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Beyond the Project: What Shapes Student Learning in Engineering Senior Design?

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Beyond the Project: What Shapes Student Learning in Engineering Senior Design?

Abstract: This work-in-progress paper examines how pedagogical design choices in senior design courses shape student learning experiences within an Industrial and Systems Engineering program at a large public university. Two senior design models are compared: a traditional, one-semester capstone (ISE498) emphasizing breadth across domains, and a selective, healthcare-focused two-course sequence (ISE520–521) emphasizing sustained client engagement and intensive faculty mentorship.

A mixed-methods research design is implemented, combining pre- and post-course surveys with qualitative analysis of student artifacts and mentoring interactions. The survey instrument targets four domains: professional identity, problem framing under ambiguity, stakeholder engagement, and perceived impact of mentorship.

Preliminary results from early-semester survey data (n=20 for ISE498; n=11 for ISE521) suggest notable differences in students' confidence in navigating ambiguity, stakeholder interaction, and domain-specific identity formation. These early trends motivate continued longitudinal analysis using end-of-semester data.

This study aims to identify how pedagogical design features influence student development and to inform scalable approaches to senior design education.

Keywords: Senior Design, Project-Based Learning, Experiential Learning, Healthcare Systems Engineering, Faculty Mentorship

1. Introduction and motivation

Senior design courses serve as a culminating experience in Industrial and Systems Engineering (ISE) curricula, providing students with an opportunity to integrate technical knowledge, professional skills, and systems-level thinking in the context of real-world problems. These courses often represent a student's final opportunity to engage in open-ended problem solving prior to entering professional practice, and they play a central role in shaping students' perceptions of engineering work and their readiness to operate in complex organizational environments [1], [2].

As engineering practice increasingly extends beyond traditional manufacturing settings, there is growing recognition that graduates must be prepared to operate within socio-technical systems characterized by high variability, multiple stakeholders, and competing objectives. Healthcare systems exemplify these challenges. Health systems engineering problems frequently involve ill-defined objectives, limited or imperfect data, strong human factors considerations, and the need to balance efficiency with patient-centered care. These characteristics pose distinct challenges for engineering education, particularly in the design of experiential learning environments that prepare students for healthcare roles [3], [4].

Traditional senior design models typically emphasize breadth, execution, and client deliverables across a wide range of application domains. While this approach offers exposure to diverse problem types, it may limit opportunities for students to develop deep domain knowledge or sustained engagement with particularly complex systems. In contrast, domain-specific pathways embedded within senior design curricula have the potential to provide greater depth, stronger professional identity formation, and increased confidence in applying engineering tools within a given context. However, there is limited empirical work comparing how different senior design structures influence student learning outcomes, particularly when multiple models coexist within the same academic program [5].

This paper examines two senior design models implemented within the same ISE department: a traditional capstone model and a healthcare-focused pathway. Rather than evaluating individual projects, this work focuses on the pedagogical design features of each model and the ways those features shape student experiences, perceived readiness, and professional development.

The purpose of this work-in-progress study is to compare these two senior design models with respect to project structure, mentorship intensity, client engagement, and early indicators of student development. Using a mixed-methods approach that includes planned surveys, artifact analysis, and faculty observations, the study seeks to inform ongoing curricular decisions and the strategic expansion of healthcare-focused pathways within ISE education.

2. Pedagogical models and course design contexts

This section describes two senior design models implemented within the same ISE program at a large R1 institution. Rather than presenting the courses independently, the models are compared across key pedagogical dimensions, including project scope, student population, client engagement, and faculty mentorship. This approach emphasizes design choices and learning mechanisms rather than course logistics [6], [7].

The traditional capstone model, ISE498, is a required one-semester course taken by the majority of undergraduate students in the program. Projects in this course span a wide range of application domains, including manufacturing, service systems, sustainability, military, and business processes. Projects typically focus on specific operational processes within organizational settings. Teams work with external partners to analyze current-state operations and develop improvement recommendations within the constraints of a single semester. While project scope is necessarily bounded, students are generally responsible for independently framing the problem, managing client interactions, and delivering an end-of-semester solution.

In contrast, the healthcare-focused pathway consists of two application-oriented courses, ISE520 and ISE521, taken by a smaller, selective cohort of students. These courses are designed explicitly around health systems engineering and feature projects conducted in partnership with regional healthcare organizations. The sequence is intentionally scaffolded. In ISE520, the entire class is presented with a single, complex healthcare project that would be appropriately sized for one team in ISE521. Students work in multiple teams, with each team focusing on a specific operational process within the larger system, such as patient check-in, nurse-to-physician handoffs, or room turnover. This structure provides early exposure to project-based learning in healthcare while supporting students as they build domain knowledge and analytical capability. In ISE521, teams independently take on complex healthcare projects, assuming full responsibility for problem framing, data collection, analysis, and client engagement. Together, these courses form a coherent pathway that gradually increases student autonomy while maintaining sustained engagement with complex healthcare systems.

ISE498 is a 3-credit course, while ISE520 and ISE521 are each 3-credit courses forming a 6-credit sequence that satisfies the senior design requirement. The two models differ substantially in student population and cohort structure. ISE498 enrolls a large and heterogeneous group of undergraduate students with varying career interests and prior exposure to specific domains. Team composition reflects this diversity, and projects are often the primary mechanism through which students encounter unfamiliar application areas. By contrast, enrollment in ISE520 and ISE521 includes a mix of upper-level undergraduates and graduate students who have self-selected into a healthcare-focused pathway. The smaller cohort size and continuity across courses contribute to a stronger sense of community and shared professional identity among participants.

Client engagement represents another key point of contrast between the two models. In ISE498, teams interact with clients periodically throughout the semester, typically on a biweekly cadence, with site visits occurring when feasible. Data availability varies by project, and teams often rely on a combination of client-provided data and limited primary data collection. In the healthcare-focused courses, client interaction is more frequent and sustained, with teams visiting clinical sites multiple times and engaging directly with frontline staff. Students are often responsible for collecting and analyzing their own data in addition to working with existing operational datasets, increasing both the realism and ambiguity of the problem-solving process [5].

Faculty mentorship structure differs markedly between the two models and represents a central design feature of the healthcare-focused pathway. In ISE498, faculty mentorship is distributed across many teams, resulting in relatively short and infrequent interactions that focus primarily on project progress and deliverables. Faculty mentorship is advisory and decoupled from course ownership. In ISE521, mentorship is a designed instructional role. Each team meets weekly with a faculty mentor for extended sessions lasting between 30 and 60 minutes. The faculty mentors are one of the two course co-instructors. These meetings emphasize not only technical analysis but also problem framing, stakeholder communication, and reflection on professional practice. This level of mentorship allows faculty to intervene more deliberately in students' learning processes and to model domain-specific reasoning in healthcare contexts [6], [7].

Taken together, these differences illustrate two distinct approaches to senior design within the same program. The traditional capstone model prioritizes breadth, exposure, and execution across diverse application areas, while the healthcare-focused pathway emphasizes depth, sustained engagement, and professional preparation within a single complex domain. Both models serve important educational purposes, and the comparison provides an opportunity to examine how specific pedagogical design choices influence student experiences and early indicators of learning [10].

3. Research questions and study design

This work-in-progress study is guided by a set of research questions focused on how pedagogical design choices in senior design courses shape student learning experiences and early indicators of professional development. Rather than evaluating the effectiveness of individual projects or specific technical tools, the study examines how differences in course structure, mentorship intensity, and client engagement influence students' preparedness to operate in complex, real-world systems, particularly in healthcare contexts.

The study is organized around the following research questions:

RQ1. How do differences in senior design structure and faculty mentorship influence students' perceived readiness to address complex, ill-defined problems?
RQ2. How does sustained engagement with healthcare clients and clinical environments affect students' confidence in applying ISE tools in practice?
RQ3. What early patterns emerge in students' professional skills development across a traditional capstone model and a healthcare-focused pathway?

To address these research questions, a mixed-methods study design is being implemented across three courses within the same industrial and systems engineering program. The study combines quantitative measures of student self-efficacy and perceived readiness with qualitative analysis of student artifacts and faculty observations. This approach is intended to capture both broad trends in student development and contextual insight into how students experience different senior design learning environments, which is particularly important when examining complex, practice-based educational settings [11].

The study includes ISE498, a required undergraduate capstone course, and ISE520 and ISE521, a two-course healthcare-focused project sequence. ISE520 and ISE521 are treated analytically as a single healthcare-focused senior design pathway spanning two semesters. Enrollment during the study period includes approximately 99 undergraduate students in ISE498 across two semesters, 17 students in ISE520, and 14 students in ISE521. The healthcare-focused courses include a mix of senior undergraduate and graduate students, while ISE498 enrolls entirely undergraduate ISE seniors.

Multiple data sources are being used to capture both student perceptions and evidence of learning. Planned quantitative data collection includes pre- and post-course surveys administered across all courses to assess changes in students' self-reported confidence, perceived readiness, and comfort with ambiguity in engineering problem solving. Survey instruments focus on domains such as problem framing, data-driven decision making, stakeholder communication, and application of engineering tools in unfamiliar contexts. Qualitative data sources include analysis of course artifacts such as final reports and posters, as well as structured faculty observations recorded throughout the semester [12].

Given the work-in-progress nature of this study, data collection and analysis are ongoing at the time of writing. The current paper emphasizes study design and preliminary descriptive results derived from early survey data, rather than presenting finalized survey results. This approach allows for early reflection on pedagogical design while maintaining transparency regarding the status of empirical findings.

Data analysis will combine descriptive statistics from survey responses with thematic analysis of qualitative data to identify recurring patterns across courses. Quantitative results will be used to examine trends within and between course models, while qualitative analysis will provide contextual insight into how students experience and interpret their learning environments. Triangulation across data sources is intended to strengthen the validity of findings and to support interpretation of observed differences.

Several limitations should be noted. Students self-select into the healthcare-focused pathway, introducing potential selection effects related to motivation and career interest. Additionally, differences in cohort size and faculty involvement may influence outcomes independent of course design. These factors will be considered explicitly in analysis and discussion, and the study is positioned as an exploratory comparison intended to inform future curricular development rather than establish causal relationships.

4. Data Collection and Preliminary Observations

4.1 Survey Instrument

To assess student development across both senior design models, a common survey instrument was administered in both courses. The survey consists of Likert-scale items (1–5) aligned with four thematic domains: professional identity and domain focus, problem framing and comfort with ambiguity, stakeholder engagement and communication, and faculty mentorship and reflective learning. These domains were selected to align with the hypothesized learning mechanisms discussed in this paper and with the study's broader focus on how senior design structure influences professional readiness.

4.2 Sample and Data Structure

Mid-semester survey data (formative stage) were collected from students in ISE498 and ISE521. The ISE498 survey was administered to the 71 students in the course; 20 students completed the survey. The ISE521 survey was only administered to undergraduate students in the course. Of the 12 undergraduate students, 11 completed the survey. End-of-semester survey data collection (summative stage) is ongoing and will allow for longitudinal comparison within each course, as well as comparison between the traditional and healthcare-focused models.

Because ISE520 and ISE521 form a two-course sequence while ISE498 is a single-semester course, the comparison is exploratory rather than causal. The present analysis focuses on preliminary descriptive trends that can inform future study design, curricular decisions, and more formal analysis.

4.3 Preliminary Observations

Preliminary descriptive analysis of mid-semester survey responses suggests emerging differences between the two senior design models. Table 1 summarizes mean responses by thematic category.

Table 1. Mid-Semester Survey Results by Thematic Category (Mean Responses, 1–5 Scale)

Thematic Category	ISE498	ISE521	Difference
Professional Identity and Domain Focus	3.22	4.52	+1.30
Problem Framing and Comfort with Ambiguity	3.74	3.95	+0.21
Stakeholder Engagement and Communication	3.79	4.11	+0.32
Faculty Mentorship and Reflective Learning	3.50	4.36	+0.86

Preliminary descriptive analysis of mid-semester survey responses reveals consistent differences between the two senior design models across several dimensions. Students in the healthcare-focused pathway (ISE521) report substantially higher levels of professional identity formation within their project domain, with a mean difference exceeding one full Likert scale point. This suggests that sustained engagement within a single domain may play a significant role in shaping students' perception of engineering practice.

Differences are also observed in faculty mentorship, where ISE521 students report notably stronger agreement that mentoring supports professional judgment and understanding of analytical reasoning. This aligns with the intentionally designed weekly mentoring structure in the healthcare-focused pathway.

More modest differences appear in problem framing and stakeholder engagement. While ISE521 students report slightly higher confidence in navigating ambiguity and interacting with stakeholders, these differences are smaller in magnitude at the mid-semester stage. This may reflect the developmental nature of these skills, which are expected to evolve more significantly by the end of the semester.

These findings are preliminary and descriptive. Ongoing data collection will allow for longitudinal analysis to assess changes over time and better evaluate the impact of pedagogical design on student development.

5. Hypothesized learning mechanisms and areas of investigation

This section articulates the hypothesized learning mechanisms that guided the survey design and preliminary analysis described above. These mechanisms are grounded in prior literature on engineering problem solving and informed by intentional pedagogical design differences between the traditional capstone model and the healthcare-focused pathway.

One area of interest in this study relates to how students engage with ambiguity and problem framing during senior design projects. Prior work in engineering education has shown that ill-structured problems require iterative framing and re-framing as new information becomes available, and that novice designers often differ from experts in how they approach this process [4], [5]. The differing pedagogical structures of the traditional capstone and the healthcare-focused pathway raise questions about how students in each environment may experience and respond to ambiguity. In particular, the healthcare-focused pathway's design may create conditions that encourage students to revisit assumptions and refine problem definitions over time. These potential differences motivate the comparative investigation described in this work.

A second hypothesized area of difference concerns how students interact with external stakeholders and clients. Authentic engagement with practitioners has been shown to play an important role in professional skill development, including communication, negotiation, and understanding organizational constraints [5]. While both senior design models involve interaction with external partners, the nature and continuity of this engagement differ. The healthcare-focused pathway's engagement structure may prompt students to adopt a more exploratory and relational approach to problem solving, whereas the traditional capstone's broader range of project contexts may encourage a more solution-oriented interaction focused on deliverable completion. This study examines whether these differing engagement structures influence students' perceptions of professional readiness and confidence in real-world settings.

Faculty mentorship structure represents another key hypothesized learning mechanism. Educational theory suggests that guided reflection and coaching are particularly important in complex, practice-based learning environments [6], [7]. In the healthcare-focused pathway, extended weekly mentoring sessions are intentionally designed to support student learning through discussion of analytical choices, data limitations, ethical considerations, and stakeholder communication. By contrast, mentorship in the traditional capstone model is necessarily more limited in frequency and duration. This study explores whether differences in mentorship intensity and structure are associated with differences in how students approach complex problem solving and professional judgment.

Finally, differences in pedagogical design may influence how students articulate system context and boundaries in their analytical work. Prior research has shown that expert engineers are more likely than novices to explicitly situate solutions within broader system constraints and interdependencies [5]. The healthcare-focused pathway's emphasis on systems thinking and operational context may therefore encourage students to more explicitly acknowledge organizational, human, and regulatory factors in their analyses. The study examines whether such differences are reflected in student artifacts, such as final reports and project presentations, across the two senior design models.

Together, these hypothesized learning mechanisms provide a conceptual framework for examining how senior design structure, mentorship, and domain specificity may shape student learning experiences. The ongoing study seeks to empirically investigate these hypotheses through mixed-methods data collection, with the goal of informing future senior design course design and pathway development.

6. Implications for program design and future work

The comparative framework, hypothesized learning mechanisms, and preliminary descriptive findings presented in this work have several implications for the design of senior design experiences within industrial and systems engineering programs. Rather than suggesting a single optimal model, this study highlights how intentional variations in course structure, scaffolding, mentorship, and domain focus may support different educational goals and student populations. These considerations are particularly relevant for programs seeking to balance broad exposure with opportunities for deeper, domain-specific engagement.

One implication concerns the role of differentiated senior design pathways within a single curriculum. The coexistence of a traditional capstone course and a healthcare-focused pathway provides flexibility for students with varying career interests while allowing programs to more deliberately align pedagogical design with intended learning outcomes. A broad capstone model may be well suited for students pursuing generalist roles across diverse industries, whereas a domain-specific pathway may better support students interested in complex socio-technical systems such as healthcare. Framing these options as complementary rather than competing models may allow departments to better serve an increasingly diverse student body.

Faculty mentorship emerges as a critical design consideration with implications for scalability and instructional investment. The healthcare-focused pathway's reliance on sustained, intensive mentoring is intentionally aligned with the complexity of the domain and the scaffolded progression from ISE520 to ISE521. While such a model may not be feasible for all students or all application areas, the hypothesized learning mechanisms discussed in this work suggest that mentorship intensity should be treated as a strategic instructional choice rather than an incidental feature of course delivery.

From a programmatic perspective, this work informs ongoing efforts to expand health systems engineering education within the ISE curriculum. The department intends to grow the healthcare-focused pathway to eventually serve approximately 20 percent of undergraduate students, while maintaining the traditional capstone as a foundational senior design experience. The conceptual framework presented in this paper will guide decisions related to pathway structure, cohort size, project sourcing, and mentorship models as this expansion proceeds.

An important limitation of this study is the difference in course duration and cohort structure. The healthcare-focused pathway spans two semesters, while the traditional capstone is completed in a single term. Additionally, the healthcare pathway includes a smaller, self-selected cohort, which may introduce selection bias related to student motivation and career interest. The presence of graduate students in earlier iterations of the course sequence also introduces variability that will be addressed in future analysis by focusing on undergraduate-only cohorts.

Future work will focus on completing planned data collection and empirically examining the hypothesized learning mechanisms described in this study. Analysis of pre- and post-course survey data, student artifacts, and qualitative reflections will be used to assess how different senior design models influence students' perceptions of readiness, professional confidence, and systems-level thinking. Longer-term work may also explore alumni outcomes and career trajectories to better understand the sustained impact of domain-specific senior design pathways. Together, these efforts aim to contribute evidence-based guidance to the engineering education literature on designing senior design experiences that prepare students for complex, real-world engineering practice.

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