1 Project identification and formulation

Survey respondents indicated that sponsors (55%, n = 57) and instructors (44%, n = 43) most frequently defined capstone design project ideas. Similarly, sponsors (42%, n = 44) and instructors (43%, n = 43) most frequently defined problem scope. However, 15% of respondents said students most frequently initiated capstone design project ideas and 17% said students defined the problem scope most frequently.

4.1.2 Course and project funding practices

Almost half of the respondents said that only "a few" (43%, n = 48) of their Capstone projects were sponsored by a specific industry sponsor, while 14% (n = 3) said that "none" were. In the same vein, while about a third of respondents (27%, n = 30) indicated that "a few" industry sponsors provided unrestricted gifts to support the entire Capstone courses almost half (45%, n = 50) said industry sponsors provided no such gifts.

4.1.3 Criteria for project success and course requirements

The vast majority of respondents (94%, n = 104) reported that the success of the final project is evaluated by the degree to which it meets technical requirements "often" or "always." Likewise, most respondents indicated that success was evaluated "often" or "always" according to whether projects met end user and/or customer needs (86%, n = 96) and sponsor needs (73%, n = 80). Similarly, while most (84%, n = 93) respondents indicated that a working prototype in their capstone design course is "often" or "always" required, only half said a customer-validated solution was (51%, n = 57). Over half of respondents indicated their Capstone courses "rarely" or "never" require business model or commercialization plans (63%, n = 70) or assessments of market size (54%, n = 60). At the same time, students are "often" or "always" encouraged to use failure to iterate on their project designs (56%, n = 62), an educational practice which appears to be consistent with the emphasis on meeting technical requirements and developing working prototypes.

4.1.4 Project duration and extended support

Most respondents (55%, n = 61) indicated that student projects sometimes continue after the course ends, though about a third said this occurred "rarely" or "never" (31%, n = 34). Likewise, nearly half said that students pursue work from a prior semester "sometimes" (49%, n = 54), but about the same number said this took place "rarely" or "never" (47%, n = 52). Sixty percent (n = 67) of respondents indicated that their institution has infrastructure in place to support students who develop their projects beyond the course.

4.1.5 Intellectual property

Most respondents said they include intellectual property (IP) protection as part of their capstone design course curriculum "often" or "always" (64%, n = 71). Most respondents (70%, n = 77) also indicated that students are able to own the IP that they create during their capstone design course. Thirty-nine percent of respondents (n = 43) indicated that students are "rarely" or "never" required to sign an exclusive license agreement and 70% (n = 77) said that students can own intellectual property they create during capstone design courses.

Research Question 2: How important is it to increase different entrepreneurial practices in the capstone design class?

4.1.6 Importance of educational outcomes

A vast majority of respondents indicated that competence in educational outcomes such as teamwork (97%, n = 108) and technical competence (95%, n = 105) were "important" or "very important" for their capstone design course. Alternatively, educational outcomes such as understanding pathways to technology commercialization (52%, n = 58) and the ability to recognize market opportunities (43%, n = 48) were "of little importance" or "unimportant."

4.1.7 Importance of entrepreneurial support: In capstone design

Slightly over half of respondents felt as though it was important or very important to increase the degree to which understanding IP (58%, n = 63) and customer validation (57%, n = 62) were supported in their capstone design classes. On the other hand, nearly half of all respondents felt that increasing the degree to which the business model or commercialization plan (46%, n = 49) or the assessment of market size (40%, n = 43) in their capstone design course were either of little to no importance. Respondents were relatively evenly divided with respect to the importance of student-sponsored projects. Forty-four percent (n = 47) felt that supporting student-sponsored projects was important or very important; 45% (n = 50) felt that it was important or very important to have infrastructure to help students continue to develop their project once the course ends.

4.1.8 Importance of entrepreneurial support: Broadly on campus

Slightly over half of respondents (59%, n = 61) said it was important to increase campus infrastructure to help students continue developing their projects once the course ends. Slightly over half of respondents also felt it was important to increase the degree to which understanding of IP was supported more broadly on their campus (57%, n = 59).

4.2 Phase 2: qualitative analysis and results

Qualitative survey data were used to identify themes that could be used to explain faculty practices in greater depth. All responses were entered into Microsoft Excel as matrix displays, and were pattern coded using thick description and anonymous quotes to reduce bias [29]. Detailed notes and recordings were used to analyze participant interview feedback. For both open-ended survey responses and interview feedback, codes were assigned to 'chunks' of data (phrases, sentences or paragraphs) that conveyed a meaningful idea or set of ideas [30, 31]. Data were further analyzed for common and divergent themes and as new themes emerged the data were partitioned and coded through an iterative process.

A codebook with three sections: codes, definitions and examples, was developed to guide the analysis [31]. Codes were used to develop high-level categories, and themes until the point of saturation (i.e., when additional analysis no longer contributes to the discovery of new information) [32]. Each response was assigned at least one code, theme, or category, and more were added when necessary. Content analysis revealed three high-level categories: Opinions, Challenges and Strategies. Several sub-themes were also identified within each of the Challenges & Strategies categories. For all themes, only the most frequently occurring are discussed within each category. Although themes with two or fewer coded responses were recorded, for the purposes of this study, only codes that represent greater than or equal to 5% (3 out of 56) of all responses are discussed. Open-ended responses were corrected for spelling where appropriate.

4.2.1 Opinions

The Opinions category was reserved for responses pertaining to respondents' opinions regarding whether or not faculty do or should integrate entrepreneurship into capstone design. Aligned with quantitative findings, most Opinions category statements acknowledged explicitly the importance of integrating entrepreneurship into engineering education (n = 10). Half of these statements, however, were coupled with statements that expressed concern about the challenges facing capstone design faculty. Table 2 lists the most common theme for the Opinion category. Eighteen percent (n = 10) of all Opinion category responses were coded into the theme *entrepreneurship is important*. No other Opinion category responses exceeded 5% representation. Recall that only codes representing greater than or equal to 5% (3 out of 56) of all responses are presented.

4.2.2 Challenge

The Challenge category was reserved for responses pertaining to actual and/or perceived challenges associated with integrating entrepreneurship into capstone design. Table 3 lists the most common themes for the Challenge category. Eighty one percent (n = 22) of all Challenge category responses were coded into one or more of the six themes below, arguing that entrepreneurship integration was either challenging due to lack of support, or inappropriate for capstone design. Faculty who said support for this approach was lacking cited two principle barriers including: 1) *insufficient resources* with respect to funding and faculty; and 2) *inappropriate timing* (capstone is too late; students need to be exposed to entrepreneurship earlier in their academic career). In addition, not all respondents were convinced that integrating entrepreneurship into capstone was appropriate, citing several concerns: 3) *limited relevance* (entrepreneurship does not make sense for all engineering disciplines, e.g., civil engineering); 4) *low demand* (most engineering students just want jobs); 5) *different focus* (capstones are about forming relationships with industry) and 6) *competing tradeoffs* (compromising coverage of the core curriculum). Illustrative quotes are provided below the table in support of the coding scheme.

4.2.2 Strategy

The Strategy category focuses on the different approaches faculty members use to integrate entrepreneurship into their capstone design courses or expose students to entrepreneurship outside of capstone design. The most common themes for the Strategy category appear in Table 4. Eighty-one percent of Strategy category responses were coded into one or more of the six themes below (n = 17). Several responses in this category were from faculty who had already integrated entrepreneurship into their Capstone course, or were actively planning to do so (n = 5); or were aware of other entrepreneurship opportunities available to students. Faculty who had already begun integrating entrepreneurship or who were planning on doing so, articulated the following strategies: (1) *future plans* to integrate entrepreneurship into capstone courses at a later date; (2) exposing students to entrepreneurship through *other courses*; (3) promoting *multi-disciplinary* student teams; (4) developing or re-developing *new courses* to accommodate entrepreneurship; (5) *exposing* students to entrepreneurship through lectures, or experiential learning opportunities (e.g. competitions) and (6) forming *partnerships* with other departments. Although these four themes accounted for the majority of strategies employed to integrate entrepreneurship into Capstone courses, faculty also sought out other ways to meet this need. They accomplished this by referring students to other courses or programs that targeted students interested in venture creation. Venture creation, and more specifically the distinction between venture creation and the entrepreneurial mindset, was explicitly mentioned by at least two respondents; prior research has demonstrated that

Table 2. Opinion Themes: Definition, Examples and Frequency

Definition	**Examples**
Theme 1: Entrepreneurship is important (n = 10)	
Recognizing the importance of incorporating entrepreneurship into Capstone or engineering education more broadly	"I think it is very important that our undergrads have tangible entrepreneurial and intrapreneurial skills upon graduation. The diversity of thought and persistence required to be a successful entrepreneur are invaluable assets for our graduates to carry forward–regardless of whether they go to work for a Fortune 500 company, a consulting firm, Wall Street, or start their own ventures. It would be fantastic if our graduates all had an ability to recognize an opportunity, create viable solutions, and articulate a value proposition that provides a unique, economically sustainable product or service"

Note. All quotes are from unique respondents.

Table 3. Challenge Themes: Definition, Example and Frequency

Definition	**Examples**
Theme 1: Resources (n = 5)	
Funding or resource (i.e., faculty training) constraints make integrating entrepreneurship into capstone a challenge. Dependence on industry sponsorship is a challenge for integrating entrepreneurship into capstone design	"Because we have industry funded projects in capstone, we do not teach entrepreneurial models in this course. . ." "I feel this is very important for our engineering capstone courses, but it requires support and resources for engineering profs who have little experience in many of these topics and application. It is also difficult to fund entrepreneurial projects."
Theme 2: Timing (n = 3)	
Entrepreneurship needs to be included earlier in the curriculum as opposed to OR in addition to Capstone	"Capstone, i.e., senior design is too late to start talking about entrepreneurship. We would like freshmen to do a business plan."
Theme 3: Relevance (n = 5)	
Relative importance of integrating entrepreneurship into capstone design varies by discipline	"Entrepreneurship in a civil engineering is not an easily integrated concept. We do not generate prototypes and very seldom generate patentable designs. We typically cannot produce a legally buildable design as a P.E. must stamp the drawings. Faculty cannot do this as the University does not have liability insurance. Civil projects are typically large in size and company ownership is not possible until at least 4 years post-graduation when an engineer obtains their P.E. license."
Theme 4: Low demand (n = 4)	
Entrepreneurship appeals to a subset of the broader engineering student body; recognize that not all students are looking to become entrepreneurs or want to learn about entrepreneurship	"The majority of students are not able or do not want to define, scope, and commercialize. How do we target the ones who do? Probably not through required courses like mine."
Theme 5: Focus (n = 3)	
Capstones should focus on fostering government/ industry relationships or conducting research	"There are other courses that would be more appropriate. Our current capstone course is not where this belongs. We want to give students the challenge of working on industry sponsored projects for professional and customer purposes. Entrepreneurship can be covered in other project courses. . ."
Theme 6: Tradeoffs (n = 3)	
Adding another topic into capstone design (i.e., entrepreneurship) means sacrificing time that could be spent on other topics/experiences and/or compromising the quality of the topics covered in the class (including entrepreneurship).	"The biggest problem with integrating entrepreneurship into capstone is the understanding that one has only so much time to do any subset of tasks, and there are trade-offs to doing all the different aspects well. Most programs want to say they do 'All of the above' – but that means 'all of the above' are likely to be mediocre, and in the end, not very realistic. . ."

Note. All quotes are from unique respondents.

this distinction is of great importance for better understanding how entrepreneurship is being integrated in engineering education [33]. Themes and examples are provided in Table 4 for additional clarity.

4.3 Phase 3: quantitative and qualitative analysis and results combined

In this final phase of the study, qualitative analysis of open-ended survey responses and follow-up interviews were combined with quantitative survey findings. Close-ended survey responses were cleaned prior to analysis and items that aligned most closely to Capstone practice elements were used to categorize responses along importance and/ or practice dimensions. Significant differences between importance versus practice matrix quadrants were analyzed using chi-square analyses and post hoc Tukey HSD tests. Interview data from respondents within each quadrant were used to explain any differences along each of the practice elements [27].

Stratified purposeful sampling was used to identify post-survey interviewees [34]. Samples were identified by selecting cases at the extremes of the practice and importance dimensions (i.e., Low Practice, High Practice, Low Importance, and High Importance). A total 28 survey constructs (composed of one or more survey items) were classified as relating to each dimension: entrepreneurial practices (n = 12) or entrepreneurial importance (n = 16). Values for each dimension were recoded and rescaled (0 to 5) such that higher numbers suggested (1) the presence of entrepre-

Table 4. Strategy Themes: Definition, Examples and Frequency

Definition	**Examples**
Theme 1: Future Plans (n = 5)	
Identified plans to integrate entrepreneurship into capstone design at a later date	"We hope at some point to integrate entrepreneurship into engineering capstone design particularly through collaboration with our business school. We have begun utilizing an innovative canvas tool to get students to think along the lines of market value and scalability of their solutions."
Theme 2: Other courses (n = 4)	
Other courses (outside of Capstone) integrate entrepreneurship principles and expose students to entrepreneurship.	"We have complimentary management of technology courses that cover entrepreneurship, project management, etc. so it is more important to bridge connections to those courses and leverage resources on campus like venture creation courses in the college of business that would allow students to work with those from other disciplines."
Theme 3: Multi-disciplinary student teams (n = 4)	
Promote integration of entrepreneurship in capstone design through the formation of multidisciplinary student teams	"We have brought in Business students to work with our engineering students on the teams. Usually 1 Bus student per 3–4 Eng. students. . ." "We are making a change in the upcoming academic year to include other students who are members of design teams but who are not engineering students in the capstone design course."
Theme 4: Course (re-) development (n = 3)	
Modify existing courses and/or developing new ones to accommodate integrating entrepreneurship into capstone design	"A new supplemental elective design course (in addition to the required capstone design courses) with more emphasis on entrepreneurship has been added this semester. . ."
Theme 5: Exposure (n = 3)	
Promote integration of entrepreneurship in capstone design by exposing students to real-world entrepreneurs, investors or experiential learning (i.e., product invention competitions etc.)	". . . [W]e have guest lectures from students who have gone on to form their own companies, we have lectures about how to start a company (business plan, etc.). . ."
Theme 6: Partnerships (n = 3)	
Faculty form relationships with other departments to integrate entrepreneurship into Capstone	"I also partner with faculty from other departments to allow engineering students to obtain experience in those disciplines and vice versa. A number of students have gone on to participate in [business plan] challenges and innovation challenges."

Note. All quotes are from unique respondents.

neurial practices (high practice) or (2) the importance of integrating entrepreneurship into capstone design (high importance). Average (equally-weighted) values determined the entrepreneurial importance and practice score of each survey respondent. Respondents with averages above 3.5 were included in the high practice and/or importance sample, and respondents with values below 2.5 were included in the low practice and/or importance sample.

In our study, 33% of cases were classified as HI Capstones, followed by 31% in the LO quadrant. Minimal differences were found between HI, LH and LO capstones for (1) sources of project funding, (2) project duration, or (3) how often IP is included in the Capstone curriculum (see Table 5). However, differences were found along other element practices. Entrepreneurial practice and importance items were averaged separately and a median split used to categorize responses (see Table 5). Remaining survey items were further subdivided by capstone element and averaged to provide element averages. Descriptive and inferential statistics were used to reveal significant differences between importance versus practice quadrants.

Subsequently, 18 survey respondents were asked to participate in a follow-up interview. After 1 week of reminders just 10 respondents agreed to participate: 6 in the Low practice/Low importance category (LO), 3 in the Low Practice/High Importance (LH) category and 1 in the High Importance/High Practice (HI) category. According to our interview sampling criteria, no respondents qualified for High practice/Low importance (HL) interviews (see Table 6 below). Interview protocols aligned with the capstone elements described by Shartrand and Weilerstein [27] and in order to produce the most insightful answers, the research team matched participants with interview questions based on their responses to certain survey items.

Table 5. Practice and Importance

	Low Importance	High Importance	Total
Low Practice	LO: 31% (n = 35)	LH: 20% (n = 22)	*57*
High Practice	HL: 16% (n = 18)	HI: 33% (n = 37)	*55*
Total	*53*	*59*	**112**

Note. Includes data from one respondent that was not actively teaching capstone design, but with significant prior Capstone teaching experience.

Table 6. Number of Interviewees by Practice-Importance

	Low Importance	High Importance
Low Practice	6	3
High Practice	n/a	1

Note. According to our criteria, no interviewees agreed to be interviewed from the High practice/Low importance category, and unfortunately only one respondent agreed to participate in an interview from the High Importance/High Practice group.

Research Question 3: How and why do faculty incorporate different entrepreneurial practices in their capstone design courses?

Significant differences between categories were found with respect to (1) how often project ideas are student or industry initiated and (2) how important it is to increase the degree to which the understanding of IP is supported in capstone design. Quantitative and qualitative differences between respondents from different institutions types are presented below:

4.4 Capstone elements: differences between institution types

4.4.1 Skills emphasized

HI faculty emphasize skills pertaining to creativity and problem solving. Low practice, High importance (LH) capstones, on the other hand, promote students' versatility:

> ". . . I think even if they are not going to start a company, having an entrepreneurial spirit or being an intrapreneur is valuable and would help them move forward in their careers."

LO faculty on the other hand are primarily concerned with preparing students for employment:

> "My experience having students work for big companies that may come back and support us, is the best strategy so far."

4.4.2 Ideal problem

In HI and LH institutions capstone project ideas are student or industry initiated. Faculty in LO institutions on the other hand rarely use student-initiated projects, most come from industry or the course instructor. This finding was validated by quantitative results. Chi-square analyses revealed statistically significant differences between HI and LH or LO institutions. Students are more likely to initiate capstone design project ideas more frequently at HI than LH or LO institutions ($\chi 2$ (2, N = 105) = 7.029, p = 0.030). Students also tend to define the problem scope of capstone design projects more frequently at HI than at LH or LO institutions ($\chi 2$ (2, N = 105) = 7.029, p = 0.030).

4.4.3 Criteria for success

In HI institutions, project teams are evaluated according to the process (problem identification, potential solutions and possibly monetization) used to come up with their solution.

> "[It matters] . . . how well they have done in the context of their problem [and that] they have done the process and demonstrated that they have gone through the thinking."

4.4.4 Student products

Prototype functionality is also important across institution types, and projects are validated and/or tested for user/commercial viability through participation in competitions. LH institutions participate in competitions, emphasize process over product, and emphasize soft skills such as time management and oral/written communication skills. In LO institutions, success depends on meeting user needs and successful demonstration of the final product.

4.4.5 Project funding

Minimal differences were found between the HI, LH or LO institutions in terms of how often industry sponsors provide unrestricted gifts to support the entire course, as opposed to a specific student project, or in terms of how often students are required to sign an exclusive licensee agreement with the sponsor.

4.4.6 Duration

Semester-long capstones are the norm across HI, LH and LO institutions and it is rare to find projects extending beyond the course.

4.4.7 Intellectual property

Minimal differences were observed between HI, LH and LO institutions on how often IP protection is included in capstone curriculum. However, significant differences were observed between how important it is to increase the degree to which the understanding of IP is supported in capstone courses, $F(3,107) = 4.862$, $p < 0.003$. Post hoc Tukey HSD tests revealed that HI institutions tend to value the importance of increasing the understanding of IP in courses more than LO institutions. However, HI faculty expressed concern that when students bring in pre-existing projects and are assigned teammates, it becomes unclear who owns the IP. LH/LO faculty stated that they lack expertise in IP or their institution lacks student IP policies and procedures.

4.4.8 Commercial and/or societal project impacts

HI faculty noted that students sometimes end up with patents at their institutions, but that this is not common. LH and LO respondents noted that projects rarely make an impact, because the duration of the class is often too short, and students rarely want to continue with their ideas beyond the course.

5. Discussion

The Phase 1 and 2 findings of this study demonstrate that while many faculty express an interest in integrating entrepreneurship into capstone design, most continue to engage students in what Shartrand and Weilerstein describe as a more traditional capstone approach [27]. For example, meeting technical requirements and developing a working prototype continue to be more important educational outcomes than understanding market size, or developing business plans and commercializing technologies. Similarly, teamwork and technical competence are considered more important than understanding pathways to technology commercialization and recognizing market opportunities. In most instances, sponsors are providing project ideas and sponsors or instructors are defining the project scope. Additionally most campuses do not provide students with the infrastructure and support needed to pursue their project once the class ends [27].

In a limited number of cases, this unrealized intention to integrate entrepreneurship into capstone design appears to be connected to the important historical role capstone design has played in preparing students for work in industry, and the close collaboration with industry sponsors that continues in some capstone courses. However, many faculty indicated only a few of their projects are sponsored by industry, which limits the impact of industry on said integration. For many faculty, this unrealized intention to integrate entrepreneurship is due to perceived curricular challenges, which includes the perception that there is insufficient room to incorporate entrepreneurial content into their courses, and the lack of curricular scaffolding to ensure students are exposed to entrepreneurial skills and knowledge prior to capstone design.

For some respondents, the challenge to implementation lies with the need for support from the broader campus both within the class and across the campus in general. For example, some faculty do not feel equipped to teach entrepreneurship; guest speakers that can supplement their knowledge on such topics as IP, or training or mentoring on how to integrate entrepreneurship into Capstone without sacrificing core content might prove useful. The broader campus can also foster integration by increasing campus-wide knowledge of student IP policies and practices, and increasing the infrastructure that supports students that want to develop their projects outside of class.

For other faculty the perceived challenge, and in some cases the hesitancy around integration of entrepreneurship into capstone design, lies in the perception that entrepreneurship might not be appropriate for all students. In civil and chemical engineering, for example, students typically design infrastructure projects or chemical manufacturing processes. These projects are not ones that students can easily spin off into a venture. Some faculty also expressed concerns that since not all students are interested in becoming entrepreneurs or starting their own businesses, a required capstone design course may not be the best vehicle for introducing entrepreneurial skills.

In spite of these perceived challenges, some faculty are currently planning to integrate entrepreneurship into their capstone design courses, and some are already successfully doing so. For these faculty, entrepreneurship is not simply about preparing students to launch a venture; it is also about better equipping students to be "intrapreneurs" who innovatively contribute to existing organizations. The opportunity for cross-pollination across disciplines that entrepreneurial capstone affords is also deemed advantageous.

Faculty have also found ways to overcome perceived challenges of integrating entrepreneurship into capstone design. For example, some faculty forge connections with faculty from other disciplines that can serve as mentors or can collaborate with them to create a multidisciplinary class and teams by combining, for example, business students and a business class with the capstone design class. Some faculty are taking the route of modifying exiting courses by including lectures by local or alumni entrepreneurs, or by fostering connections with other entrepreneurially-focused courses and extracurricular offerings on their campus. Faculty have also found ways to overcome discipline-specific challenges, for example, by starting to develop "products with prototypes" in the context of a chemical engineering class. Still others do not see the integration of entrepreneurship as detracting from or reducing traditional capstone design content; however, they do note that the inclusion of entrepreneurship motivates students.

The Phase 3 analysis demonstrates that perspectives and practices vary depending upon where in the importance versus practice matrix faculty reside:

- *LO respondents* adopt a more traditional approach to capstone, emphasizing industry or faculty initiated projects. Projects are evaluated based on the ability of a functioning prototype to meet sponsor needs. Preparation for a job is the ultimate goal.
- *LH respondents* depart from this approach by integrating student initiated projects; they encourage student participation in competitions where students likely communicate how their project meets a customer need; additional soft skills are emphasized including written communication and time management; the process students adopt is considered more important than a final, working prototype. LH respondents consider the integration of entrepreneurship valuable because it equips students to innovatively contribute to an existing organization.
- *HI respondents* also emphasize student-initiated projects, and amplify the sense of student ownership by having students develop their own scope. Students are evaluated based on their process, as well as the degree to which their prototype meets a customer need and is commercially viable. Increased understanding of student IP is fostered, and in a limited number of cases, patents are awarded.

The integration of these different practices appears to be driven by respondents' own definitions of entrepreneurship and potential outcomes, beneficial or otherwise, perceived to arise from that definition. Some faculty, for example dismiss entrepreneurship due to its focus on starting new ventures, which is perceived as irrelevant for many students. However, LH respondents credit entrepreneurship for its ability to prepare students to become intrapreneurs and prepare students for jobs in industry through the development of a variety of soft skills. HI faculty, by comparison, understand the breadth of what entrepreneurship as a discipline entails. This is reflected in their teaching practices, which cover the gamut of entrepreneurial skills, from empowering students to select their own projects, to fostering skills such as creativity and problem solving, to preparing students for commercialization by increasing their knowledge of IP and exploring commercial viability.

Together, all 3 phases of this study provide insights into the key three reasons why implementation practices may vary among faculty:

5.1 Definition of entrepreneurship

Faculty that fall into the HI quadrant and implement more entrepreneurially focused capstones understand the breadth of what the entrepreneurship discipline entails, the potential outcomes and applicability to different students. As discussed by Gilmartin et al., venture creation is only one of the skills entrepreneurship education may foster [33]. If entrepreneurial practices are to be further adopted in capstone, and faculty are to move into the HI quadrant, it is critical that faculty develop a broader understanding of what entrepreneurship is and how the different facets can be applicable to students and their varied interests and goals. As discussed by Wheadon and Duval-Couetil, broadly speaking, entrepreneurship education offerings can encompass traditional business skills, small business creation, preparation to contribute entrepreneurially to an existing organization, as well as venture creation [35].

5.1.1 Faculty support

Once faculty understand the potentially broad applicability of entrepreneurship and entrepreneurial skills to their students, they need support with implementation. Traditionally, faculty that teach entrepreneurship have entrepreneurial experience. For faculty that are not entrepreneurs it will be critical to offer professional development training, or the ability to collaborate or co-teach with entrepreneurial faculty. Also important is access to best practices that demonstrate how to successfully integrate entrepreneurship into discipline-specific capstone design classes while simultaneously teaching core technical concepts and meeting ABET standards.

5.1.2 University culture and support

Capstone instructors are already challenged by large classes sizes, a sense that there is insufficient time for students to complete their projects, and the need to find funding for projects [36]. Additionally, some faculty lack the expertise to integrate entrepreneurship in their capstone design class. Institutions can support faculty in their efforts by addressing class size, time and funding issues. Institutions can also help foster entrepreneurship teaching expertise among faculty by providing access to training in entrepreneurship education, and putting in place policies and systems to foster collaboration and co-teaching arrangements among faculty. Institutions may similarly support faculty by investing in university infrastructure to support students that wish to pursue of their project outside of class, assisting with funding of student-driven projects, and educating faculty and students about student IP policies and practices. Ideally, an entrepreneurially-focused institution will also provide multiple entrepreneurial experiences that students can avail themselves of throughout their academic careers, providing the scaffolding needed to succeed in a more entrepreneurially focused capstone. For some institutions, this represents a large shift, or as one respondent put it, "[t]he boldness to be innovative and entrepreneurial needs to become a culture."

6. Limitations and future research

The survey as designed generated significant insights into how and to what extent faculty members incorporate different entrepreneurial practices, and revealed some of the perceived challenges faced when preparing to integrate entrepreneurship. Still, one primary limitation exists: 74% of respondents are affiliated with VentureWell and Epicenter's Pathways to Innovation program, which focus directly on fostering entrepreneurship education. Therefore, the study findings may not be generalizable to the full population of institutions. However, the practices discussed in this study illustrate that given the right context and conditions, motivated faculty can innovatively integrate entrepreneurship into capstone design. This feedback, together with further analysis of how VentureWell and Epicenter affiliated capstone design instructors and their institutional contexts differ from other non-affiliated capstone design instructors, will help us understand how entrepreneurship can be more broadly integrated into capstone design and how institutions can best support faculty in these efforts.

Additionally, the integration of different entrepreneurial elements appears to be predominantly driven by respondents' own definitions of entrepreneurship. Further analysis is however needed to better understand the degree to which a faculty member's own definition of entrepreneurship aligns with Wheadon and Duval-Couetil's Intention-Uncertainty matrix [35]. This analysis might help us understand whether the degree of alignment with either a single quadrant, or multiple quadrants in the matrix, can serve as a predictor of entrepreneurial practices implemented, and the importance associated with implementing entrepreneurial practices.

Finally, a longitudinal analysis of entrepreneurial practices and perceptions in capstone design would be useful. Such an analysis could track changes over time, and help us understand the shifting landscape of interventions needed, if institutions wish to foster more entrepreneurially focused capstone design classes.

7. Conclusion

The integration of entrepreneurship into engineering education can better prepare to contribute to this competitive, global economy by providing them with skills that are highly sought by employers, along with the ability start their own companies based on their own innovations. This research demonstrates that while many faculty express interest in the integration of entrepreneurship into capstone design, a conservative approach to said integration is typically adopted including using failure to iterate on a design and competence in teamwork, both of which fall comfortably within the traditional domain of capstone with its focus on design and industry. However, some faculty integrate less traditional entrepreneurial practices including student-sponsored projects, assessment of market size, and the development of a business or commercialization plan. Still others point to obstacles associated with said integration including insufficient room in the curriculum, lack of relevance to most students, challenges of fit associated with specific engineering disciplines such as civil or chemical engineering, lack of entrepreneurship expertise, and limited support from their campus. If increasing numbers of faculty are to begin integrating entrepreneurial practices into capstone design, there appears to be a need to: (1) educate faculty about the relevance of entrepreneurial skills to many students; entrepreneurship can span business skills, small business creation, preparation to contribute entrepreneurially to an existing organization, as well as venture creation; (2) provide faculty with support on their integration including training, best practices for integration, and policies and processes that empower faculty to collaborate and co-teach; and (3) support students by providing entrepreneurship experiences throughout their university career, and infrastructure to support the continuation of their project beyond the life of the class.

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