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Project-Centered Flipped Senior Design (UB-PCFSD): Multi-Year Redesign and Outcomes in a Two-Course Capstone Sequence

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Project-Centered Flipped Senior Design: Multi-Year Redesign and Outcomes in a Two-Semester Capstone Sequence

Abstract

This paper presents a project-centered flipped instructional model for senior capstone design and reports multi-cohort assessment results from a two-semester mechanical engineering capstone sequence. Building on a prior ASEE implementation, the course sequence was redesigned over multiple years to shift MAE 451: Design Process and Methods from a lecture- and exam-centric format to a flipped, project-centered structure supported by eleven scaffolded design deliverables, followed by MAE 494: Design Project, where teams prototype and test within a continuous design framework.

In the refined model, asynchronous instructional content supports in-class project work, weekly progress reviews, and structured approval gates aligned with the formal engineering design process. Traditional quizzes and exams were replaced with rubric-based deliverables and milestone reviews to emphasize iterative design, documentation, and feedback. The redesign emphasizes instructional intentionality, with structured scaffolding, frequent feedback, and explicit alignment between deliverables, rubrics, and learning objectives.

A multi-cohort survey-based assessment compared student perceptions across two course iterations: a current cohort experiencing the fully refined flipped structure with expanded deliverables, and a prior cohort that completed an earlier version of the flipped format. Results indicate generally positive perceptions across both cohorts, with higher ratings in the refined cohort for domains related to course structure, instructional support, and clarity of expectations. Item-level and agreement-rate analyses further show stronger endorsement of lecture relevance, feedback effectiveness, and deliverable structure following implementation of the refined model. Qualitative responses reinforced the importance of structured deliverables and consistent feedback, while also highlighting ongoing challenges related to team coordination.

The paper contributes a scalable, project-centered flipped model for senior design instruction, multi-cohort evidence on the impact of structured scaffolding and feedback mechanisms, and practical guidance for implementing flipped capstone courses in large-enrollment, team-based environments. Additional analysis using program-level assessment data demonstrates alignment between the instructional structure and ABET-defined student outcomes, including professional responsibility and acquisition of new knowledge.

1. Introduction

Senior design courses play a critical role in engineering curricula by integrating technical knowledge, professional skills, and real-world problem solving into a culminating educational experience [1] - [3]. These courses are intended to prepare students for professional practice by emphasizing open-ended problem solving, teamwork, communication, and design under realistic constraints [4], [5]. However, traditional lecture-based approaches to senior design instruction often struggle to balance content delivery, team mentoring, assessment, and meaningful in-class project progress, especially in programs with large enrollments and multiple project teams [6], [7]. As a result, students may experience fragmented learning, delayed feedback, and limited opportunities for structured reflection on the engineering design process [8].

In recent years, flipped classroom models have gained traction in engineering education as a means to shift foundational content outside of class and reserve in-class time for higher-order learning activities, collaboration, and instructor feedback [9] - [11]. Studies in engineering courses have shown that flipped instruction can improve student engagement, promote active learning, and enhance conceptual understanding when paired with purposeful in-class activities and timely feedback [12] - [14]. While the flipped model has been widely studied in foundational and mid-level engineering courses, fewer studies have examined its sustained implementation and assessment within senior capstone design contexts, where project complexity, team dynamics, and deliverable scaffolding play a central instructional role [15], [16].

Prior work by the author has demonstrated that well-structured senior design projects can lead to publishable research outcomes, particularly when projects integrate emerging technologies, experimental validation, and iterative design processes. Undergraduate capstone projects have resulted in publications and conference contributions in areas such as energy harvesting, sensing systems, microfabrication, and fluidic device design [17] - [23]. These outcomes highlight the potential of structured, project-centered capstone experiences to bridge engineering education and applied research.

This paper presents the Project-Centered Flipped Senior Design (UB-PCFSD) model implemented in a two-semester mechanical engineering capstone sequence at the University at Buffalo. The model integrates asynchronous instructional content, structured in-class project work, weekly progress reviews, and a formalized sequence of design deliverables aligned with professional engineering practice. Unlike approaches that treat senior design primarily as a project management exercise, UB-PCFSD emphasizes instructional intentionality, using the flipped format to support continuous learning, accountability, and skill development throughout the design lifecycle.

To evaluate the effectiveness of this approach, student perceptions were collected across two cohorts: a current senior design cohort experiencing the fully refined flipped structure with eleven formal deliverables, and a prior cohort (from the preceding semester) that completed an earlier version of the flipped format with fewer structured deliverables. Survey results provide insight into student experiences related to learning, engagement, preparedness, course structure, and perceived outcomes. The study also isolates and evaluates the impact of a peer evaluation platform used during one semester, which was ultimately discontinued based on empirical findings and instructional considerations.

The contributions of this paper are threefold: (1) it presents a scalable flipped instructional model tailored for large-enrollment senior design courses; (2) it reports multi-cohort assessment data examining the impact of structured deliverables and feedback mechanisms; and (3) it offers evidence-based insights to inform future capstone course design and support continuous improvement.

2. Background and Related Work

Flipped classroom methodologies have been widely adopted across engineering disciplines to promote active learning, improve student engagement, and enhance conceptual understanding [9], [12], [24]. In a flipped model, instructional content is typically delivered outside of class through videos or readings, allowing in-class time to be devoted to problem solving, discussion, and application-based activities [10], [11]. Prior research has demonstrated that flipped instruction can lead to improved learning outcomes and student satisfaction, particularly when in-class activities are intentionally designed and aligned with course objectives [12], [14], [25].

Project-based learning (PBL) and capstone design courses represent a natural extension of active learning principles in engineering education [4], [26]. These courses emphasize teamwork, open-ended problem solving, communication, and professional practice. However, assessing learning in capstone courses remains challenging due to variability in project scope, team dynamics, and individual contributions [6], [27]. Many programs rely heavily on milestone presentations and final reports, which may limit opportunities for formative feedback and iterative improvement during the design process [7], [28].

To address these challenges, several studies have explored structured assessment frameworks and peer assessment tools [29] - [31]. Structured deliverables have been shown to improve pacing, clarify expectations, and support student reflection on design decisions [32]. Similarly, regular formative feedback has been identified as a key factor in improving student learning and engagement in project-based environments [8], [33].

Peer evaluation platforms have also been introduced in capstone courses to promote accountability and address imbalances in team contribution [30], [31]. While such tools can be effective under certain conditions, prior research emphasizes that their success depends strongly on implementation quality, grading transparency, and student trust in the evaluation system [34]. Poorly integrated peer assessment mechanisms may introduce grading inconsistencies or distract from core instructional goals.

Despite growing interest in flipped and project-based instructional models, there remains a need for empirical studies that examine how flipped delivery, structured deliverables, and continuous feedback interact within senior design courses. In particular, limited work has compared different iterations of flipped capstone implementations across cohorts or examined how refinements to deliverable structure influence student perceptions of learning, clarity, and preparedness [15], [16].

This work builds on prior efforts to redesign senior capstone instruction through project-centered and industry-integrated approaches. In particular, earlier work by the authors introduced a multidisciplinary, industry-sponsored capstone framework emphasizing structured design processes and real-world project engagement [35]. The current study extends this work through a multi-year refinement of a flipped, project-centered instructional model and provides empirical evidence of its impact on student perceptions, instructional clarity, and course structure.

3. Course Context and Instructional Design

3.1 Course Context

The instructional model described in this paper was implemented in the Department of Mechanical and Aerospace Engineering at the University at Buffalo. The model was applied within a two-semester mechanical engineering capstone sequence consisting of MAE 451 (Design Process and Methods) and MAE 494 (Design Project). MAE 451 focuses on problem definition, concept generation, concept selection, analysis, and final design, while MAE 494 emphasizes fabrication, testing, and validation.

Each offering of MAE 451 enrolls approximately 30 student teams. Each team consists of an average of six student members, reflecting the scale and complexity of the projects and the need for structured instructional support. Projects span a range of mechanical engineering applications and are structured to simulate professional engineering practice. MAE 494 teams generally continue the same projects initiated in MAE 451, providing continuity across the design lifecycle.

The study reported in this paper includes data from two student cohorts: 1) a current MAE 451 cohort experiencing the fully refined flipped instructional model with eleven structured deliverables, and 2) a smaller MAE 494 cohort that completed MAE 451 during the previous semester under an earlier version of the flipped model with fewer formal deliverables.

3.2 Flipped Classroom Implementation

The UB-PCFSD model adopts a flipped classroom structure in which foundational instructional content is delivered asynchronously prior to class meetings. These materials include short lecture videos, design process explanations, examples of professional documentation, and guidance on analytical and modeling techniques relevant to ongoing projects.

In-class time is reserved for project-centered activities, including team work sessions, design reviews, and instructor-led progress discussions. A defining feature of the model is the use of weekly in-class progress reviews, during which teams report on completed tasks, upcoming goals, and challenges. These reviews provide regular accountability while allowing instructors and teaching assistants to deliver immediate, targeted feedback.

This structure shifts the instructional emphasis from content delivery to mentorship, enabling instructors to monitor team progress continuously and intervene early when conceptual or organizational issues arise.

3.3 Structured Deliverables and Course Evolution

A key refinement to the UB-PCFSD model was the introduction of eleven structured deliverables in MAE 451, designed to align explicitly with stages of the engineering design process. These deliverables include problem definition artifacts, requirements documentation, concept evaluation, preliminary analysis, and design reviews. Each deliverable is supported by clear rubrics and submission guidelines to promote consistency across teams.

The earlier cohort (now enrolled in MAE 494) experienced a flipped classroom format but it included fewer formal deliverables and less explicit scaffolding between concept development activities and project execution. Feedback from that cohort informed the redesign of the course structure, resulting in the expanded deliverable sequence evaluated in this study.

In addition to instructor and TA feedback, a peer evaluation platform was introduced during one offering of MAE 451 to support team accountability. Due to mixed student perceptions regarding fairness and instructional value, the platform is evaluated separately in this study.

Instruction and feedback were delivered across multiple sections of MAE 451 across the two cohorts included in this study. In the current offering (Group A), four sections were taught, three by the primary instructor and one by a second instructor. In the prior offering corresponding to Group B, a single section was taught by the same primary instructor. Each section was supported by a dedicated TA who attended class sessions, provided in-class support to student teams, and participated in grading and feedback.

To promote consistency across sections, all assignments were evaluated using standardized rubrics, and grading practices were coordinated across instructional staff. After initial grading by TAs within each section, the primary instructor conducted a secondary review of feedback and assigned scores across all sections to ensure alignment in evaluation standards and to make adjustments where needed. This centralized review process helped maintain consistency in feedback quality and grading across sections despite the multi-instructor structure.

4. Assessment Methodology

4.1 Survey Instrument Design

To evaluate student perceptions of the Project-Centered Flipped Senior Design (UB-PCFSD) model, a structured survey instrument was developed and administered near the end of the semester. The survey consisted of Likert-scale items and open-ended questions designed to capture student experiences across multiple instructional dimensions.

Likert-scale items used a five-point scale (1 = Strongly Disagree to 5 = Strongly Agree) and were grouped into the domains: 1) experience with the flipped classroom structure, 2) learning and skill development, 3) preparedness and performance modeling, 4) course structure and instructional support, and 5) perceived outcomes and overall effectiveness. In addition, a small set of comparative items asked students to reflect on the flipped format relative to traditional lecture-based instruction. Open-ended questions were included to allow students to elaborate on aspects of the course that most supported or challenged their learning. For example, items within the “Preparedness & Performance Modeling” domain assessed students’ perceptions of their ability to apply prior knowledge, perform analytical modeling, and evaluate design performance within the context of their project.

During the most recent offering of MAE 451, a peer evaluation platform was used to support team assessment. Because this platform was not used consistently across cohorts and was later discontinued, survey items related to the peer evaluation platform were intentionally isolated and analyzed separately.

4.2 Participants and Data Collection

Survey data were collected from two cohorts: group A where students enrolled in MAE 451 (*Design Process and Methods*) during the current academic year, experiencing the fully refined flipped instructional model with eleven structured deliverables, and group B where students enrolled in MAE 494 (*Senior Design Project*) who had completed MAE 451 during the previous academic year under an earlier version of the flipped model with fewer structured deliverables.

Participation was voluntary, and students received a small amount of bonus course credit for completing the survey. Student identities were collected only to verify completion and assign bonus credit; all identifying information was removed prior to analysis.

4.3 Data Processing and Analysis

Survey responses were exported to spreadsheet format for analysis. Likert-scale responses were treated as ordinal data and analyzed using descriptive statistics. Consistent with common practice in engineering education research, mean and standard deviation were computed under the assumption of approximately uniform spacing between response categories, enabling comparison of central tendencies across cohorts. For each survey item, the mean, standard deviation, and number of responses were computed separately for each cohort.

To support higher level interpretation, related survey items were grouped into domains corresponding to instructional and learning constructs. For each student, domain scores were computed as the average of the relevant items, and cohort level domain means and standard deviations were then calculated.

Because the peer evaluation platform was not used by group B, the peer evaluation platform-related items were excluded from cross-cohort comparisons and analyzed only for group A. No inferential statistical testing was performed, as the primary goal of the study was exploratory evaluation of instructional design rather than hypothesis testing.

5. Results and Descriptive Analysis

5.1 Participant Overview

A total of 170 students participated in the survey, including 151 students from MAE 451 (group A) and 19 students from MAE 494 (group B). Group A experienced the fully refined flipped instructional model, which included eleven structured design deliverables, integrated weekly feedback, and the use of the the peer evaluation platform. Group B consisted of students currently enrolled in MAE 494 who had completed MAE 451 in the previous semester, prior to implementation of the expanded deliverable structure and without use of the peer evaluation platform. Table 1 summarizes participant distribution and cohort characteristics.

Table 1. Participant Overview

Cohort	Course	N	Notes
Group A	MAE 451	151	Full flipped format, 11 deliverables, peer evaluation platform
Group B	MAE 494	19	Completed MAE 451 previously, no peer evaluation platform

5.2 Domain-Level Results

Table 2 summarizes mean Likert scores and standard deviations for each instructional domain across both cohorts. Across all domains, mean ratings exceeded the midpoint of the scale, indicating generally positive student perceptions of the capstone experience in both course iterations.

Table 2. Domain-Level Comparison of Student Perceptions
(Likert scale: 1 = Strongly Disagree, 5 = Strongly Agree)

Domain	MAE 451 Mean ± SD	MAE 494 Mean ± SD
Flipped Structure	3.76 ± 1.00	3.55 ± 1.04
Outcomes	3.78 ± 1.07	3.82 ± 0.83
Comparative Items	4.04 ± 0.91	4.03 ± 0.75
Structure & Instructional Support	4.07 ± 0.82	3.67 ± 0.86
Skills Development	4.20 ± 0.76	4.28 ± 0.62

Group A reported higher mean scores in Flipped Structure and Structure & Instructional Support, while Skills Development and Preparedness & Performance Modeling were rated highly and comparably across both cohorts. These patterns indicate that students in both offerings perceived the course as effective in developing professional and technical skills, with differences emerging primarily in how course structure, pacing, and instructional support were experienced.

The largest domain-level difference between cohorts occurred in Structure & Instructional Support, where Group A's higher mean suggests improved clarity of expectations, feedback usefulness, and alignment between deliverables and evaluation criteria following the refined course design. In contrast, outcome-related perceptions were similar across cohorts, indicating that both iterations of the flipped model supported students' overall sense of readiness and engagement.

Figure 1 provides a visual comparison of domain-level means, highlighting these relative patterns across cohorts.

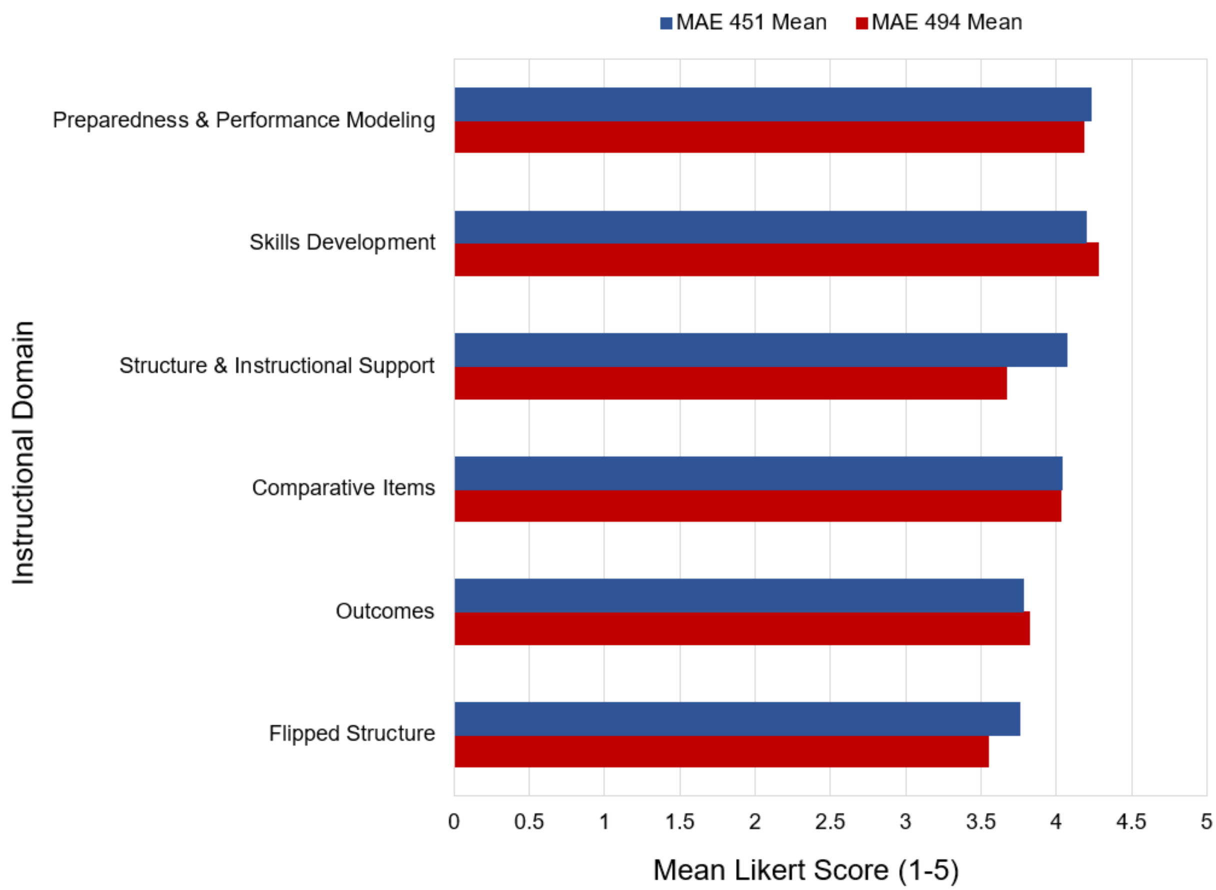

Figure 1. Domain-Level Comparison of Student Perceptions Across Instructional Domains

5.3 Item-Level Differences Between Cohorts

To further examine which specific instructional elements contributed to observed domain-level differences, selected item-level comparisons were conducted. Items were selected based on their alignment with instructional features modified between course iterations, including structured deliverables, rubrics, and feedback mechanisms.

Figure 2 illustrates these item-level differences by plotting the mean difference between cohorts for each selected item. Abbreviated item labels are used for readability; full survey item wording is provided in Table 3. The results indicates that all selected items demonstrate higher mean agreement in Group A. The largest differences were observed for items related to lecture relevance, feedback clarity, and deliverable structure. In particular, students in Group A more strongly agreed that weekly project-centered lectures were relevant to their ongoing design work and that instructor and TA feedback helped clarify expectations and improve assignment quality.

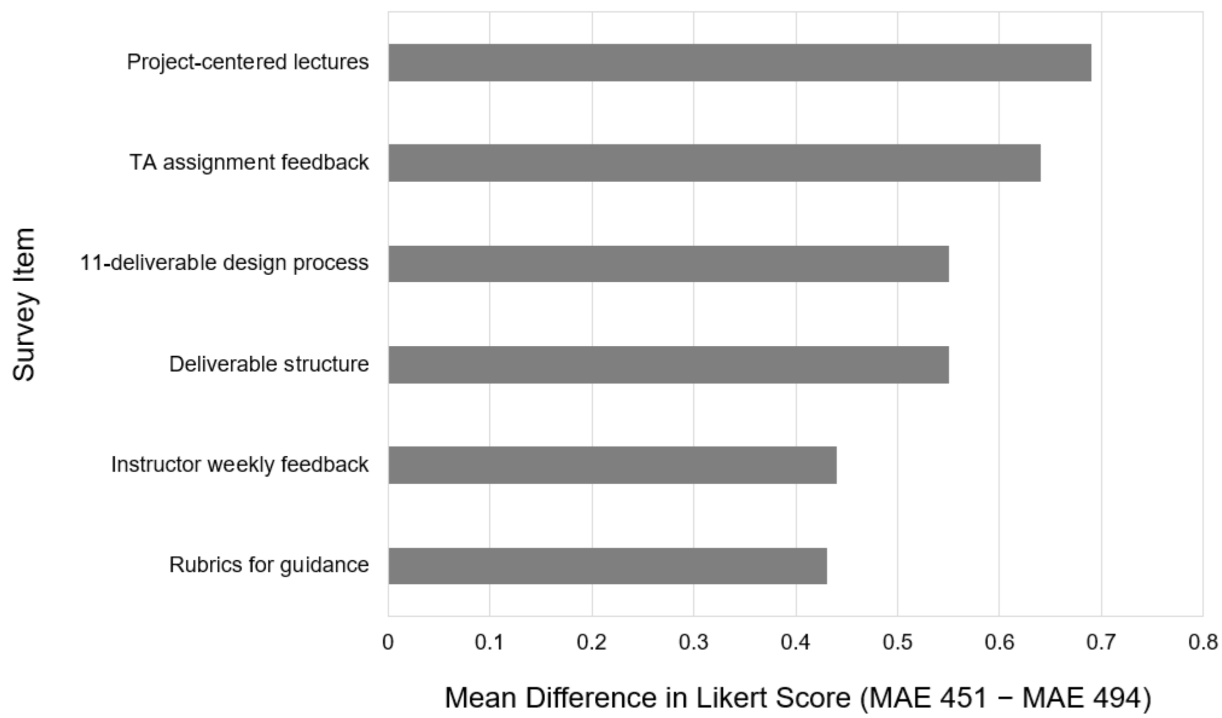

Figure 2. Mean Differences in Selected Item-Level Survey Responses Between Cohorts.

Table 3. Selected Item-Level Differences Between Cohorts

Item	MAE 451 Mean	MAE 494 Mean	Δ (MAE 451 − MAE 494)
Rubrics helped guide work	4.12	3.68	0.43
Instructor weekly feedback clarified expectations	4.23	3.79	0.44
Deliverable structure helped team stay on track	3.96	3.41	0.55
11 structured deliverables clarified the design process	4.08	3.53	0.55
TA feedback on major assignments improved work	4.01	3.37	0.64
Weekly project-centered lectures were relevant	4.01	3.32	0.69

Items addressing the role of structured deliverables similarly showed notable differences. Group A reported greater agreement that deliverables helped teams stay on track and clarified the formal design process, suggesting that the expanded sequence of deliverables influenced students' understanding of how weekly tasks fit within the broader design lifecycle.

5.4 Peer Evaluation Platform Results

Analysis of the peer evaluation platform-related survey items was limited to Group A, as the platform was not used in the earlier course iteration. As shown in Table 4, students generally rated the platform as easy to use. However, ratings related to perceived instructional value, accountability, and grading fairness were more mixed.

While some students reported that grade-curving features were helpful, lower agreement regarding overall value and accountability indicates variability in how the platform was experienced across teams. These mixed perceptions were considered alongside instructor observations when evaluating the role of peer evaluation tools in the course.

Table 4. Peer Evaluation Platform Results (MAE 451 Only)

Item	Mean
Easy to use	4.08
Improved accountability	2.98
Grades fair and accurate	3.38
Added value to course	2.87
Curving revisions helpful	3.52

5.5 Response Distribution and Agreement Rates

To complement mean-based analyses, response distributions were examined for the comparative survey item evaluating the flipped format relative to traditional lecture-based instruction. As shown in Table 5, a larger proportion of Group A students selected Agree or Strongly Agree, whereas Group B responses were more evenly distributed across Neutral and Agree categories. Figure 3 illustrates the full response distribution across Likert categories for both cohorts, highlighting the shift toward higher agreement levels in the refined course implementation.

Table 5. Response Distribution for Flipped vs. Traditional Instruction
(Item: "Compared to traditional lecture-based learning, the flipped format was more effective.")

Cohort	Strongly Disagree (%)	Disagree (%)	Neutral (%)	Agree (%)	Strongly Agree (%)
MAE 451	7.3	11.3	21.9	23.8	35.8
MAE 494	0.0	5.3	31.6	31.6	31.6

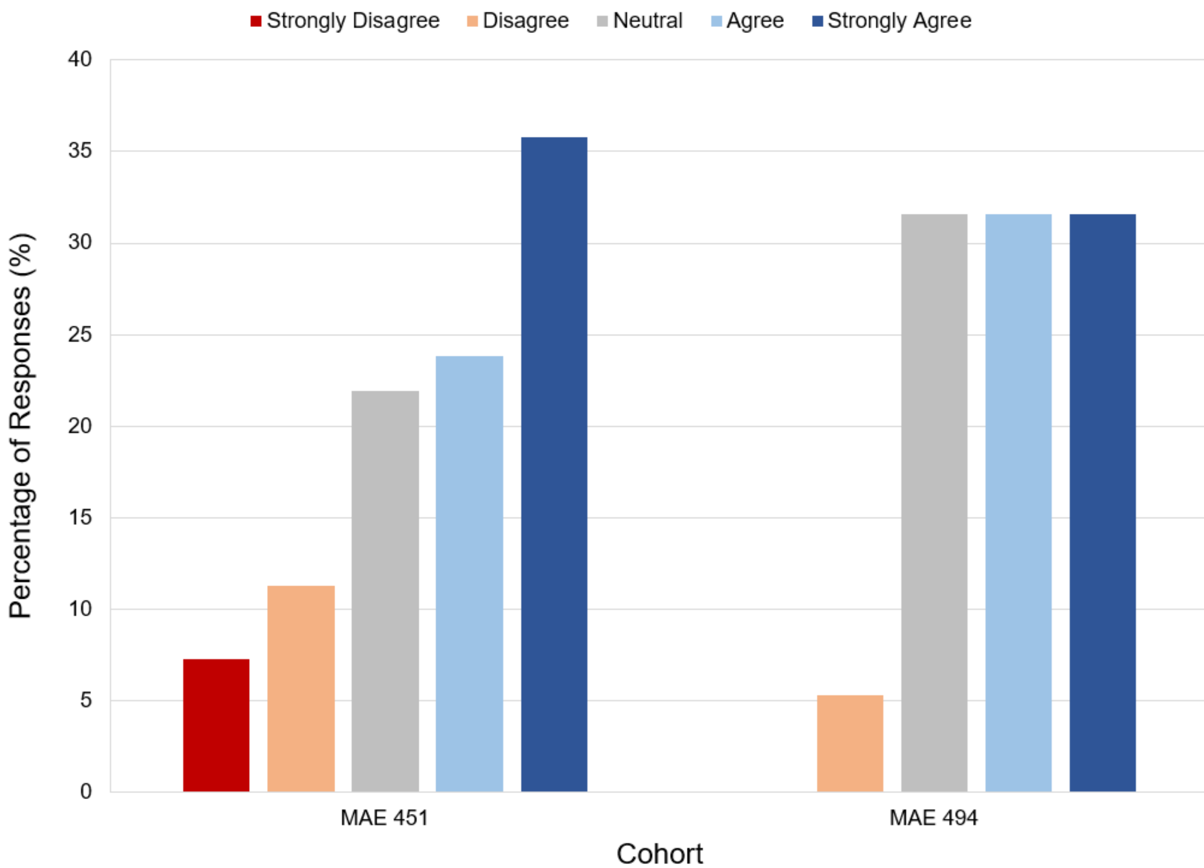

Figure 3. Response distribution for the survey item "Compared to traditional lecture-based learning, the flipped format was more effective." Bars represent the percentage of student responses in each Likert category.

Agreement rates aggregated by instructional domain (Table 6) further highlight cohort-level differences. Figure 4 provides a visual comparison of agreement rates (Agree and Strongly Agree) across cohorts, highlighting higher agreement in domains associated with structured deliverables and instructional support in the refined course model. Group A demonstrated higher agreement in domains directly related to course structure and support, while both cohorts reported strong agreement in skill development and preparedness. These patterns indicate that refinements to course structure and feedback mechanisms influenced students' perceptions of instructional organization and clarity, while perceptions of skill development remained consistently positive across cohorts.

Table 6. Agreement Rates by Instructional Domain
(Percent selecting Agree or Strongly Agree)

Domain	**MAE 451 (%)**	**MAE 494 (%)**
Flipped Structure	64.4	56.7
Skills Development	81.5	89.5
Preparedness & Performance Modeling	88.1	78.9
Structure & Instructional Support	74.8	57.0
Outcomes	64.0	64.9

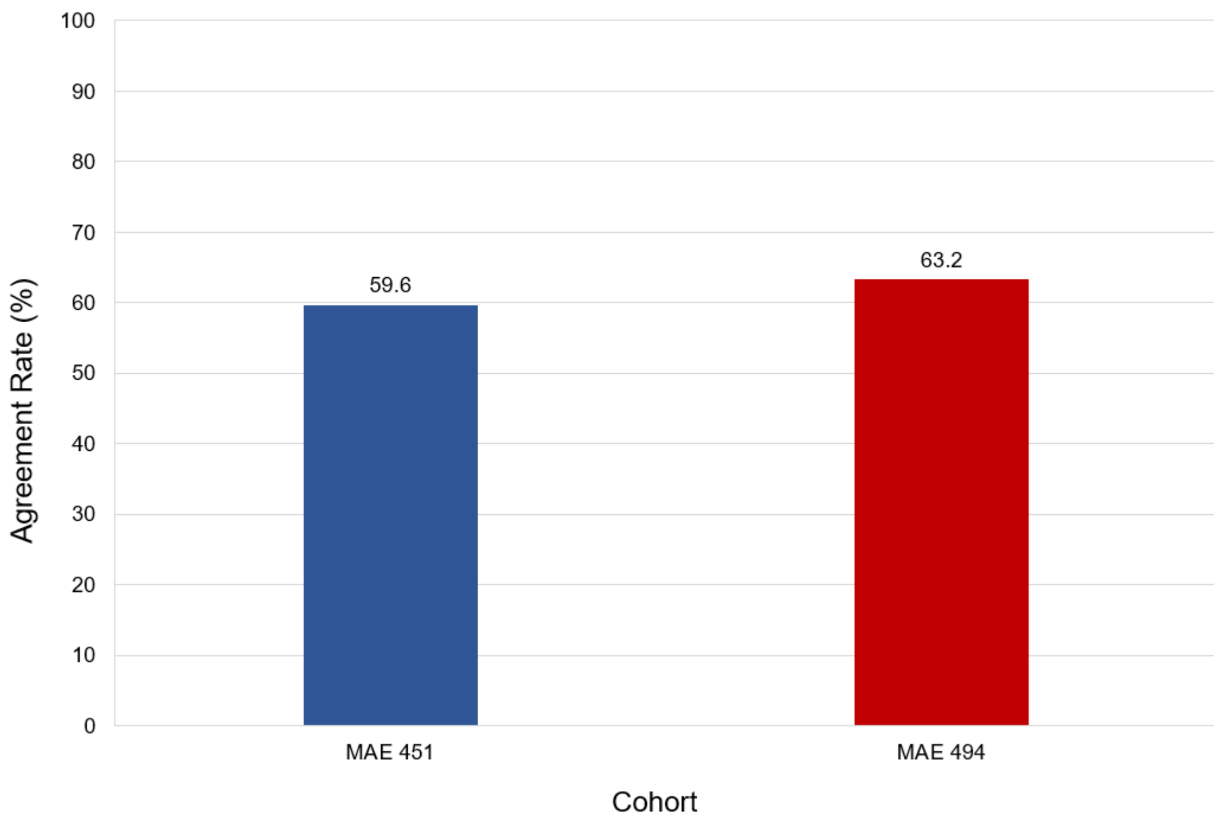

Figure 4. Percentage of students who agreed or strongly agreed that the flipped format was more effective than traditional lecture-based instruction.

5.6 Reliability and Qualitative Feedback

Internal consistency analysis indicated strong reliability across all multi-item survey domains for both cohorts (Table 7), supporting aggregation of individual survey items into broader instructional constructs.

Open-ended responses were thematically coded to identify common patterns in student feedback. As summarized in Table 8, qualitative responses frequently referenced structured deliverables, instructor feedback, and regular progress reviews as supporting learning and accountability. Students also noted challenges related to team coordination and workload management, providing additional context for interpreting the quantitative results.

Table 7. Internal Consistency of Survey Domains (Cronbach's Alpha)

Domain	# Items	α (MAE 451)	α (MAE 494)
Flipped Structure	6	0.88	0.84
Skills Development	8	0.94	0.92
Structure & Instructional Support	6	0.86	0.90
Outcomes	3	0.88	0.86

Table 8. Common Themes from Open-Ended Responses

Theme	Frequency	Representative Student Comment
Structured deliverables	High	"I like that the deliverables follow the engineering design process."
Instructor feedback	Medium	"The instructor always offered help and guidance during class."
Team coordination	Medium	"Scheduling time to work on the project with peers was challenging."
Workload	Low	"Weekly deliverables, no real down time in the semester."

6. Discussion

This section interprets the findings through the lens of the study's guiding research questions, situating the results within the context of capstone design pedagogy and large-enrollment engineering instruction. The discussion emphasizes *mechanisms* rather than simply outcomes, with the goal of identifying which aspects of the Project-Centered Flipped Senior Design (UB-PCFSD) model most strongly influenced student perceptions and why those effects matter for scalable capstone implementation.

6.1 Research Question 1: How Do Students Perceive the Effectiveness of the Flipped, Project-Centered Capstone Model Compared to Traditional Lecture-Based Instruction?

Results from both cohorts indicate that students generally view the flipped, project-centered format as more effective than traditional lecture-based instruction. This is evidenced by high mean ratings on comparative items and, more importantly, by the response distribution analysis, which shows a clear shift toward *Agree* and *Strongly Agree* responses in the refined MAE 451 cohort.

The distribution-level evidence is particularly important. While mean Likert scores suggest positive sentiment, the distribution reveals how broadly that sentiment is shared. Group A exhibits a stronger concentration of high-agreement responses, whereas Group B responses cluster more heavily around Neutral and Agree. This pattern suggests that while the flipped model itself is effective, the strength of endorsement increases when the model is accompanied by clearer structure and feedback mechanisms.

These findings align with prior literature indicating that flipped classrooms are most successful when in-class time is intentionally structured around meaningful activities rather than left open-ended. In the context of capstone design, where ambiguity is inherent, students appear to benefit from instructional designs that balance autonomy with guidance. The UB-PCFSD model demonstrates that flipping content delivery alone is insufficient; the flipped format becomes more effective when paired with explicit project scaffolding.

6.2 Research Question 2: Which Instructional Elements Contribute Most Strongly to Improved Student Perceptions in the Refined Capstone Model?

Item-level analysis provides insight into which aspects of the redesigned course most strongly influenced student perceptions. The largest positive differences between cohorts were associated with: 1) relevance of weekly project-centered lectures, 2) clarity provided by instructor weekly feedback, 3) effectiveness of TA feedback on major assignments, 4) usefulness of rubrics, and 5) role of structured deliverables in pacing and process clarity.

These elements share a common theme: they reduce uncertainty. Capstone courses require students to navigate ill-defined problems, evolving constraints, and team-based decision-making. Without sufficient instructional scaffolding, students may struggle to determine whether their effort is aligned with expectations or whether they are progressing appropriately.

The refined MAE 451 structure addressed this challenge by externalizing expectations through deliverables and rubrics and reinforcing them through frequent feedback. Rather than constraining creativity, this structure appears to have enabled productive autonomy, allowing students to focus cognitive effort on design decisions instead of procedural ambiguity.

From an instructional design perspective, this suggests that the most impactful elements of a flipped capstone are not technological or novelty-driven, but organizational and pedagogical. The results support the argument that clarity, pacing, and feedback are primary levers for improving student experience in large, team-based design courses.

6.3 Research Question 3: Does the Refined Flipped Model Support Skill Development and Preparedness for Engineering Practice?

Both cohorts reported high levels of agreement in domains related to Skills Development and Preparedness & Performance Modeling, indicating that the capstone experience effectively supports professional skill acquisition regardless of iteration. Skills related to communication, planning, standards application, modeling, and decision-making were consistently rated highly.

Interestingly, agreement rates for skills development were slightly higher for group B. This may reflect the temporal context of reflection: students currently engaged in fabrication and validation (MAE 494) may more clearly recognize the skills developed during the earlier design-focused semester. This highlights an important methodological consideration for capstone assessment: students' perception of skill development may evolve as they progress through later project phases.

The consistently strong preparedness ratings across cohorts suggest that the flipped, project-centered format supports integration of prior coursework and application of analytical methods. However, the refined structure did not dramatically change perceived preparedness, reinforcing the interpretation that the redesign primarily improved the learning process rather than altering the ultimate outcomes, which capstone courses already tend to promote.

6.4 Research Question 4: How Does Instructional Structure and Feedback Influence Student Engagement and Accountability?

The Structure & Instructional Support domain showed one of the clearest cohort differences, with group A reporting substantially higher agreement rates. This domain captures students' perceptions of feedback usefulness, rubric clarity, and deliverable structure, elements that directly influence engagement and accountability.

Weekly progress reviews, in particular, appear to function as a dual-purpose mechanism: they provide formative feedback while also establishing an expectation of steady progress. In a course with approximately 30 teams, this cadence likely reduces procrastination and surfaces issues earlier, benefiting both students and instructors.

The findings suggest that accountability in capstone courses is most effective when embedded in instructional structure rather than imposed through punitive assessment. Structured deliverables and regular reviews create accountability organically, without relying on high-stakes exams or frequent summative grading.

6.5 Alignment with ABET Student Outcomes

In addition to survey-based findings, course outcomes were examined in relation to ABET student outcomes using existing program assessment data. These assessments were conducted on the prior cohort (Group B), and are presented here as illustrative evidence of alignment between course structure and ABET-defined competencies. The structure of the UB-PCFSD model, particularly the use of scaffolded deliverables, formal design reviews, and comprehensive project documentation, aligns closely with ABET outcomes related to professional responsibility, design context awareness, and acquisition of new knowledge. Table 9 provides alignment of course components with ABET student outcomes including key results.

For ABET Outcome 4 (ethical and professional responsibility and consideration of societal, environmental, and economic factors), assessment was conducted in MAE 451 using the prior cohort (Group B) through the final project memo. This artifact integrates multiple components of the design process, including problem definition, benchmarking, customer needs analysis, concept selection, and embodiment design. Results indicate that student performance was consistently strong across all performance indicators. Specifically, all teams met or exceeded expectations, with 80% achieving exemplary performance in structured design approach, 100% demonstrating exemplary recognition of broader design impacts, and 60% achieving exemplary performance in developing structured plans addressing these considerations. These results suggest that the structured deliverable framework effectively supports students' ability to incorporate professional and contextual considerations into engineering design.

ABET Outcome 7 (ability to acquire and apply new knowledge) was assessed in MAE 494 for the same cohort (Group B) through the final project memo (Design Methodology section) and Critical Design Review 2 (CDR2), which evaluates prototype integration and validation. Results show strong performance in knowledge acquisition, with 80% of teams achieving exemplary performance in identifying and using appropriate technical sources. Performance in knowledge integration was more varied, with the majority of teams achieving satisfactory or higher performance, reflecting successful system assembly and integration, but with some variability in demonstration quality and validation completeness. These findings indicate that while students are highly capable of acquiring new technical knowledge, additional emphasis on testing rigor and validation practices may further strengthen outcomes.

Importantly, both outcomes are directly supported by key instructional components of the UB-PCFSD model. Structured deliverables guide students through formal design processes, critical design reviews reinforce accountability and communication, and final project memos require integration of technical, professional, and contextual considerations. Together, these elements provide a coherent framework that supports development of ABET-aligned competencies within a project-centered, flipped instructional environment. While these results are based on a single cohort, they provide supporting evidence of alignment between the instructional design and ABET outcomes and complement the multi-cohort perception data presented earlier.

Table 9. Alignment of Course Components with ABET Student Outcomes

ABET Outcome	Course Components	Assessment Artifact	Key Result
SO4: Ethical & Professional Responsibility	Structured deliverables, benchmarking, QFD, design planning	Final Project Memo (MAE 451, Group B)	100% ≥ satisfactory; majority exemplary
SO7: Acquire & Apply New Knowledge	Design methodology, component selection, prototyping, CDR2	Final Memo + CDR2 (MAE 494, Group B)	80% exemplary (knowledge acquisition); majority ≥ satisfactory (integration)

6.6 Interpreting the Role of Peer Evaluation Tools

The peer evaluation platform provides a useful counterpoint in the discussion. While students found the tool easy to use, perceptions of fairness, accountability, and instructional value were mixed. These results underscore a broader lesson: tools must earn their place in the instructional ecosystem.

In this case, the platform did not clearly enhance learning or accountability beyond what was already achieved through deliverables and instructor/TA feedback. Importantly, the decision to discontinue the peer evaluation platform reflects a data-informed instructional choice rather than a failure of implementation. The findings reinforce the idea that peer evaluation systems should be adopted cautiously in capstone contexts, particularly when grading stakes are high and team dynamics are complex.

6.7 Integration of Qualitative Feedback

Qualitative themes strongly reinforce the quantitative findings. Students most frequently cited structured deliverables and feedback as beneficial, confirming that these elements were not merely tolerated but actively valued. At the same time, team coordination challenges emerged as a recurring concern, particularly in larger teams.

This highlights an inherent tension in capstone design: while larger teams reflect industry practice and enable complex projects, they require intentional support for coordination and communication. The findings suggest that future iterations of the course may benefit from explicit team-management scaffolds without altering the core instructional model.

6.8 Implications for Scalable Capstone Design Instruction

Taken together, the results support several instructional design principles for implementing senior capstone courses at scale. First, the flipped delivery model is most effective when paired with intentional project scaffolding that structures student progress throughout the design lifecycle rather than relying on unstructured project time alone. In this context, structured deliverables function as learning supports rather than administrative overhead when they are explicitly aligned with the engineering design process and reinforced through consistent evaluation criteria. Frequent and predictable feedback, delivered through weekly progress reviews, instructor guidance, and TA support, emerges as a critical mechanism for improving clarity, sustaining engagement, and maintaining steady project progress. Rubrics further serve an instructional role by making expectations explicit and supporting student self-regulation, particularly in complex, open-ended design tasks. Finally, the mixed results associated with the peer evaluation platform highlight the importance of evaluating instructional tools based on demonstrated learning value and alignment with course goals, rather than convenience or novelty. Collectively, these principles are transferable across engineering disciplines and institutional contexts, particularly for programs managing large numbers of teams with limited instructional resources.

7. Limitations

While the findings support the effectiveness of the UB-PCFSD model and the refined deliverable structure, interpretation must consider constraints related to cohort size differences, reliance on self-reported perceptions, and the evolving nature of course design.

Several limitations should be considered when interpreting the results of this study. First, the analysis relies primarily on self-reported student perceptions, which may not directly correspond to objective measures of learning or performance. While perceptions are an important indicator of instructional effectiveness, future work should incorporate artifact-based assessment or performance metrics.

Second, the cohort sizes differ substantially (151 in MAE 451 vs. 19 in MAE 494), and the cohorts do not include overlapping students. As a result, comparisons between cohorts should be interpreted as exploratory rather than causal. Differences observed in student perceptions may reflect both instructional changes and cohort-specific variation, and therefore do not constitute controlled experimental evidence.

Third, the study captures perceptions at a single point in time. Students' understanding of skill development and preparedness may evolve as projects progress through fabrication, testing, and validation. Longitudinal data would strengthen causal interpretations.

Finally, while the survey demonstrated strong internal consistency, the results reflect a single institutional context. Replication across programs, disciplines, or institutions would help establish generalizability.

8. Conclusions and Future Work

This study demonstrates that a project-centered flipped capstone model, when combined with structured deliverables, clear rubrics, and frequent formative feedback, can significantly improve students' perceptions of instructional clarity, support, and engagement in large-enrollment engineering capstone courses.

The findings suggest that the most impactful elements of the UB-PCFSD model are not the flipped format alone, but the instructional scaffolding it enables. Structured deliverables and consistent feedback emerged as primary mechanisms for improving the learning experience, while peer evaluation tools played a less decisive role.

These findings are further supported by program-level assessment results, which demonstrate alignment between the structured deliverable framework and ABET student outcomes related to professional responsibility and knowledge acquisition.

Future work will focus on several directions. First, data collection will be expanded across additional cohorts to increase sample size and enable more robust comparison of instructional approaches. This will allow the trends observed in the current study to be further validated across multiple semesters and student populations. Second, the instructional team plans to examine objective performance indicators, such as design quality, documentation quality, and milestone completion rates. Third, longitudinal data will be collected across both semesters of the capstone sequence to better understand how perceptions and performance evolve over time. Finally, the course design will continue to be refined to support team coordination and workload management without sacrificing flexibility or authenticity.

Overall, this work contributes practical, evidence-based guidance for engineering educators seeking to implement or refine flipped, project-centered capstone courses at scale, emphasizing that structure, feedback, and clarity, not complexity, are the keys to effectiveness.

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