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PAPER

Enhancing the Industrial and Systems Engineering Capstone Design Course through a Collaborative Approach

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ABSTRACT

This paper explores the current strengths and challenges of an Industrial and Systems Engineering (ISE) senior capstone design course in an ABET-accredited program. We aim to propose changes to improve the course through collaborative discussions with the course instructor. The major contribution of this consultation work is that—by leveraging the educational expertise in the field of engineering education research—it serves as a promising testament to the transformative potential of collaboration efforts in driving educational excellence in course design, delivery, and assessment of a senior capstone design course in a traditional engineering department. Consultations with the Capstone course instructor uncovered some gaps. In particular, we propose the inclusion of learning outcomes that focus on Fink's Taxonomy of Significant Learning dimensions that have not been sufficiently addressed in the current version of the course to extend beyond the cognitive domain to encompass social and emotional aspects of learning, namely the Human Dimension, Caring, and Learning How to Learn. Recommendations were shared with the Capstone design instructor for potential future implementation through the engineering education faculty overseeing the engineering course improvement initiative.

KEYWORDS

senior capstone design, course improvement, consultation

1 INTRODUCTION AND MOTIVATION

This paper documents and analyzes the processes and findings of collaboratively participating in a senior (final-year) undergraduate Industrial and Systems Engineering (ISE) Capstone Design Course improvement consultation project. Measured against the criteria set by ABET (Accreditation Board for Engineering and Technology), the primary objective of this study was to gain a clear understanding of the strengths and challenges of the Capstone Design Course and to identify ways

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it can be improved. This understanding informed the development of our proposed changes. Intentional study of engineering senior capstone design projects with an eye towards course improvement offers an invaluable opportunity to enhance the educational experience for future engineering students. By carefully examining the structure, implementation, and assessments of senior capstone projects, we were able to identify areas for improvement and opportunities for innovation and change within the engineering curricula and pedagogy. Understanding the effectiveness of current formats, approaches, and assessment methods can further inform strategies to optimize student learning outcomes.

This work—which partially fulfills the course requirements for a graduate engineering education course in applied design and assessment of educational experiences in engineering that involves an active engagement and consultation with the instructor of an engineering course—contributes to the ongoing evolution and continuous improvement of this critical component of the undergraduate curriculum for the engineering department. Further, researching senior capstone projects enables the exploration of emerging trends, technologies, and interdisciplinary collaborations shaping the field of engineering. By continuously refining and adapting senior capstone experiences, educators can better prepare students for the challenges and opportunities they will encounter in their future careers.

Our study ultimately contributes to the ongoing evolution and improvement of a critical component of engineering education, ensuring that graduates are equipped with the skills, knowledge, and mindset necessary to thrive in a rapidly changing world. Specifically, this work sets out to answer the following research questions:

RQ-1: What are the current strengths, challenges and areas for improvement?
RQ-2: What are some ways to improve the capstone design course in its current form in reference to both faculty input and relevant educational research?

2 RELATED WORK

To assess our current states of knowledge on research about teaching and assessing project-based senior capstone design courses, it is useful to first review the ABET general criteria for accrediting undergraduate engineering programs, focusing on Criteria 3 and 5, which have the explicit goal of preparing graduates to enter the professional practice of engineering—consistent with the nature and purpose of the course that is taken by final-year students immediately before transitioning into the workforce. Specified under the ABET Criterion 5(d) for Curriculum [1], accredited programs must include "a culminating major engineering design experience that 1) incorporates appropriate engineering standards and multiple constraints, and 2) is based on the knowledge and skills acquired in earlier course work." Like most senior capstones in engineering for their respective majors, the Industrial and Systems Engineering senior capstone design project course satisfies this particular requirement for the ISE undergraduate curriculum.

Project-based learning (PBL) in STEM has been shown to challenge and motivate students and allows them to learn to analyze, think critically, and engage in higher-order thinking skills [2, 3]. The current capstone design course, inherently by its primary purposes in the curriculum, fulfills most, but not all, of Criterion 3(1) to (7) for Student Outcomes. The specified ABET outcomes, quoted verbatim, are as follows:

1. "An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.

2. An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
3. An ability to communicate effectively with a range of audiences.
4. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
5. An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.
6. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
7. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies."

For comparison, the current course learning objectives are discussed in this paper, and the extent to which they are in congruence with the latest ABET requirements will also be explored in later sections.

Consistent with ABET requirements, students in engineering capstone design courses are required to demonstrate their ability to use a broad range of critical thinking skills to address complex problems by drawing upon discipline-specific knowledge from previous courses while acquiring new knowledge and skills necessary for the contexts applicable to their specific projects [4–6]. However, even though capstone design courses mark a pivotal transition from school to work for undergraduate engineering students, there exists a lack of systematic studies on the teaching of capstone design courses, impeding our understanding of how teaching practices in such courses correlate with learning outcomes [4]. To fill this gap, Pembridge and Paretti [4] developed a comprehensive description of the 28 pedagogical practices used by capstone instructors from a functional perspective—with nine functions such as challenge, provide exposure, and build rapport—that can serve as a future research framework.

Further, Paretti et al. [6] highlighted the importance of self-directed learning experienced through the capstone design process that provides critical preparation for professional practice in managing both knowledge and time. Studies aimed at introducing novel capstone design course design and assessment methods in specific engineering disciplines continue to emerge in recent years, such as the study that details how an electrical engineering capstone design course can make use of a "four-dimensional" practical teaching mode to allow students to experience complex engineering problems that are more realistic [7].

Previously, Beyerlein et al. [8] conducted a national study that aimed at understanding assessment practices in capstone design courses across engineering disciplines. Their findings indicated that some ABET criteria are not thoroughly assessed in current capstone design courses, leading faculty members to express interest in collaborating on assessment development and implementation efforts. Their study also highlighted faculty members' uncertainty regarding reliable assessment practices, including the drafting of course objectives, selection of appropriate assessment strategies, effective sampling of material, and addressing potential mis-measurement of student achievement. Further, there has been strong interest in describing the status quo of engineering capstone education and in sharing successful practices and efforts to improve how engineering colleges conduct capstone design courses [9–11], and more generally, the unique benefits of PBL in various engineering education contexts [12–15].

In particular, PBL has gained prominence in engineering education due to its ability to enhance critical thinking, problem-solving, and collaboration—essential skills for future engineers. Recent studies highlight the positive impact of PBL on student outcomes in disciplines such as signals and systems, biomedical engineering, and civil engineering. For example, students who engaged in PBL demonstrated superior conceptual understanding and exam performance compared to those taught through traditional lecture-based methods [12]. Furthermore, the integration of PBL in engineering programs has shown improvements in problem-solving abilities, teamwork, and accreditation outcomes [13]. PBL's active, hands-on approach ensures better preparation for addressing real-world engineering challenges, such as sustainability and safety [14]. Additionally, the implementation of PBL in civil engineering programs has been linked to enhanced acquisition of generic competencies and project development skills [15]. In terms of innovation, a PBL study reports on a prototype project-based engineering course that utilized asynchronous instruction within the general engineering curriculum during the COVID-19 pandemic. This course was successfully adapted from an in-person format to simulate the experience of a cross-border engineering workplace [16]. Therefore, involving engineering education researchers in collaboratively providing consultation to faculty teaching undergraduate engineering design capstone design courses is a logical extension of course improvement efforts.

The next section offers a detailed overview and background of the capstone design course, providing essential contexts for our subsequent recommendations.

3 BACKGROUND AND OVERVIEW OF CURRENT COURSE STRUCTURE

The primary goals of the ISE senior capstone design course revolve around developing students' problem-solving, engineering design, teamwork, and communication skills to address open-ended engineering problems effectively. Through a structured design process, students learn to manage projects, communicate their progress and results, and adapt to evolving project requirements and objectives. Specific course objectives and learning materials, as well as key learning activities and assessment components, are outlined in detail in this section.

3.1 Course objectives

The legacy course objectives, provided to us by the course instructor, are outlined for each of the two semesters. They are structured to ensure that students achieve proficiency in key areas such as project scoping, data analysis, team collaboration, and effective stakeholder communication. Course objectives for the capstone design course in both the fall and spring semesters are shown in Figure 1.

Further, the course content is carefully structured to cover essential topics, with approximately 60 percent focused on project coordination, management, and communication skills. The remaining content delves into project design, data analysis, and performance evaluation. By integrating theoretical knowledge with practical application, the senior capstone project equips students with the skills and competencies necessary to thrive in their chosen field of engineering and make meaningful contributions in their future employment.

3.2 Course structure, format and prerequisites

In its current form, this year-long senior capstone project course, taken by ISE students in the last year of their program, spans two semesters and follows a sequential design format, integrating lectures with practical project work conducted in teams of three to four students. Specifically, tasks required in the second-semester sequence of the project are arranged in a logical order designed to progress in steps that build upon each other. While the capstone requirements are spread over two semesters logistically, the instructor considers it as one single course that spans the entire academic year.

Course communication and announcements, which primarily occur through Canvas, that facilitates regular check-ins to maintain continued engagement of students, are essential, especially during the spring semester when there are no regularly scheduled classes to attend. Canvas is a popular learning management system (LMS) commonly used in educational institutions to facilitate online learning and course management. Further, students are given detailed information concerning important policies regarding late submissions, attendance expectations, academic integrity, and accommodation for disabilities. Together, this reflects the course instructor's commitment to fostering an inclusive and ethical learning environment. Prerequisites for the course include a minimum grade requirement in several within-major ISE courses; this ensures that students possess the necessary background knowledge to excel in the capstone project.

Fall (First) Semester

1. Describe the life-cycle stages of a project and define how to measure project performance;
2. Translate sponsor-provided challenges into an industrial and systems engineering design problem statement and project scope;
3. Obtain, analyze, and synthesize relevant knowledge resources related to project scope;
4. Identify appropriate constraints (accessibility, aesthetics, codes, etc.) and items to consider (public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors) during project planning.
5. Apply industrial and systems engineering and project management methods, tools and techniques to real-world, team-based projects with external sponsors.
6. Design an appropriate data collection and analysis plan to support project goals.
7. Work effectively on a team (create a collaborative and inclusive environment, establish goals, and plan tasks) on a real-world project, interacting with external stakeholders.
8. Effectively communicate project scope and progress via written documents and oral presentations to different types of stakeholders.

Spring (Second) Semester

1. Design a system or process to meet desired needs and specifications, while satisfying identified constraints (accessibility, aesthetics, codes, etc.) and considering identified items (public health, safety and welfare, as well as global, cultural, social, environmental, and economic factors), all while accounting for risks and trade-offs during design.
2. Apply industrial and systems engineering and project management methods, tools and techniques to real-world, team-based projects with external sponsors.
3. Integrate relevant information and prior ISE coursework to develop alternative design solutions.
4. Implement an appropriate data collection and analysis plan to support project goals.
5. Identify and evaluate the implications of design solution(s) to the broader organization.
6. Design and apply evaluation criteria to select the preferred solution given the unique context for the project.
7. Work effectively on a team (provide leadership, create a collaborative and inclusive environment, and meet objectives) on a real-world project, interacting with external stakeholders.
8. Effectively communicate project progress, findings, and recommendations via written documents and oral presentations to different types of stakeholders.

Fig. 1. Course objectives for the year-long capstone design course

3.3 Course materials

Key course materials include the Project Management Institute's Guide to the Project Management Body of Knowledge (PMBOK® Guide) [17], accessible for free through the library at the university. This guide serves as a foundational resource, providing students with industry-standard project management practices. Student teams also use a variety of software, including statistical and data analysis tools such as Python and R, optimization software such as AMPL, LINDO, and Gurobi, as well as project management and simulation platforms, among others. Further, students are required to create and print posters for the end-of-semester symposium event within a given budget. These materials are needed to ensure that students are well-prepared to tackle their projects with a solid theoretical and practical grounding, as well as to showcase their work in a standardized format for presentation.

3.4 Teaching and learning activities: Lectures, project work, and meetings

Class sessions, especially in the first semester that starts in August, encompass discussions, lectures, and exercises aimed at enhancing students' understanding of project management techniques and their application to real-world engineering challenges. Important lectures covering the various topics, such as concept generation, mind mapping, affinity diagrams, morphological charts, and design considerations, were given. Further, the course emphasizes structured systems engineering, incorporating the acquiring of hands-on learning of project management, planning, executing technical projects, designing solutions, stakeholder communication, and teamwork skills. Throughout the course, students engage in regular meetings with their project teams, technical advisors (i.e., their assigned faculty), and project sponsors.

Students are first asked to select the top 10 projects that interest them early in the first semester and are then assigned to one of the projects and teams. A wide range of projects that cater to diverse interests and strengths are available for teams to choose from, some examples of which include supply chain work movement analysis, smart metal additive manufacturing, multi-process scheduling optimization, manufacturing predictive environmental controls, improving post-quenching product quality, under-cutter delay analysis, and commonwealth mobile threat detection, to name a few. Project teams have their "meet your team day" and "meet your client day." They are also given the opportunity to visit their sponsor site.

This course offers students an immersive learning experience, requiring an average commitment of approximately eight hours per week. This includes attending two 50-minute classes (less structured class times for the second half of the year-long capstone design course), participating in a team meeting lasting 30–60 minutes, and engaging in advisor and sponsor meetings, each lasting around 30–60 minutes for weekly check-ins and updates on progress. Additionally, students are expected to allocate individual work time for project-related tasks. By the beginning of the spring semester, students are expected to have completed approximately 60% of the detailed design of their solutions, with implementation scheduled for mid-February and testing and improvement activities spanning March. Project work is expected to be completed by April 1st, with the following month dedicated to project close-outs. At the conclusion of the second semester in May, teams are asked to submit their final presentation video and a final report and participate in a senior project symposium.

By engaging students in discussions, lectures, and hands-on exercises, the course fosters a deep understanding of project management techniques crucial for their future careers. Regular interactions with project teams, technical advisors, and sponsors, along with site visits, enhance the practical learning experience. The commitment required from students is largely reflective of the demands of professional engineering roles to help prepare them for the workforce. This rigorous engagement better ensures that by the end of the academic year, students are well-prepared to manage and execute engineering projects efficiently.

3.5 Course assessments

Assessment within the course is designed to reflect the diverse nature of project work and the various skills students develop throughout the year. The senior capstone project entails a comprehensive set of deliverables, collectively contributing to the holistic evaluation of students' performance. Assignments account for 25% of the total grade and encompass a variety of individual and team tasks, such as impact forms, design considerations, quizzes, and in-class activities. These assignments, along with their specifications, are accessible through Canvas. Additionally, regular update meetings with members of the teaching team, scheduled at least twice per semester, constitute 5% of the grade, ensuring ongoing communication and progress monitoring.

A significant component of the evaluation is the final presentation, which requires students to create a consulting-style video summarizing their project journey comprehensively. This presentation, due before the symposium, carries a weight of 10% in the final grade. Similarly, the written final report, structured similarly to a conference paper and covering the project from inception to completion, constitutes another 10% of the grade. Both the final presentation and report serve as culminating deliverables, encapsulating and highlighting students' efforts and achievements throughout the course. Students receive valuable feedback from both their advisors and project clients on criteria such as solution quality, communication, and achievement of project objectives.

Professionalism is integral to the course, accounting for 10% of the grade, emphasizing the importance of representing oneself, the team, and the university with integrity and professionalism. Student conduct is evaluated based on feedback from various stakeholders, including clients (i.e., industry sponsors), advisors, teaching team members, and peers. This evaluation encompasses factors such as punctuality, communication, teamwork, adherence to guidelines, and engagement with course activities.

Feedback and assignments from both clients and advisors are essential components, ensuring alignment with project expectations and technical requirements. Peer evaluations, conducted using the CATME system [18], gauge individual contributions within teams and influence grades for symposium deliverables and the final written report—the evaluation scale adjusts final individual grades based on peer feedback, emphasizing equitable teamwork and contribution.

This comprehensive assessment strategy, along with the detailed course materials and structured learning outcomes, ensures that students are not evaluated only on their academic and project work but also on their professional development and ability to work effectively in teams. Overall, the course schedule, detailed with class topics and assignment deadlines, provides a structured framework for students to navigate their project milestones and deliverables effectively.

4 METHODOLOGY

The successful execution of this consultation project undertaken at an R1 institution with a significant engineering enrollment in the mid-Atlantic region of the United States rested heavily on careful planning prior to faculty consultations. The instructor for the course was selected for interview from a list of engineering courses and instructors—most of whom were teaching-track faculty in a department of engineering—that were identified as being interested in the course improvement projects. The instructor, responsible for all sections of the ISE capstone design course with a total of 199 students, currently holds the position of Collegiate Professor in the ISE department, a role that emphasizes academic instruction and includes additional responsibilities related to student engagement and service.

The process began with preparing a list of questions to serve as starting points for discussion during a semi-structured interview. Questions included: 'Have ISE students taken mostly the same courses in their program, and how does this affect their participation and performance in the course?', 'How do you effectively assess the complex and multifaceted nature of senior capstone projects?' and 'How can feedback be used to inform continuous improvements in course design and assessment practices?' The points discussed and opinions shared formed the foundation for an overall impression across the various topical areas.

The capstone design course Canvas site served as the primary information source for gathering details on the current course format, structure, required materials, and assessment methods to identify areas for improvement. Various course documents and class lecture slides were made available, such as those on project lifecycles and team charter discussing elements of problem statement, understanding and addressing business goals, objectives, issues, opportunities and others.

Consultations with the course instructor were then conducted through email and in person to discuss their perspectives on the course and to gather feedback, while exploring emerging trends in engineering education. An in-person interview with the course instructor lasting about an hour provided essential clarifications and more thorough contexts to accurately interpret the given information about the course on Canvas. It formed the basis on which our impressions were analyzed and a situation analysis was conducted, and on which our targeted improvement recommendations were made and communicated to the course instructor through the engineering education faculty for this consultation project.

The consultation process involved the primary instructor of record as introduced above, who voluntarily consented to participate in the process. No specific students or teams were discussed by name, ensuring that third-party confidentiality was not at risk. Furthermore, no personal information about the instructor were solicited. As the data collected pertained solely to the course for the purpose of course improvement, this study was not considered human subject research.

5 FINDINGS AND DISCUSSION

During the final weeks of the consultation project, the gathered data were analyzed for common emphases and overall impressions (refer to Table 1), culminating in the formulation and brainstorming of recommendations for course enhancement. This was followed by the preparation of a targeted course improvement proposal that outlines specific changes supported by both faculty input and educational research references.

Table 1. Impressions from analyzing course syllabus and interview with the course instructor

Emphasis	Description
Fostering Acquisition of Professional Skills	The emphasis given to project management skills, problem-solving, and systems thinking highlights an overarching goal of preparing students for real-world challenges and employment as engineers.
Focus on Communication and Collaboration	The emphasis on communication skills, team dynamics, and collaboration underscores the importance of effective interpersonal skills in project-based learning environments and in future workplace.
"Induced Chaos" to Mimic Real-World Scenarios	This course emphasizes the importance of creating a project learning environment that mirrors less well-defined real-world industry experiences; this is different from solving a given design problem in some other disciplines (e.g., mechanical engineering).
Challenges Concerning Sponsors of Senior Projects	The course structure involves regular meetings with industry sponsors; however, sponsors vary in their level of engagement, posing significant challenges.
Faculty Involvement and Support	The recruitment of volunteer faculty in advising team projects, providing technical support, and guiding students through challenges indicates the critical roles of faculty support in facilitating student learning and project success. In connection to this, faculty members are financially incentivized to engage with teams regularly and grade final reports.
Feedback Mechanisms and Student Accountability	The use of feedback mechanisms, performance evaluations, and explicit documentation of student contributions underscores the importance of accountability and continuous assessment for improvement.
Course Evolution and Adaptation	The course has evolved over the years, with changes made to improve structure and effectiveness. The emphasis on continuous course improvements and course evolution reflects a recurring focus on adaptability and the importance of continuously refining the program to better meet the needs of students, faculty, and the industry.

5.1 Situational analysis of strengths and challenges

To provide answers to RQ-1, insights were gained from conversation with the course instructor concerning the strengths and challenges of the course in its current iteration. The evolving landscape of capstone education research informs the need for a detailed situational analysis of the current course. Such an analysis better enables a comprehensive understanding of the course's strengths, weaknesses, and challenges, laying the groundwork for a targeted improvement strategy grounded in reality and the actual status quo. This capstone design course is required for all graduating seniors in the ISE undergraduate program. Unlike some other programs—such as the Department of Electrical and Computer Engineering that allows students to choose their focus areas—students enrolled in the undergraduate program in ISE do not have such options. All ISE students would have taken the same set of core courses throughout their four years, supplemented by nine ISE technical elective credits (plus other engineering science/technical, general education, and free electives). Because of this, it is less likely that students would be unprepared to engage in the required tasks that call for them to apply knowledge gained from the ISE undergraduate curriculum. However, there are always opportunities for students to expand and build on skills that are not strictly a part of the ISE curriculum—for example, some students may wish to take this opportunity to acquire or brush up on their coding proficiency and choose to be in charge of aspects of their team project that make use of this skill set. However, team members do not have fixed assigned roles, and active participation in consultation with other team members is actively encouraged.

The course is team-taught; the teaching team consists of the course instructor, a full-time staff who handles sourcing student projects from industry sponsors, three graduate teaching assistants, and faculty advisors. There were 52 teams for the academic year when this consultation project took place; each team was assigned a different project. A major challenge is that the level of complexity may not be uniform across all projects for the teams, potentially raising questions about fairness. Further, the engagement level of industry sponsors (whom students refer to as 'clients,' with both terms used interchangeably in the course) can vary, as can that of the faculty advisors, which may compromise the learning experience of students. Further, the course also does not have regularly scheduled face-to-face class meetings, especially in the second half of the course; this could prove challenging for the course instructor to more closely monitor how students are managing their learning and workload.

Additionally, the course objectives can be more effectively analyzed by grouping related requirements, as demonstrated in our analysis and presentation in Figure 2, complementing their individual listing in Figure 1.

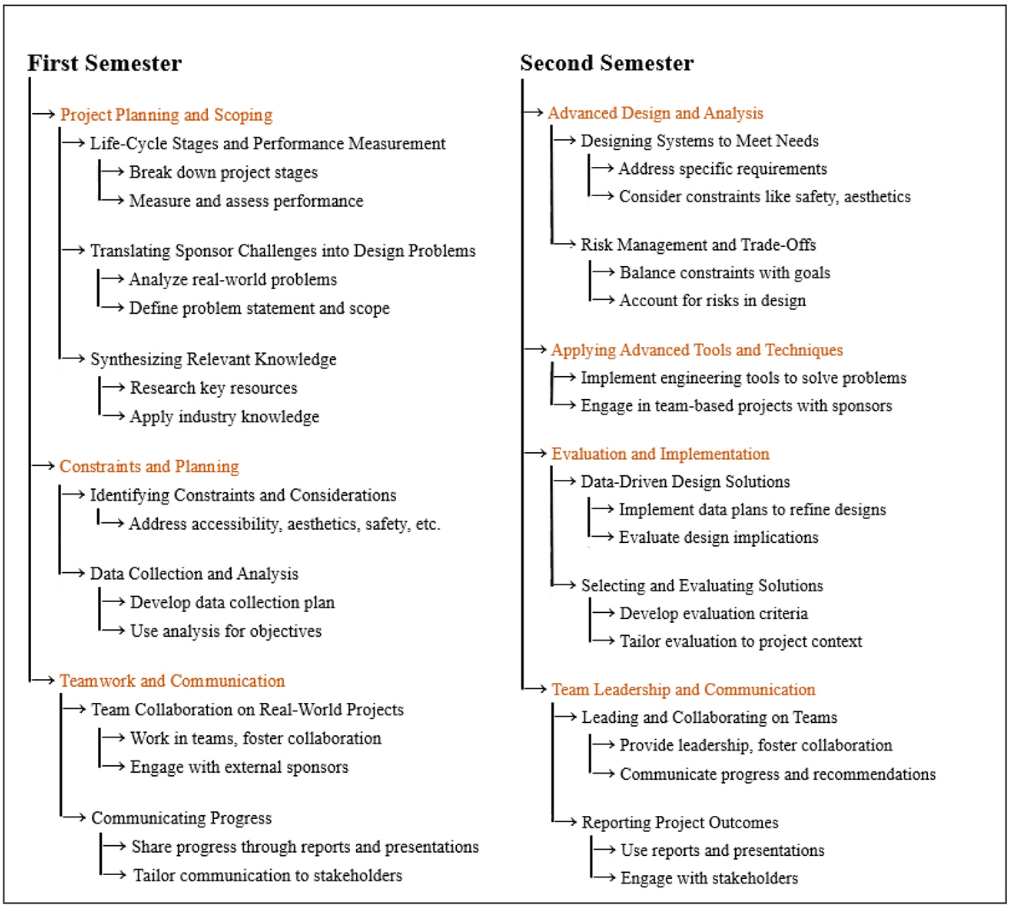

Fig. 2. Grouping course objectives by related requirements

Overall, ABET student outcomes [1] appear to be largely and fundamentally matched by the course objectives, as shown in Figure 1, for the ISE capstone, even though they may not use the exact same wordings or language, possibly due to version updates of the ABET document. For example, ABET Student Outcome 5: "an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives" is directly mirrored by Course Objective 7: "work effectively on a team (provide leadership, create a collaborative and inclusive environment, and meet objectives) on a real-world project, interacting with external stakeholders." In addition, wordings of additional objectives were also modified in course objectives to give them a more ISE-focused or specific context, such as, "Translate sponsor-provided challenges into an industrial and systems engineering design problem statement and project scope."

The three components of content, assessment, and pedagogy for this capstone design course may not be in perfect alignment due possibly to the course having gone through several iterations of updates through the years. The current instructor was also not the faculty initially responsible for drafting the official course syllabus. Assessment and pedagogy could have been modified during course improvement efforts, but course content to deliver the learning outcomes typically remains the same due to procedural limitations on the instructor's ability to modify them from year to year. While most of them are well-aligned, some are not. For example, professionalism is given a weight of 10% in assessment, in which students are expected to act or behave "in a manner consistent with that of an ISE professional and the corresponding code of conduct and ethics;" however, this was not a part of course objectives. This oversight also becomes apparent from its absence from Figure 2.

5.2 Proposed improvement and discussion

While the lack of uniformity in project complexity and sponsor engagement are important issues, they are not easily modifiable or actionable due to the practical limitations of availability. However, revising the course objectives presents a more realistic option, as ABET accreditation explicitly permits this after meeting the required outcomes ("...plus any additional outcomes that may be articulated by the program" [1]). This forms the basis for our answers to RQ-2.

It is critical to have specific outcomes to ensure that the capstone design course prepares students not only in technical skills but also in personal and professional development, equipping them with the tools necessary for continuous growth and adaptability in their careers. From the analysis above, it is clear that the revision would benefit from explicitly incorporating professionalism and ethics into the course objectives for better alignment with assessment.

Further, for a senior capstone design course, aligning learning outcomes with Fink's Taxonomy of Significant Learning [19] offers a comprehensive approach that not only addresses the acquisition of knowledge but also fosters a range of skills and attitudes beneficial for future engineers. It has been successfully used as a framework in engineering education [20–22]. Fink's Taxonomy of Significant Learning (see Figure 3) is a framework proposed by L. Dee Fink to guide educators in creating transformative learning experiences for students. It comprises six categories of learning objectives that represent different levels of learning, namely, Foundational Knowledge, Application, Integration, Human Dimension, Caring, and Learning How to Learn with "each category of significant learning contains several more specific kinds of learning that are related in some way and have a distinct value for the learner." In contrast to Bloom's original and revised taxonomies [23–25], Fink's Taxonomy is non-hierarchical, emphasizing the interaction between its elements to stimulate the other kinds of learning. Fink's Taxonomy offers a holistic perspective on learning, acknowledging the interconnectedness of its categories. Moreover, unlike Bloom, Fink's taxonomy extends beyond the cognitive domain to encompass emotional and social aspects of learning (see Figure 3).

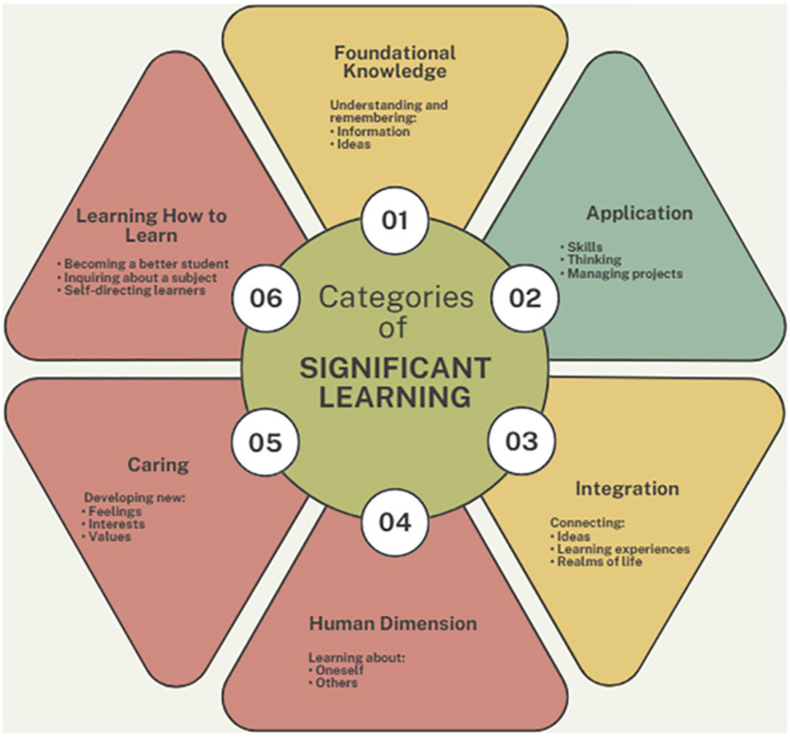

Fig. 3. Fink's Taxonomy of Significant Learning, adapted from [19]

We propose the inclusion of learning outcomes that reflect Fink's emotional and social aspects that have not been sufficiently emphasized in the current version: Human Dimension, Caring, and Learning How to Learn. Human Dimension emphasizes students' understanding of themselves and others, exploring self-image, self-ideal, interpersonal dynamics, and the discovery of what they have learned that could have personal and social implications. Caring reflects the extent to which students develop new feelings, interests, or values about a subject, driving motivation and engagement. Learning How to Learn focuses on students' grasp of the learning process itself, including methods for inquiry and self-directed learning, facilitating ongoing and effective learning in the future. These dimensions collectively enrich the learning experience by fostering personal growth, motivation, and the development of lifelong learning skills. Lifelong learning skills are essential for engineers, particularly in the face of rapid technological advancements like artificial intelligence (AI). These skills enable engineers to adapt to evolving technologies, innovate and problem-solve effectively, consider ethical implications, and maintain career longevity.

An additional learning outcome is to recognize the importance of professionalism and ethics (part of ABET Student Outcome 4), which is the focus of the proposed Learning Outcome 1 (LO1). In addition, ABET Student Outcome 7: "an ability to acquire and apply new knowledge as needed, using appropriate learning strategies" was not featured in the current iteration of the course objectives; thus, in line with Fink's Dimension of Learning How to Learn, we propose the addition of this as LO3. Again, lifelong learning is an indispensable skill and mindset that will prepare future engineers in the ever-changing work and socioeconomic environments. Surprisingly, this is not articulated in the ABET Student Outcomes. We propose incorporating this critical outcome as LO2. A summary of the proposed Learning Outcomes is outlined in Table 2.

Table 2. Proposed additions to course learning outcomes based on Fink's Taxonomy

Learning Outcome	Description	Fink's Dimension
LO1	Students reflect on their personal and professional growth, recognizing their evolving role as engineers in society and developing a deeper understanding of the meaning of professionalism and ethical implications of their work.	Human Dimension
LO2	Students develop a strong sense of professional responsibility and a commitment to contribute positively to the engineering profession and society, motivating them to pursue lifelong learning and engage in sustainable practices.	Caring
LO3	Students demonstrate the ability to independently acquire and apply new knowledge and skills relevant to the practice of engineering, effectively utilizing resources to learn beyond the classroom setting and into their professional careers.	Learning How to Learn

Of note, intentional design of student learning outcomes in senior engineering capstone design courses has continued to yield fruitful results [26]. Including these learning outcomes, LO's 1 to 3, will likely not require significant additional resources in terms of obtaining approval and the requirements of new pedagogical activities and assessment methods. Thus, the feasibility for implementation represents the primary strength of these proposed improvements. The major limitation mainly concerns changing the course syllabus. At the institution where this course consultation took place, instructors are only allowed to implement course revisions that do not require formal academic governance approval only if they are considered "minor" revisions of 20 percent change or less. In that case, only administrative review is required per the institution's undergraduate/graduate program approval guidelines.

LO1 is already being assessed partially through feedback from various stakeholders. All three learning outcomes can also be assessed by using weekly reflective journals that have been successfully adopted by extant pedagogy studies [6]. Further, LO3 can also be assessed by the extent to which students are able to actively acquire and correctly apply skills beyond those taught in the standard ISE curriculum and solve problems in new contexts, as evidenced by their deliverables.

Continuous improvement and innovation in project-based curricula, such as capstone design courses, is crucial, as studies have continued to show that this learning modality is significantly more effective than lectures in enhancing students' understanding and application of concepts [12–15].

6 LIMITATIONS AND FUTURE DIRECTIONS

There are some limitations to this current work. First, the feasibility of implementing these proposed changes with regard to resources and additional workloads may remain an area of concern for some. Further, the recommended changes may not be generalizable to other institutions and other departments that may face unique challenges and constraints in modifying legacy course learning outcomes.

We also would like to acknowledge that conventional assessment methods may not fully capture the essence of our newly proposed learning outcomes, particularly those pertaining to 'future-looking' skills crucial for students' professional development as students are increasingly facing the ever-changing job demands brought on by the advances in artificial intelligence. Although the current project did not involve post-implementation empirical data collection, which is beyond the scope of this paper, future studies should explore the extent to which the proposed changes can be adopted, their reception among students and teaching staff, and the potential impact of the proposed learning outcomes. This will further contribute to the ongoing efforts to enhance course effectiveness and enrich student learning experiences.

7 CONCLUSION

We have largely achieved our goal of leveraging educational expertise in engineering education research to propose targeted changes aimed at enhancing the design, delivery, and assessment of an engineering senior capstone design course, the results of which were shared with the course instructor through the engineering education faculty overseeing the engineering course improvement initiative. The course consultation process yielded valuable insights and revelations. At the start, a thorough understanding of the course's structure, pedagogical strategies, and assessment methods was attained. This led to an exploration of the course's strengths and potential areas for improvement, informed by existing literature on pedagogical research and consultations with the course instructor. Initially, there were concerns that only minimal enhancements could be suggested, given the course's extensive history and iterative development. For example, noteworthy improvements, such as the introduction of the Sponsor Liaison role to better streamline the procuring of potential projects, had significantly bolstered project acquisition and quality control over time. However, a shift in perception occurred as the consultation process unfolded and deeper engagement with educational research literature was undertaken. Overlooked aspects of course design were identified, revealing opportunities for enhancement that the capstone design course instructor may not have considered beyond fulfilling ABET requirements. These include the more prominent incorporation of social and emotional aspects into the course learning outcomes.

Further, from the perspective of the graduate-level design/assessment course, the collaborative nature of working with a course instructor proved invaluable; this has facilitated practical proposals or suggestions for changes that could directly benefit students within an authentic learning environment. This stands in stark contrast to some other educational assessment and design courses, where students are tasked with designing an engineering course from scratch, often relying on completely hypothetical scenarios. In such cases, relevant situational factors may not be fully addressed, potentially compromising their practicality and usefulness.

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