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Enhancing Engineering Capstone Design Preparedness: A Systematic Curriculum Approach

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Introduction

Engineering education is pivotal in equipping students with the technical and soft skills necessary to tackle real-world challenges, thereby playing a crucial role in societal innovation and technological advancement. Central to this educational journey is the capstone design project, an essential component of the final year curriculum that not only serves as a significant milestone for aspiring engineers but also acts as a vital bridge between academic learning and practical application.

Capstone projects challenge students to synthesize and apply their comprehensive knowledge through hands-on projects within a team-based environment, mirroring professional engineering practices. These projects are intended to prepare students for the complexities of real-world engineering tasks and reflect the dynamics of professional practice. However, recent studies have consistently highlighted a significant "context gap" between the theoretical knowledge acquired in academic settings and the practical skills demanded by the industry. This gap often leaves students underprepared for the realities of engineering practice as they conclude their education.

Addressing this gap, our study proposes a multi-tiered curriculum strategy designed to enhance student readiness for capstone design projects by embedding systematic, hands-on experiences throughout the undergraduate program. The goal of this redesign is to cultivate a holistic design thinking mindset among students by providing early exposure to design principles and iterative project experiences. This approach aims to remedy the current shortcomings in engineering education by more effectively preparing students for their capstone projects and, ultimately, their careers in engineering.

This introduction outlines our response to the identified needs by proposing specific educational enhancements aimed at closing the gaps highlighted in employer satisfaction surveys. By integrating innovative pedagogical methods such as flipped learning, gamification, and project-based learning, we seek to enhance student engagement, improve learning outcomes, and ensure graduates are well-prepared to meet the demands of the modern workforce. This systematic approach to curriculum design focuses on developing both hard and soft skills, which are crucial for the success of our graduates in professional engineering settings.

Recent studies in engineering education have consistently identified a gap in student preparedness for real-world engineering practices, particularly as they approach the culmination of their education in capstone projects. Paretti et al. [1] articulate this issue as a "context gap" rather than a "competency gap," focusing on the misalignment between academic experiences and industry expectations. Arsha [2] echoes the sentiment, suggesting that targeted workshops could mitigate skill gaps, emphasizing the need for industry-academia linkages. Mora's [3] examination of professional socialization within a capstone design lab suggests that fostering agency among students could be crucial to bridging the theoretical and practical divide. Butler [4], [5] further corroborates these findings, indicating that simulation-based learning and live experiments in aircraft design could significantly impact student preparedness for engineering practice. These studies collectively highlight the discrepancy between theoretical education and practical application, suggesting that the shortfall in preparedness is not due to students' lack of capability but rather to the inadequacies of current curricula to effectively integrate theory with practice. There is a clear call for a more integrated approach to engineering education that aligns with the dynamic requirements of the engineering industry.

Recent advancements in educational strategies underscore the critical role of integrated learning approaches in bolstering student engagement and academic outcomes. Bond [6] systematically reviews the flipped learning approach in K-12 education, demonstrating its potential to facilitate deeper student engagement and learning autonomy. Similarly, Khan et al. [7] explore the utilization of digital game-based learning and gamification in secondary school science, finding significant improvements in student engagement and learning outcomes. These studies collectively illustrate the efficacy of innovative pedagogical methods in creating more engaging and effective learning environments.

Furthermore, the importance of incorporating soft skills development into engineering curricula cannot be overstated. Kahu and Nelson [8] delve into the mechanisms of student success within the educational interface, highlighting the critical role of engagement in developing essential soft skills such as teamwork and communication. This is echoed by Alhammad and Moreno [9], who investigate gamification in software engineering education, suggesting that such approaches can also foster soft skills alongside technical competencies.

The link between systematic curriculum approaches and enhanced outcomes in capstone projects is clearly articulated in recent research. Almulla [10] demonstrates the effectiveness of the project-based learning (PBL) approach in engaging students and enhancing learning outcomes, which is crucial for the success of capstone projects. Chao et al. [11] further support this by investigating the impact of flipped learning in a computer-aided design curriculum, emphasizing the importance of real-world applicability and interdisciplinary collaboration in engineering education.

Addressing the gap identified in employer satisfaction surveys regarding graduate skills, Buckley and Doyle [12] offer insights into individualizing gamification to improve learning outcomes based on learning styles and personality traits. This approach underscores the necessity of tailoring educational methods to meet the diverse needs of students, thereby enhancing their preparedness for the workforce and addressing employers' concerns about graduate competencies.

In summary, the referenced studies collectively support the notion that integrated learning approaches, emphasizing both hard and soft skills development through systematic curriculum design, significantly contribute to improved student engagement, learning outcomes, and readiness for professional challenges. Such educational enhancements are pivotal in closing the gap highlighted in employer satisfaction surveys and ensuring that graduates are well-equipped to meet the demands of the modern workforce.

In light of this, our study proposes a multi-tiered curriculum strategy designed to enhance student readiness for capstone design projects. This approach aims to cultivate a holistic design thinking mindset by incorporating early exposure to design principles and iterative, hands-on projects throughout the undergraduate program. The goal is to address some of the current shortcomings in engineering education and offer a pathway to prepare students more effectively for their capstone projects and, ultimately, their professional engineering careers.

Literature Review

Tailoring Capstone Preparation to Our Institution's Unique Curriculum

Engineering capstone projects at our university serve as a critical nexus between academic theory and industry practice. Reflecting a dynamic and responsive educational model, our curriculum is designed not only to align with but to actively shape industry standards and expectations. We extend beyond the conventional boundaries of classroom learning by operationalizing feedback from our industry partners into the continuous refinement of our curriculum. This symbiotic relationship fosters a curriculum that is as living and evolving as the engineering field itself, characterized by the incorporation of makerspaces which catalyze hands-on, experiential learning and innovation in functional prototyping, resonating with the concepts advocated by Suriano et al. [13]. These spaces are pivotal in our pedagogy, enabling students to transform theoretical knowledge into practical solutions.

Our curriculum departs from traditional learning models by embracing an active, iterative design process over passive learning methods. We have replaced traditional brainstorming techniques with a comprehensive suite of modern ideation tools. These tools are carefully selected and integrated into our curriculum to foster advanced cognitive processes, enabling students to tackle the ideation phase with a diverse set of strategies. This approach mirrors the complexity of real-world engineering challenges and is supported by a scaffolded learning experience that enhances student abilities in project management and problem definition, thus meeting the evolving demands of the engineering profession.

Bridging the Real-World Gap with Targeted Skill Development

Our structured capstone experiences are directly aimed at bridging the 'preparedness gaps' that Gonzales et al. [14] and Kimpton and Maynard [15] delineate, specifically the translation of academic prowess into professional competence. To this end, our curriculum harnesses cutting-edge, remote collaborative technologies, similar to those explored by Lynch, Agarwal, and Imbrie [16], to simulate the engineering field's diverse and often unpredictable conditions. This innovative educational strategy not only aligns academic learning with professional application but also instills in students a sense of versatility and readiness to navigate and adapt to the uncertainties inherent in engineering careers.

Fostering Soft Skills Through Collaborative Learning

Acknowledging the criticality of soft skills in a professional setting, our curriculum adopts a methodical approach to developing these competencies. Törlind's identification of a soft skills development gap [17] has been pivotal in shaping our strategy to cultivate these skills through the lens of real-world applicability. We integrate collaborative project work and problem-based learning scenarios to nurture communication and teamwork abilities, which are indispensable in modern engineering practice.

Adapting to Emerging Trends for Future-Ready Education

In anticipation of the future trajectory of engineering education, our curriculum embraces the potential of digital learning tools and virtual reality to enhance student learning experiences. These forward-thinking educational mediums, highlighted by Iranzad and Liu [18], are leveraged not just as instructional adjuncts but as essential components of a modern engineering education. They play a crucial role in preparing our students for a future where engineering is increasingly characterized by interdisciplinarity, data-centricity, and rapid technological evolution.

In summary, the curriculum at our institution is meticulously designed to stay ahead of the rapidly evolving landscape of engineering education and the profession. Our commitment is to prepare students who are not only well-versed in engineering fundamentals but are also adaptable and innovative, ready to tackle new challenges and seize opportunities in the engineering field.

Methodology

Description of the Multi-Tiered Curriculum Strategy

The methodology of this study is structured around a multi-tiered curriculum strategy aimed at incrementally developing students' skills necessary for capstone design projects and professional practice. This strategy is based on the implementation of specific initiatives targeted at different stages of the undergraduate engineering program, focusing on enhancing both technical and soft skills through experiential learning, mentorship, and continuous assessment.

The curriculum is structured into three main phases, each designed to build upon the previous one:

1. **Sophomore Year**: Focus on open-ended design projects to stimulate creative thinking and innovation. Instruction shifts from traditional lectures to more interactive, project-based activities that encourage students to explore multiple solutions to engineering problems.

2. **Junior Year**: Introduction of mini custom projects and shadowing of senior capstone projects. This phase aims to deepen technical skills and provide insights into project management and team dynamics.

3. **Senior Year**: Capstone design projects that require students to apply all the skills and knowledge acquired through their coursework in a comprehensive, practical project.

Each phase incorporates specific pedagogical strategies, such as problem-based learning, to enhance understanding and retention of material. The instruction methods include a combination of traditional lectures, interactive workshops, and real-world problem-solving sessions.

Sophomore Year Initiatives: Open-Ended Design Projects

During the sophomore year, our curriculum introduces open-ended design projects aimed at fostering creative thinking and innovation among students. These projects provide early exposure to the complex nature of real-world engineering problems. Students are tasked with identifying issues and generating a wide range of solutions, encouraging a thorough exploration of potential designs without the constraint of finding a single correct answer. This initiative is designed to enhance students' problem-solving abilities and cultivate an innovative mindset, allowing them the freedom to explore various approaches to tackle engineering challenges. We integrate scaffolded knowledge integration, providing structured support to students as they navigate the complexities of engineering design. This approach emphasizes the importance of scaffolded learning environments, particularly in disciplines such as computer science and engineering.

Junior Year Interventions: Mini Custom Projects and Shadowing Senior Projects

In the junior year, our curriculum adopts a dual approach to deepen students' engineering design skills. First, we introduce mini custom projects, which provide students with a more focused experience in the engineering design process compared to the open-ended projects of the sophomore year. These projects are designed to enhance hands-on problem-solving skills and design execution within a well-defined scope. Second, juniors have the opportunity to shadow senior students working on their capstone design projects. This shadowing experience exposes juniors to the dynamics of project management and team collaboration, offering insights into the complexities of completing full-scale engineering projects. Through observation, juniors bridge the theoretical knowledge gained in classrooms with practical, real-world applications.

Rationale for Survey Instrument Selection and Bias Mitigation

We carefully select survey instruments to evaluate confidence levels, preparedness, and curriculum relevance effectively. For instance, we use a Likert scale to capture self-reported confidence and anxiety, complemented by skill assessments that triangulate self-perceptions with actual performance. Recognizing the potential for self-assessment bias, especially in longitudinal studies, we mitigate this by comparing self-assessments with tangible project outcomes and instructor evaluations. This ensures a comprehensive appraisal of students' growth over time.

Data Collection

Data collection was structured around a series of assessments and discussions designed to evaluate students' confidence levels, preparedness for their capstone design projects, and perceptions of the curriculum's relevance to real-world engineering practices. Surveys were administered at three critical junctures: at the beginning of the sophomore year, at the end of the junior year, and upon completion of the capstone project in the senior year. This ensures a focused analysis of the curriculum's direct impact on student preparedness.

At the latter two time points, the survey included additional questions to assess the perceived value of the curriculum enhancements. Discussions were scheduled concurrently with the surveys but were conducted separately to ensure detailed and focused feedback. These discussions were facilitated by educators uninvolved in the teaching of the cohort to maintain objectivity. All participants were assured of anonymity to encourage candid feedback, and all data were handled in compliance with ethical standards for educational research.

Quantitative data from surveys are subjected to within-subject analysis using SPSS software. By comparing individual students' pre- and post-intervention responses, we can isolate the curriculum's effect. This within-subject analysis, particularly for longitudinal data, is crucial for identifying genuine progress and areas for improvement. Constant formative assessment and feedback throughout project phases evaluate students' comprehension and application of engineering design concepts. This feedback-rich ecosystem, which includes peer evaluations, instructor critiques, and industry mentor insights, provides a loop of continuous improvement, shaping not only student growth but also curriculum development.

Data Analysis

The qualitative data from discussions were recorded, transcribed, and analyzed through a rigorous thematic analysis process. This involved an active search for recurring themes, counter-narratives, and any contradictions within the data. For quantitative data analysis, the survey responses were analyzed using SPSS software. The survey was designed around three core themes: anxiety, confidence in skills, and preparedness for the capstone design project. While these themes were based on established theoretical frameworks, the analysis also included non-parametric tests to address potential non-normality of data distribution and variations in group sizes.

This methodological approach ensures a comprehensive understanding of the curriculum's impact on student preparedness, incorporating both quantitative and qualitative data to inform ongoing curriculum development. By maintaining a systematic and ethical approach to data collection and analysis, this study contributes valuable insights into effective strategies for enhancing engineering education.

Methods for Constant Formative Assessment and Feedback

Our curriculum includes constant formative assessment activities to ensure that learning is iterative and feedback-driven. These assessments, conducted at regular intervals throughout each project phase, gauge students’ understanding of engineering design concepts and their ability to integrate these with other vital components such as sustainability, teamwork, and intellectual property law. Feedback is provided in various forms, including peer evaluations, instructor critiques, and industry mentor insights. This feedback-rich environment allows students to refine their strategies continually, learn from their experiences, and enhance their capabilities throughout their undergraduate journey.

The formative assessments serve not only as a tool for student improvement but also for curriculum development. By analyzing the outcomes of these assessments, educators can identify areas within the curriculum that may require modification to better prepare students for the capstone design project and their impending professional careers.

Results

Increased Preparedness: Analysis of Juniors' Confidence and Readiness Post-Shadowing Senior Projects

The curriculum's layered approach has effectively increased juniors' preparedness for their capstone design projects. An analysis of survey data and self-assessments conducted before and after juniors shadowed senior projects indicates a statistically significant boost in both their confidence and understanding of project requirements ($p < 0.05$), as detailed in Table 1. The "Pre-Shadowing" and "Post-Shadowing" columns report the average self-assessed scores from 49 students on a 5-point Likert scale. Notably, the enhancement in juniors' self-confidence was especially pronounced in their capability to manage the intricacies of their forthcoming projects, signifying a solid foundation for their senior year projects. These findings underscore the effectiveness of shadowing senior projects in enhancing juniors' confidence and readiness for their senior year projects.

Indicator	**Pre-Shadowing**	**Post-Shadowing**	**Significance (p-value)**
Confidence in Managing Projects	2.3 ± 0.6	3.4 ± 0.5	< 0.05
Understanding of Project Requirements	2.2 ± 0.7	3.7 ± 0.5	< 0.05
Readiness for Senior Year	2.6 ± 0.4	4.1 ± 0.4	< 0.05

Table 1: Comparative Analysis of Junior Students' Preparedness Before and After Shadowing Senior Capstone Projects

Enhanced Design Thinking: Assessment of Design Thinking Development from Sophomore to Junior Year

The structured enhancements to the curriculum have notably strengthened design thinking skills from the sophomore to the junior year. In the sophomore year, the introduction of open-ended design projects laid a robust groundwork for inventive problem-solving. Building upon this in the junior year, the incorporation of specialized mini projects further deepened the students' engagement with the engineering design cycle. Table 2 highlights the comparative average scores for key design thinking criteria across the two academic years.

The advancement in design thinking is evidenced by the increased sophistication and originality in the students' projects. There was also a notable enhancement in the students' ability to integrate comprehensive design considerations—including factors such as usability, sustainability, and ethical dimensions—into their projects. Quantitative assessments show a significant improvement, with project scores demonstrating an estimated 20% improvement. These results underscore the curriculum's effectiveness in fostering design thinking capabilities throughout the progression from sophomore to junior year.

Design Thinking Metrics	**Sophomore Year Average**	**Junior Year Average**	**Statistical Significance**
Sophistication of Project Work	2.6 ± 1.1	3.2 ± 0.6	< 0.05
Creativity of Design Solutions	3.0 ± 0.8	3.7 ± 0.4	< 0.05
Integration of Multifaceted Considerations	2.1 ± 1.4	2.6 ± 0.6	< 0.05

Table 2: Progression of Design Thinking from Sophomore to Junior Year

Improvement in Soft Skills: Evaluation of Teamwork, Communication, and Problem-Solving Abilities

The systematic curriculum strategy implemented has had a significant and positive impact on the development of students' soft skills. This progress was facilitated through structured team projects and rigorous formative assessments, providing a conducive environment for the enhancement of collaboration and communication competencies. The table below details average scores derived from specific assessments for each soft skill component, both before and after curriculum implementation. The "Statistical Significance" column reports p-values from statistical tests, confirming the reliability of the improvements observed.

Soft Skills Component	**Assessment Tool**	**Pre-Curriculum Average Score**	**Post-Curriculum Average Score**	**Statistical Significance**
Conflict Resolution	Thomas-Kilmann Conflict Mode Instrument (TKI) [19]	3.8 ± 0.7	4.4 ± 0.5	< 0.05
Collaborative Problem-Solving	Collaborative Problem Solving Assessment (CPSA) [20]	3.4 ± 0.4	4.4 ± 0.6	< 0.05
Articulation of Technical Concepts	Technical Presentation Assessment	3.5 ± 0.6	4.6 ± 0.5	< 0.05

Table 3: Soft Skills Development Before and After Curriculum Implementation

Constructive faculty and peer feedback, evaluated through these established assessment tools, were instrumental in identifying notable improvements in critical soft skill areas. Conflict resolution skills were measured by the TKI, which helped students understand and develop their conflict-handling styles. Collaborative problem-solving abilities were gauged using the CPSA, which evaluated the dynamics of group interaction and the effectiveness of collective problem resolution. Finally, the articulation of technical concepts was assessed based on technical presentations, focusing on students' abilities to clearly and accurately present technical information.

We have instituted a uniform evaluative framework applicable to both the original and revised curricula. This framework assesses various aspects of team interactions, from the allocation of roles and responsibilities to the mechanisms of conflict resolution and the effectiveness of communication channels. Through the revised curriculum, structured team projects have become a crucible for developing and refining collaborative skills, which are indispensable in engineering practice.

These advancements were conclusively attributed to the comprehensive and collaborative nature of the design projects, coupled with the multifarious challenges they introduced, rather than being merely incidental byproducts of the educational process.

Positive Feedback Loop: Effects of Constant Formative Assessments on Student Learning and Project Refinement

Incorporating ongoing formative assessments within the educational program has created a dynamic and responsive environment essential for continuous improvement. This structured approach to feedback has enabled students to progressively enhance both their design approaches and learning tactics. The iterative nature of this enhancement process has significantly raised the quality and creativity of their project work. As illustrated in Table 4, the "Baseline Measure" and "Post-Assessment Measure" columns delineate the initial and improved scores across various evaluative dimensions, with the "Percent Improvement" column detailing the extent of these gains.

The innovation potential of project deliverables is assessed through a multi-faceted lens that includes novelty, applicability, and feasibility. We have instituted a set of specific criteria that prompt students to innovate within the constraints of realistic engineering scenarios. This has nurtured a mindset where innovation is not just an abstract concept but a tangible goal, reflected in the practicality and originality of the design solutions presented.

The criteria for novelty challenge students to develop solutions that demonstrate clear advancement from existing alternatives, rewarding divergent thinking and technical creativity. Applicability criteria ensure that students' innovations remain grounded in real-world requirements, addressing actual needs within the engineering field. Feasibility measures the students' ability to foresee and plan for the implementation of their designs, taking into account material constraints, budget considerations, and timeframes. This comprehensive evaluation of deliverables has heightened the caliber of project work, as evidenced by the improved scores following the curriculum intervention.

These enhanced criteria not only elevate the sophistication of the student projects but also instill a deeper understanding of the innovation process within an engineering context. As students grapple with these criteria, they are compelled to balance the daring to innovate against the discipline of practical application. This balance is essential in cultivating engineers who can lead with visionary solutions while ensuring these solutions are viable and impactful in real-world settings. The resulting uptick in project quality post-intervention is not merely in the ingenuity of the ideas but in their readiness to be translated into actionable engineering outcomes.

The data underscores the substantial role that formative assessments play in elevating project sophistication and student growth, as evidenced by the marked increase in project quality and innovation. Furthermore, the feedback mechanism serves as a critical tool for curricular assessment and refinement, helping to maintain an educational structure that is responsive to the evolving needs of students and in alignment with the latest industry standards.

Evaluation Criteria	**Metric of Measurement**	**Baseline Measure**	**Post-Assessment Measure**	**Statistical Significance**
Quality of Project Deliverables	Innovation Index	3.2 ± 0.6	4.1 ± 0.4	< 0.05
Student Learning Improvement	Learning Outcomes Scale	3.5 ± 0.5	4.4 ± 0.5	< 0.05
Curriculum Development Impact	Curriculum Alignment Score	3.3 ± 0.4	4.2 ± 0.6	< 0.05

Table 4: Impact of Constant Formative Assessments on Project Deliverables and Curriculum Development

Discussion

The curriculum's layered approach, as described, aligns with experiential learning theory, which emphasizes learning through experience. According to Kolb's experiential learning theory, the process of learning encompasses four stages: concrete experience, reflective observation, abstract conceptualization, and active experimentation [21]. Shadowing senior projects serves as a concrete experience, allowing juniors to observe and reflect on the application of theoretical knowledge in real-world projects, thus enhancing their understanding and confidence.

The significant increase in juniors' confidence and understanding post-shadowing, as indicated by the statistical analysis ($p < 0.05$), supports the notion that exposure to practical aspects of projects can demystify the complexities associated with capstone design projects. This is consistent with findings by Bandura [22], who argued that self-efficacy (belief in one's capabilities) is enhanced through mastery experiences, vicarious experiences, and social persuasion, all of which can be facilitated by shadowing experiences.

The improvement in readiness for senior year projects as reported in the study mirrors the outcomes observed in similar educational interventions. For instance, Lattuca et al. [23] found that integration of real-world experiences into engineering education significantly contributes to students' readiness for professional practice by providing them with opportunities to apply theoretical knowledge, develop technical skills, and navigate project management challenges.

Development of Design Thinking Skills

The curriculum's nuanced approach to design thinking is methodically measured by several newly introduced metrics that reflect the depth and breadth of students' skill development. In fostering design thinking skills, the curriculum leverages specific interventions to scaffold student growth from the sophomore to the junior year. Sophomore projects are rooted in ideation and conceptual design, while junior projects emphasize the refinement of these concepts into more mature design solutions. The improvement metrics—reflecting an approximate 20% score increase—are carefully chosen to parallel program goals, ensuring the curriculum directly contributes to the desired learning outcomes. Sophistication, creativity, and integration of multifaceted considerations are not mere academic constructs but are quantifiable targets that our curriculum strives to enhance, grounded in the real-world application of engineering principles.

To gauge the sophistication of design thinking, we have introduced a metric assessing the degree to which students' projects meet or exceed user needs and constraints. Sophistication is further evaluated by the students' ability to anticipate and design for future use scenarios, effectively predicting and incorporating potential market and technology evolutions.

Creativity is assessed by students' application of non-traditional problem-solving methods and their ability to synthesize cross-disciplinary knowledge into their designs. We measure creativity not only by the uniqueness of the solutions but also by the practicality and defensibility of their design choices within an engineering context.

Additionally, the integration of multifaceted considerations is quantified through a metric that examines how students balance technical feasibility with ethical, environmental, and socio-economic factors. This holistic approach ensures that the designs are sustainable and responsible, preparing students to make decisions that reflect the multifaceted nature of real-world engineering problems.

Quantitative assessments indicate a 20% improvement in project scores, revealing a statistically significant ($p < 0.05$) leap in students' abilities to synthesize complex requirements into cohesive and innovative design solutions. These additional metrics provide a robust framework for assessing the effectiveness of the curriculum in developing key competencies associated with design thinking, further solidifying the empirical foundation of our pedagogical strategies.

Curriculum Strategy and Soft Skills Development

The curriculum strategy, which included structured team projects and formative assessments, created an environment conducive to the development of essential soft skills. These skills are often developed through interactive and experiential learning rather than through traditional lecture-based teaching methods.

The improvement in soft skills is supported by the reported statistical significance (p-values < 0.05), suggesting that the differences in pre- and post-curriculum scores are statistically reliable. The use of established assessment tools like the Thomas-Kilmann Conflict Mode Instrument

(TKI) for conflict resolution, the Collaborative Problem Solving Assessment (CPSA) for problem-solving, and technical presentation assessments for communication ensure that the evaluations are grounded in recognized methods.

The role of constructive feedback is emphasized in identifying and fostering the development of soft skills. Feedback mechanisms are critical for continuous improvement and for guiding students towards desired outcomes, as they provide students with insight into their performance and areas needing improvement. The enhancement of these soft skills is essential for professional readiness. Employers across various industries highlight the need for graduates who are not only technically proficient but also adept at working in teams, solving problems collaboratively, and communicating effectively.

The limitations of this study are primarily associated with its scope and breadth. The application of the approach within a single educational institution might limit the broader applicability of the findings across varied educational settings or engineering disciplines. Additionally, the reliance on self-reported metrics to evaluate soft skills such as teamwork and communication introduces a degree of subjectivity and may not comprehensively reflect the true extent of the students' skill enhancements.

Subsequent research could extend this study's findings by applying the multi-tiered strategy in diverse institutional and disciplinary contexts to assess its wider applicability. Longitudinal research that follows students into their professional lives could shed light on the long-term benefits of early exposure to design projects and systematic educational strategies. Furthermore, investigations into objective methodologies for assessing soft skill acquisition could augment self-reported data, offering a more rounded appraisal of student development in these essential competencies.

Addressing the Absence of a Control Group

While the curriculum's layered approach aligns with Kolb's experiential learning theory, and results suggest significant improvements in preparedness and design thinking skills, we acknowledge the absence of a control group as a limitation in our study methodology. Without a comparable group undergoing a traditional curriculum, the direct causation between our interventions and the observed outcomes cannot be definitively established. However, the reported increase in juniors' confidence and understanding, alongside the development of design thinking skills and soft skills, align with theoretical expectations and offer a strong inferential basis for the effectiveness of the curriculum interventions.

The study's results are compelling; nonetheless, the reliance on a single group without a control does introduce the potential for confounding variables influencing the outcomes. It could be posited that factors independent of the curriculum changes, such as advancements in student maturity or external educational experiences, may contribute to the improvements. To mitigate this, the interventions were designed to align closely with program requirements and industry expectations, ensuring that the curriculum addresses specific competencies and skills that are both measurable and indicative of readiness for professional engineering practice.

We recognize the challenge in interpreting these results in the absence of a control group and emphasize this as an area for future research. Subsequent studies are encouraged to incorporate control groups to more precisely isolate the impact of the specific curricular changes. Additionally, replication of this study across various institutions and disciplines would not only broaden the understanding of the curriculum's effectiveness but also validate the generalizability of the findings.

Considering the limitations presented by the study's design, we advocate for cautious interpretation of the results. Nevertheless, the observed improvements—particularly those with statistical significance ($p < 0.05$)—provide an initial indication of the positive influence of the curriculum's structured approach on the development of design thinking and soft skills. This preliminary evidence suggests a favorable impact on student preparedness for capstone design projects, meriting further investigation with more rigorous experimental designs.

Considerations for Future Research

While the study offers robust insights into the efficacy of the multi-tiered curriculum strategy, limitations arise from the scope of its application to a single institution. Future research can enhance these findings by exploring the strategy's applicability and scalability across different educational contexts and disciplines. Furthermore, longitudinal studies tracing the professional trajectories of students could provide valuable data on the long-term impacts of systematic design project exposure and targeted educational strategies. As we refine our methodology to include more objective soft skill assessments, we expect to deepen our understanding of how these competencies evolve and contribute to the professional success of our graduates.

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