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## **AC 2012-4451: A REVIEW OF CAPSTONE COURSE DESIGNS USED IN INDUSTRIAL ENGINEERING PROGRAMS**

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# A Review of Capstone Course Designs Used in Industrial Engineering Programs

## Introduction

Within engineering curricula, capstone courses are an essential element of the undergraduate experience. In capstone (or senior design) courses, seniors are able to use the knowledge gained throughout their studies to analyze a design problem. The capstone course is critical in ensuring that students have the requisite knowledge and can integrate it effectively before embarking into the field as engineering professionals. As such, the course also serves as an important benchmarking tool for engineering programs to ensure they are meeting program outcomes. Not only are capstone courses important for the profession and the academic programs, they are also critical to student success. The design experience they complete in the course has the potential to influence their career trajectory, satisfaction with the academic program, and self-efficacy. The challenge then becomes determining the best capstone model to maximize this potential. A comprehensive understanding of various capstone course models will help determine if there is one best model or if it may depend on characteristics of the program such as geographic location, student body size, and faculty size.

## Literature Review

Past research on capstone design courses in engineering has focused on how to best structure the course to serve the educational needs of the students, as well as how to effectively deliver and manage these courses. According to Farr et al.<sup>3</sup>, a successful capstone design course is one in which students utilize a variety of analytical tools, function in a team-based environment, solve a real-world problem, work to close any non-technical competency gaps, and follow a total design process. Many of these essential course features are echoed by Beyerlein et al.,<sup>1</sup> including focusing on not only the solutions students develop through a capstone design course, but also how each student develops individually. To this end, it becomes important to structure courses that support not only program curriculum and educational objectives,<sup>5</sup> but also the professional development needs for each student.<sup>1</sup>

One of the primary ways in which capstone design courses differ between engineering programs is the type of design project students complete. There has been a recent trend for engineering programs to partner with industry to provide capstone design projects direct from the “real world.” In 1994, industry projects accounted for approximately 59% of capstone design projects in surveyed engineering programs, compared to 71% in 2005.<sup>4,8</sup> Not only do these projects enrich students’ appreciation of educational relevance, but they are also beneficial in establishing industry ties to programs and encouraging faculty professional development.<sup>3</sup> Industry sponsored projects present a number of drawbacks, however, including difficulty in finding projects, determining an appropriate scope, and a high level of effort needed for project and course coordination.<sup>3</sup> Faculty are also beginning to utilize external competitions as a source for design projects.<sup>4</sup>

The structure of a capstone course also varies depending on the program. Capstone courses are most commonly one semester in length (43%<sup>4</sup>), though two semester courses are also common (37%<sup>4</sup>). Teams are used in the vast majority of capstone courses (81-88%), with intermittent use (21-47%) of multiple disciplines or students from various departments on a single team.<sup>4,5,8</sup> Large dedicated teams are also common, with 60% of teams consisting of 4 to 6 students, and 71% of courses assigning a single team to each project.<sup>4</sup>

Capstone design courses face the cumbersome but necessary task of incorporating a vast array of coursework into a single comprehensive project. Research advocates integrating courses from not only the technical curriculum but also general education curriculum as well.<sup>6</sup> Within engineering programs, this coupling of technical and professional topics is apparent. According to the results of a 2005 survey,<sup>4</sup> over half of programs surveyed included the following topics in their capstone design courses: written communication (87%), oral communication (83%), engineering ethics (76%), project planning and scheduling (72%), decision-making (68%), teambuilding (66%), team dynamics (63%), engineering economics (61%), developing/writing functional specifications (56%), safety in product design (52%), and leadership (50%).

Course design has been linked to student self-efficacy.<sup>7</sup> In capstone design courses, problem based learning and reflective journaling have been shown to improve self-efficacy.<sup>2</sup> By exposing students to the need for technical and professional skills, introducing them to the proper problem solving approach, and allowing the course to support student development, students are more likely to report high confidence in their own abilities.<sup>2</sup>

This paper will build upon the previous literature and examine Industrial Engineering capstone courses from across the nation. The researchers hope to identify characteristics of capstone courses that positively affect student self-efficacy.

## **Methodology**

The review included industrial engineering programs in the United States. Data was gathered via internet searches, email inquiries, and reviews of course syllabi. Twenty-eight universities were included in the data analysis due to availability of syllabi. The syllabi were reviewed and categorized based on the following factors:

- Course design – Courses were categorized and compared based on course format and design. Example designs include industry sponsored project, company simulation, and independent (non-industry) project.
- Course structure – Data regarding the number of credit hours in capstone course, number of semesters, and grading structure were compiled.
- Teams and disciplines – Data regarding the use of teams and other (non-industrial engineering) disciplines in the course were compiled.
- Topics covered – The intent of a capstone course is to present a summative learning experience that utilizes knowledge gained during the curriculum. Topics covered in senior design courses were compared.

- Relevance to IE profession – The topic areas were then compared to those included on the Fundamentals of Engineering (FE) and Principles and Practice of Engineering (PE) exams to measure relevance to what is expected of new IE professionals.

## Results

### *Course Design and Structure*

Syllabi from 27 Industrial Engineering programs (and 1 Engineering Management program) were examined to determine the design and structure of their capstone courses. Information that was readily available for each program included course design (type of projects), credit hours per semester, number of semesters, grading structure, whether work was conducted as teams, and if other disciplines were included in the course. Characteristics common across all programs are the use of teams and the use of an A-F grading scale (with the exception of one university).

The majority of the capstone course projects were strictly sponsored by industry as seen in Figure 1. Two of the universities (7%) utilized an independent project design where students either chose their own idea or there were preset projects for each semester. An additional two universities incorporated a format in which the projects could vary and were sponsored by either industry or faculty members.

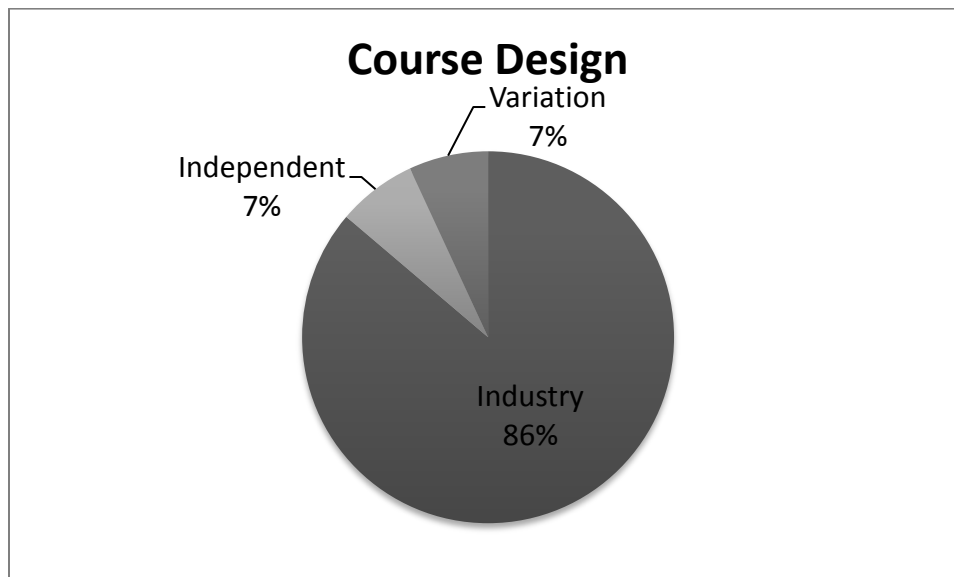


Figure 1: Course Design for Project Sponsorship for 28 Industrial Engineering Capstone Courses

The greatest variation among universities was in the credit hours for the capstone course (all quarter hours were converted to semester hours). Figure 2 shows that more than half (62%) of the capstone courses are three credits, about a fifth are four credits, and 17% are only two credits. However, because about 30% are two-semester sequence courses (Figure 3), the total credits for the capstone courses vary from two to six credits (Figure 4).

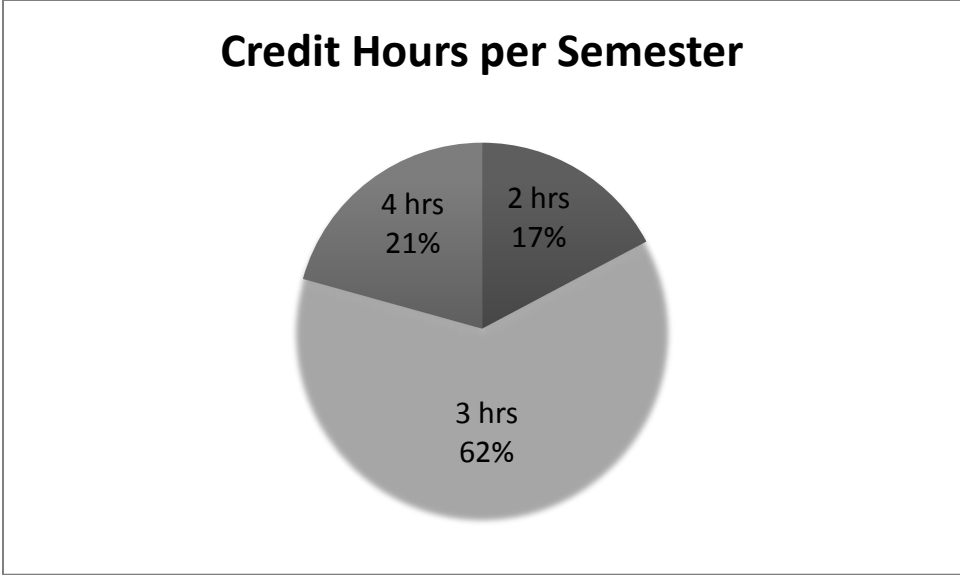


Figure 2: Semester Credit Hours for 28 Industrial Engineering Capstone Courses

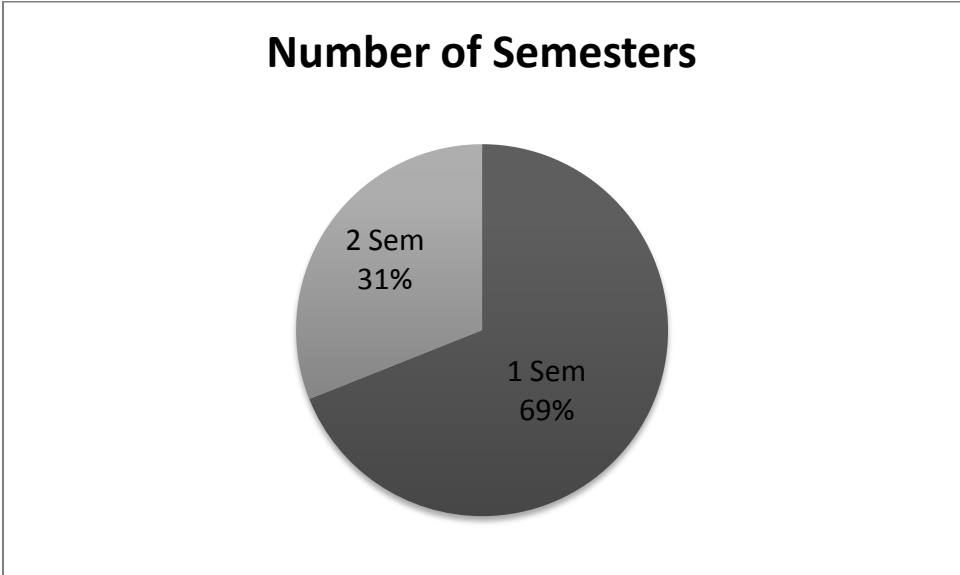


Figure 3: Number of Semesters for 28 Industrial Engineering Capstone Courses

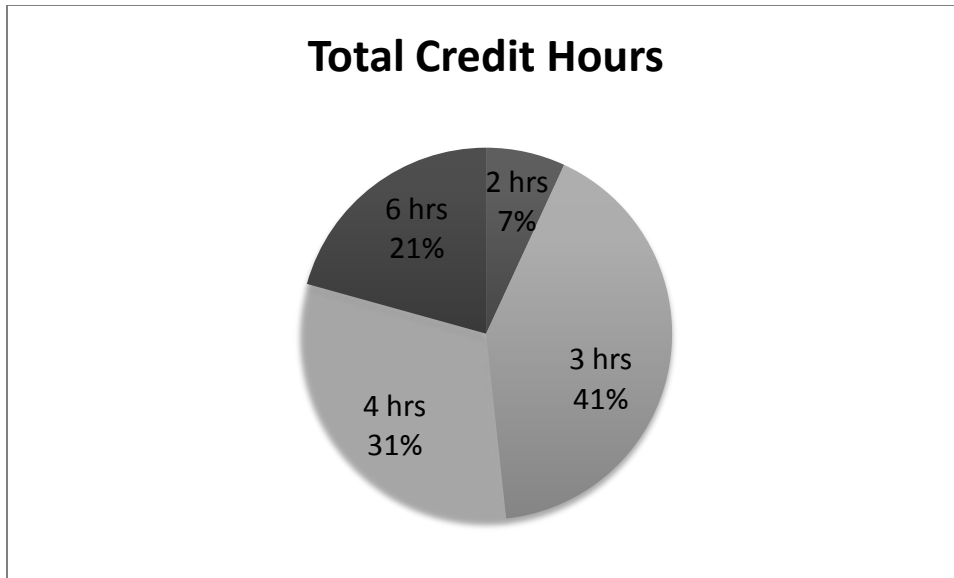


Figure 4: Total Credit Hours for 28 Industrial Engineering Capstone Courses

The last characteristic that was easily extracted from the syllabi was the inclusion of other majors in the Industrial Engineering capstone course. It was determined that only 14% of the universities indicated there was at least one additional major either in the course or on the capstone project teams (Figure 5).



Figure 5: Inclusion of Other Majors for 28 Industrial Engineering Capstone Courses

### *Topics and Relevance to IE Profession*

Syllabi from 26 universities (sufficient data was not available for two of the universities in the review) were reviewed to examine course topic areas and compare these to material included on the Fundamentals of Engineering (FE) and Principles and Practice of Engineering (PE) exams.

Key words and phrases from capstone course syllabi were mapped to the topic areas for each exam. If a syllabus contained at least one key word or phrase for a topic area, the course was deemed to include coverage of the corresponding topic. If not, we deemed coverage unknown for that topic in that course.

The FE topic areas for the industrial engineering exam include engineering economics; probability and statistics; modeling and computation; industrial management; manufacturing and production systems; facilities and logistics; human factors, productivity, ergonomics, and work design; and quality. Figure 6 summarizes the percentage of courses covering each of these eight topic areas. Two topics, industrial management and manufacturing and production systems, are covered in all of the capstone course syllabi we reviewed. This reflects the common focus on project planning and management, team projects, and system design elements in these courses. Engineering economy and modeling and computation appear in nearly 62 percent and 54 percent of courses, respectively. The remaining topics are explicitly mentioned in syllabi of fewer than half of the courses we reviewed. Only one capstone course in this sample clearly includes coverage of all FE topics. In that course, preparation for the FE exam is a specific component of the capstone experience.

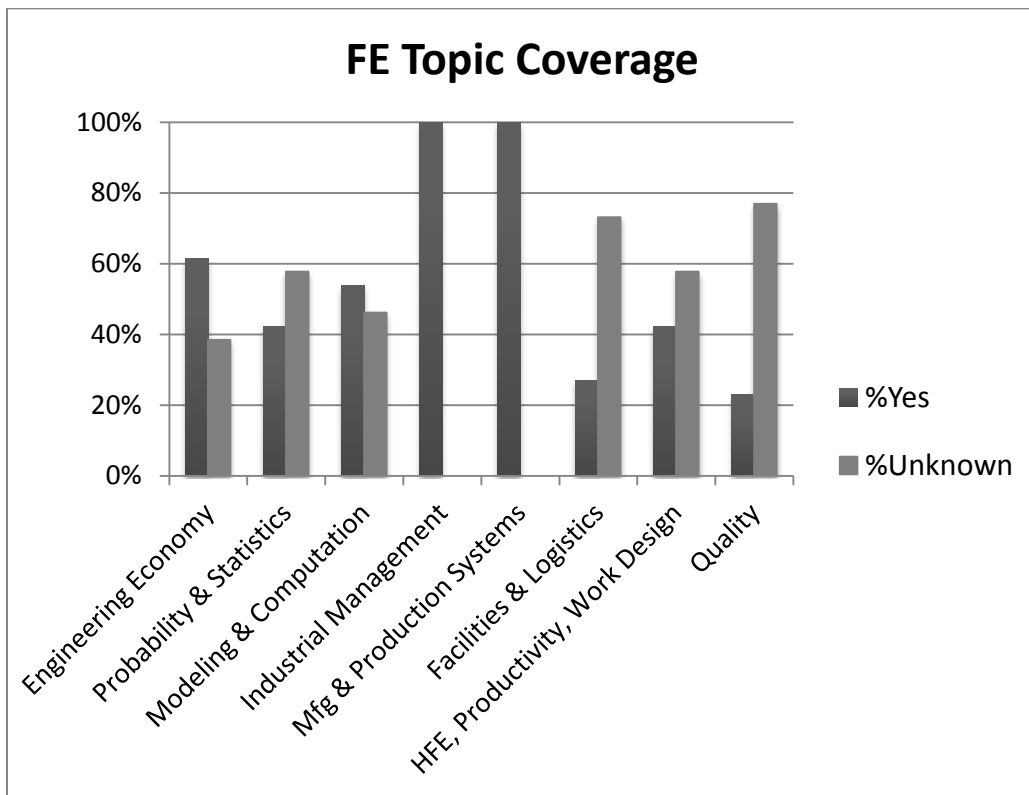


Figure 6: FE Topic Coverage in 26 Industrial Engineering Capstone Courses

The PE exam for industrial engineers includes six topic areas: facilities engineering and planning, systems analysis and design, logistics, work design, ergonomics and safety, and quality engineering. There is naturally a high degree of correlation between some FE and PE exam topics, as is the case for the quality topic area on the FE exam and the quality engineering topic

area on the PE exam, for example. However, the PE exam separates some individual topic areas from the FE exam into multiple categories, which provides additional insight into the relative fraction of courses covering different topical elements. Figure 7 illustrates PE topic coverage in the 26 syllabi we reviewed. Key words corresponding to systems design and analysis appear in all of the syllabi, as expected. Coverage of the remaining topics is more difficult to determine from the syllabi, with the majority of courses having unknown coverage of each of the other five topic areas. Among the topics of work design and ergonomics and safety, which are separate on the PE exam but part of a single topic on the FE exam, key words indicating coverage of ergonomics and safety are more prevalent than those indicating work design (appearing on 35 percent and 19 percent of syllabi, respectively). Similarly, key words corresponding to facilities engineering and planning (on 27 percent of syllabi) are more common than those corresponding to logistics (on 19 percent of syllabi). Overall, the analysis of PE topics results in a greater fraction of courses with unknown coverage than does the analysis of FE topics.

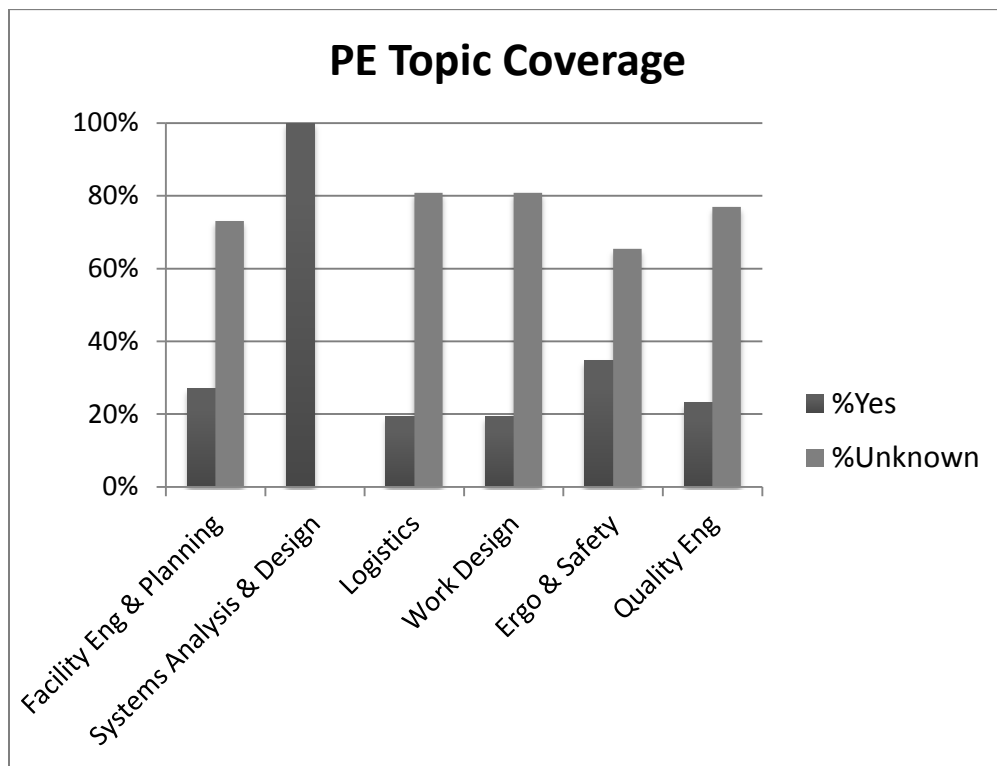


Figure 7: PE Topic Coverage in 26 Industrial Engineering Capstone Courses

## Discussion & Conclusions

The initial review of Industrial Engineering Capstone courses has produced several questions on the design and content of these courses, such as why the universities decided to format them as they did and how the formats may affect student performance and self-efficacy. When the majority of programs share characteristics, it will be particularly intriguing to explore why that model is common and if there is a reason why there are so few that chose a different design. On the other hand, if the capstone course should be designed to culminate an Industrial Engineering



student's schooling, why is there such variation in areas such as the total credit hours? Common design characteristics among the universities included the use of industry-sponsored projects, having teams that were comprised strictly of Industrial Engineering students, and the exclusion or lack of acknowledgement on the syllabi of FE and PE topics such as Probability and Statistics, Facilities Layout, Quality, and Human Factors, Productivity, and Work Design.

All but two of the reviewed universities had at least some industry-sponsored projects the capstone course. This practice now seems to be the norm from this review and previous work by Todd et al.<sup>8</sup> and Howe and Wilbarger.<sup>4</sup> However, the concerns described by Farr et al.<sup>3</sup> are relevant to this review: How is it that companies continually have projects for students and can this continue? Are there too many "problems" that cannot be addressed by their own employees? Is it a way for the company to get their name out there or find future hires? On the other hand, why are two universities in this review not using any industry-sponsored projects? Do geographic constraints, lack of resources, or other reasons determine the use of independent student or faculty projects? Although the use of industry-sponsored projects appears to be the model followed by most departments, only four of the 28 universities incorporate other majors (e.g., Mechanical, Computer, and Electrical Engineering) on their capstone teams. These findings correspond to earlier studies<sup>4,5,8</sup> but do not follow the notion that in industry engineers need to be able to work with individuals from multiple disciplines. If engineers do indeed commonly work with others outside their own major area, why are capstone courses not embracing this concept?

According to Beyerlein et al.<sup>1</sup>, the capstone course should include topics that focus on the students' professional development. However, this review of syllabi suggests that many capstone courses may be missing opportunities to incorporate important elements of professional development, namely the ability to work in multi-disciplinary teams and to integrate fundamental concepts of Industrial Engineering explicitly. Using the FE and PE topics as a foundation for proficiency of Industrial Engineering graduates, basic concepts of experimental design work, such as probability and statistics, are not directly mentioned in the syllabi of over half of the universities in this study. This warrants further investigation. Does not specifically including these topics in the syllabus imply that students do not need to use the concepts at all in their projects or in their careers after college? Do students feel they are sufficiently prepared to understand and use concepts that are not incorporated in their projects? On the other hand, do the syllabi simply not reflect the breadth of concepts that students are expected to apply in the capstone experience? The researchers understand that students should already have an understanding of the FE and PE concepts from other courses and the capstone course is not the place to introduce them. However, these topics should be integrated in the capstone experience to enable students to gain a better understanding of applying their fundamental knowledge in an open-ended project.

The only design characteristic that had a large variation among the reviewed programs was the total number of credit hours for the capstone course. Although a majority of the universities used a one-semester format, all universities with a two-semester format allocated between four and six total credit hours to the capstone sequence. These findings agree with those by Howe and Wilbarger<sup>4</sup> that most programs use a one-semester format but many others have a two-semester course; however, they leave one to wonder why there is such a variation among schools

when the capstone course should be a similar experience for all students. What about the students at the universities that give only two total credits? Are they gaining the same knowledge and experience as a student who is in a capstone course over two semesters and receives six credits? Do the students and faculty believe the credits received are appropriate for the level of work produced and time invested? This inequality in credits for the capstone course and how it may affect student performance, career choice, and self-efficacy is definitely an area that should be explored further.

Future work, including student feedback, should address many of these issues and create a more detailed analysis of why some universities may be restricted in their capstone course design. We propose to match FE and PE topics with the individual department's focus areas (e.g., Operations Research, Human Factors, Manufacturing) to better understand why some syllabi lack evidence of certain FE and PE topics in the capstone course. We will also explore the connection between capstone course design and student career efficacy to help develop a common guideline for any Industrial Engineering capstone course.

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