# Reverse Engineering the Pre-Capstone Experience: A Practice-Oriented Model for Industry-Relevant Engineering Education

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Abstract

Engineering education often struggles to bridge the gap between classroom learning and real-world engineering practice. In this full paper, we present a reverse-engineered redesign of a pre-capstone mechanical engineering course, guided by feedback from alumni and industry partners. The goal was to align course outcomes with professional expectations to better prepare students for professional engineering practice.

The redesign focused on aligning course structure, assignments, and evaluation methods with authentic engineering workflows. Traditional written reports were replaced with oral and poster presentations, that mirror design reviews commonly used in professional settings. These changes encouraged students to articulate their design rationale, defend decisions in real time, and collaborate effectively across teams—skills essential for engineering communication and teamwork. In addition, a phase-gated project structure was introduced to promote iterative design and accountability. Each stage required students to justify key design choices before progressing, fostering ownership and responsibility.

To support this transformation, a Lean Engineering module was incorporated to introduce foundational principles such as continuous improvement, waste reduction, Kanban, and the Andon system. These concepts were directly connected to prototype development and process optimization, offering students with practical tools to guide decision-making.

Preliminary outcomes indicate that students demonstrated stronger engagement, deeper understanding of design trade-offs, and improved confidence in presenting technical work. This course redesign illustrates how rethinking assessment strategies—supported by industrial practices and lean principles—can cultivate student ownership and bridge the gap between academic learning and engineering practice.

## 1. Introduction

Engineering education continues to face a persistent challenge in preparing students to transition effectively from classroom-based learning to professional engineering practice. While pre-capstone design courses are intended to serve as this bridge, they frequently rely on instructional and assessment structures that differ substantially from authentic engineering workflows. As a result, students may demonstrate technical competence yet lack experience in iterative decision-making, real-time technical communication, and accountability within team-based design environments. Addressing this gap requires deliberate alignment between course structure, assessment strategies, and the expectations of professional engineering practice.

In this work, we present a reverse-engineered redesign of a pre-capstone mechanical engineering course informed directly by feedback from alumni and industry partners. The primary objective was to align course outcomes with professional engineering expectations by restructuring project workflows, assessments, and instructional modules. Traditional written reports were replaced with oral and poster-based design reviews that mirror professional design reviews, requiring students to articulate design rationale, defend decisions in real time, and communicate effectively with diverse audiences. A phase-gated project structure was introduced to promote iterative design, accountability, and ownership, with progression contingent upon justification of key engineering decisions at each milestone.

To support this transformation, a Lean Engineering module was integrated into the course to introduce foundational principles such as continuous improvement, waste reduction, Kanban workflow management, and the Andon system. These concepts were directly connected to project planning, prototype development, and process optimization, providing students with practical tools commonly used in industry to guide engineering decision-making.

ABET performance was operationalized through a sequence of scaffolded, design-centered assessments that mirror professional engineering workflows. Students translated the problem statement and background research into a structured requirements list, distinguishing between needs and wants across technical, manufacturing, aesthetic, and economic categories, thereby grounding design decisions in clearly defined constraints. Project planning and accountability were reinforced through the development and continuous updating of a Gantt chart that budgeted time for design, fabrication, and testing throughout the semester. Design embodiment was achieved using computer-aided design (CAD), where students developed solid models for all components, assembled complete systems, and specified materials and visual attributes to enhance clarity and manufacturability. These models served as the basis for iterative refinement, with students required to document and justify design changes informed by CAD insights.

Analytical rigor was further reinforced through finite element analysis (FEA) of critical components. Students selected representative parts from the final assembly, identified their functional roles and potential failure modes, and performed appropriate finite element analyses to evaluate structural performance. Design modifications resulting from simulation outcomes were explicitly documented, linking analysis to physical realization. Prototyping and testing activities culminated in reflective evaluation, where teams assessed what aspects of the design process succeeded, what failed, and how analytical predictions were validated or invalidated during fabrication and testing. Students then explored and justified design changes that could improve system performance and demonstration outcomes, reinforcing engineering judgment, iterative problem solving, and continuous improvement.

Collectively, these assessments supported ABET student outcomes related to engineering design with consideration of societal and economic factors, effective communication with diverse audiences, ethical and professional responsibility, teamwork and leadership, experimentation and data-driven analysis, and the ability to acquire and apply new knowledge. Preliminary outcomes indicate stronger student engagement, deeper understanding of design trade-offs, and improved confidence in presenting technical work. This course redesign illustrates how rethinking assessment strategies—grounded in industrial practice, lean principles, and ABET-aligned performance criteria—can more effectively bridge the gap between academic learning and professional engineering practice.

## 2. Methods

### 2.1 Literature Review

There have been previous efforts to improve mechanical engineering pre-capstone or design focused courses to better prepare students for professional practice as well as their eventual senior design or "capstone" experience. [1] [2] [3] One area of significant focus has been to more explicitly offer opportunities within the course to experience design methodologies and reflect on the experience. [4] Lean Engineering has been identified as an area of interest with increased use in industry, and efforts have been made to introduce the topic through lectures and group discussions. [5]

In addition to the typical content on design topics, pre-capstone courses also emphasize communications and teamwork skill development, and there is significant literature on both topics. Research has shown that focus on task planning and task assignment within teams generally results in improved outcomes for projects. [6] Surveys, both pre and post, have been found useful to evaluate student efficacy in a variety of areas, including technical skills, analysis skills, communication skills, teamwork skills and others. [7] While this has long been a feature of capstone experiences [8], there is limited work on surveys being deployed in pre-capstone courses to collect student opinions on preparedness for capstone courses and eventual professional practice.

### 2.2 Pre-Revision Course Details

The pre-capstone course takes place in the fall semester of the senior year of the mechanical engineering curriculum; the course has been in its current format for at least 25 years. [9] The students have completed the majority of their core courses, including traditional theory courses, laboratory experiences, design-focused courses, and computational courses including programming and CAD. The course is the first in a 2-course sequence, where the classic capstone course follows it in the spring semester; the students are assigned to their capstone projects and begin capstone work near the end of the pre-capstone course. The cohort size has traditionally been between 90 and 110 students in recent years, but with increasing enrollment in the department, the cohort is expected to reach over 150 students next year and potentially 200 in 3-4 years. There have not been any students in the last five cohorts who have had to repeat the course. While the course has seen some minor alterations and changes in recent years, the overall structure and content of the course has not been changed in over ten years.

### 2.3 Project Details

The pre-capstone course has traditionally been anchored by a semester-long design project, where students complete a thorough design process with the goal of a fully realized prototype at the conclusion of the project. Each of the assignments that the student groups complete features elements of the design process, including the demonstration of their completed prototype. The project has historically featured a multi-faceted task, where the students build a device designed specifically for the chosen task within instructor-provided constraints. The task is typically changed every two years to ensure originality from student designs; the task for fall 2025 had been used in the course in 2021 and 2022.

The project for the fall 2025 semester was a pipe-climbing vehicle, where the device was required to move within the interior of a 5-inch acrylic pipe vertically 5 feet. At the top of the pipe, the device was expected to pop 6 balloons located around the exit of the pipe. The device had to be autonomous, where the students would activate the device and from that point onward there was no additional interaction between the students and the device. The device was expected to carry one of two payloads – either 100 grams or 500 grams and was required to complete the task within 90 seconds. The devices had a length restriction of 18 inches at activation and a budget of $100. Figure 1 shows an image of the test stand. In addition to the technical project details and constraints, a narrative is provided to the students to tether the project to appropriate stakeholders and make the experience more authentic. The narrative for the pipe climber presented the task as a rescue mission, where the payload represented personnel and the balloons represented "defense drones" that needed to be neutralized.

*Figure 1: Project Test Stand*

### 2.4 Course Feedback

Prior to the beginning of the fall 2025 semester, the instructors contacted a group of alumni and other industry representatives to discuss the course and how it could potentially be improved. A survey was provided to collect feedback, and after review of the results the instructors invited those interested to join for a discussion on their feedback. While the feedback was varied and included both positive and negative items, the primary points that were made in the survey and discussion were that much of the work the students were being asked to do was not in line with what was expected in industry. Furthermore, some important topics, such as lean engineering, were not discussed at all.

## 2.5 Course Revisions

Following the feedback from alumni, industry representatives, students and colleagues, the instructors collaborated to make changes to the overall structure and individual assignments of the course. The primary goals of the changes were to attempt to focus the course and its products on the primary outcomes of the course – to prepare students for their upcoming capstone design projects that begin in mid-November, and to prepare students for their eventual entry into the engineering work force. The instructors began by reviewing the overall structure and schedule of the course, then addressed each assignment sequentially based on their traditional order.

One of the most critical pieces of feedback received from both alumni and students alike was the length and number of written assignments for the course – students viewed the length of some assignments as burdensome and alumni commented that lengthy design documents were becoming less and less common in their work, but rather shorter documents supplemented with presentations were becoming more beneficial. With this in mind, the instructors replaced two of the required five written assignments with a design review presentation and a project culminating poster. The design review presentation, in addition to replacing a lengthy written assignment, also replaced two separate design progress team meetings, which students commented were not effective in previous iterations of the course. The poster, in addition to replacing a written assignment, also allowed the students to have a preview of their capstone poster fair in a less formal, simpler format.

Another common piece of feedback received from students in previous semesters was how the course schedule didn't mesh well with the needs of the project schedule; students mentioned that the assignment schedules didn't permit students to complete critical design and prototyping steps on a timeline that would allow sufficient time for a quality, well-tested device to be delivered. In response to this, the timeline of the course lectures and due dates was adjusted to front-load more of these items to allow design and prototyping work to begin sooner. Figure 2 shows a side-by-side comparison of the two schedules. In the new schedule, students received feedback on their designs at least two weeks earlier than in the previous iteration.

| Class # | Old Schedule | | New Schedule | |
|---|---|---|---|---|
| | Lecture Topic(s) | Items Due | Lecture Topic(s) | Items Due |
| 1 | Course Introduction and Discussion of Project | none | Course and Project Introduction | none |
| 2 | Communication Styles | none | Communication Styles | Team Formation Submissions |
| 3 | Teamwork | Team Formation Submissions | Teamwork | none |

| | | | | |
|---|---|---|---|---|
| 4 | Project Planning/Requirements List | none | Project Planning/Requirements List | none |
| 5 | Assignment 2 Discussion | none | Lean Engineering | none |
| 6 | Assignment 2 Discussion | none | Lean Engineering | none |
| 7 | Assignment 2 Discussion | Assignment 1 | Lean Engineering | Assignment 1 |
| 8 | AME Machine Shop Visit | none | AME Machine Shop Visit | Peer Evaluation #1 |
| 9 | Guest Lecture – Innovation Hub | none | Guest Lecture – IHub Fabrication Lab | none |
| 10 | Design Review 1 | none | A2 Presentations | Assignment 2 slides |
| 11 | Design Review 1 | none | A2 Presentations | none |
| 12 | A2 tutorial | none | Assignment 3 discussion | none |
| 13 | A2 tutorial | none | Work on Assignment 3 And Assignment 4 | Peer Evaluation #2 |
| 14 | Assignment 3 discussion | Assignment 2 | Work on Assignment 3 And Assignment 4 | none |
| 15 | Work on Assignment 3 And Assignment X | none | Product/Process Reflection | none |
| 16 | Review 2 Team Prototype Update | none | Work on Assignment 3 And Assignment 4 | Assignment 3 |
| 17 | Review 2 Team Prototype Update | none | Guest Lecture – FE Exam and Professional Licensure | none |
| 18 | Assignment 4: Product/Process Reflection | none | Work on Assignment 4 | none |
| 19 | Work on Assignment 3 And Assignment X | Assignment 3 | Project Demonstrations Round 1 | Assignment 4 deliverables |
| 20 | Capstone Project Descriptions & Project Grouping | none | Capstone Project Descriptions & Project Grouping | Peer Evaluation #3 |
| 21 | Project Demonstrations Round 1 | none | Work on Assignment 4 | none |
| 22 | Work on Assignment X | Capstone project Preference | Work on Assignment 4 | none |

| | | | | |
|---|---|---|---|---|
| 23 | Assignment 5 Discussion | none | Project Demonstrations Round 2 | Due 11/5 by 11:59 PM: Capstone project Preference |
| 24 | Work on Assignment X | none | | |
| 25 | Project Demonstrations Round 2 | none | | |

*Figure 2: Side-by-Side of Old and New Schedule*

In addition to these schedule adjustments, efforts were also made to make adjustments to the in-class content. In the previous iteration of the course, many lectures were very traditional and passive, with limited student interactions. Within the new course, attempts were made to ensure as much active learning as possible to increase student engagement within those lectures. TopHat [10], a student engagement platform, was utilized to solicit student responses to questions in many lectures. Examples of these questions include "What are some characteristics of a good communicator?" (from the Communication Styles lecture) and "Name a harmful personal trait for a team project" (from the Teamwork lecture). For each TopHat question, students were given time to discuss the question as group and submit responses, which were reviewed at the class level.

The other major change to the lecture content of the course was the introduction of a module on Lean Engineering led by the course instructors. This addition was made in response to feedback from alumni on the prominence of Lean Engineering principles in design processes and discussions in many companies and industries. Within this three-lecture sequence, the goals were to introduce Lean Engineering principles and demonstrate how the ideas could be utilized in the development of their course project. In the first lecture, students were introduced to the 8 types of waste and identify them within some scenarios. In the second lecture, students learned more about value-stream mapping through the introduction of the design of experiments software JMP [11] and the task-tracking software Kanban. In the third lecture, students applied Kaizen principles of continuous improvement through a hands-on building project (assembling small wooden vehicle models).

One additional scheduled item was an adjustment in the peer evaluation process for the course. In previous iterations of the course, teams completed team evaluation through a teamwork assessment questionnaire that focuses on 7 different areas of team performance. [12] The teams completed the assessment prior to their two design reviews and submitted the results as part of their submission. While the questionnaire potentially revealed differing opinions on team dynamics and project performance, it was limited in ascertaining individual team member contributions. The decision was made to incorporate CATME [13] three times during the semester; students offered feedback on all their team members and themselves, and were required to offer written feedback on each team member. The data was compiled and shared along with the written feedback after the review period; each of the three evaluations were completed after the completion of one of the six assignments of the project.

After the larger course structure/scheduling decisions had been made, the instructors turned their attention to the individual assignments. As previously mentioned, two of the five written assignments were transitioned to a presentation/poster to vary the type of submissions, reduce the amount of written assignments, and to heed the advice of our alumni/industry feedback. Within each assignment, the instructors reviewed the existing assignment and identified the critical elements that were needed for the overall design process that the students were completing as well as the necessary elements for ABET student outcome data. Extraneous assignment elements were eliminated, reduced, or combined with other items. Detailed scoring rubrics were recreated for each assignment to ensure students have clear instructions for successfully completing each assignment. In addition to these assignment modifications, a phase-gate structure was introduced, where students could not move forward to the next phase of their project without satisfactory completion of the previous phase. For example, if the design presentation (Assignment 2) did not appropriately justify their chosen design, or the design had major concerns, the team would be asked to rework their design and present again.

The first assignment focuses on team formation and project scheduling. Much of this assignment remained as it had been previously, including the adoption of a team contract and the creation of a project requirements list identifying the functional, technical, buildability, safety and other requirements for their project. The most significant update to this assignment dealt with the required Gantt Chart for their project; following the recommendations from industry representatives, the decision was made to move the project timeline from a static Excel template to Microsoft Planner. Use of Microsoft Planner allowed for a more flexible schedule to be created and edited throughout the project. Students were required to submit an update to the schedule for each subsequent assignment throughout the project.

The second assignment focuses on the design process for their project; students were expected to take the requirements list from assignment 1 and develop multiple concepts for their project, then using a series of tools such as Function Structure, Morphological Charts, Plus Minus Interesting (PMI), Go/No Go Analysis, and Process Decision Program Chart (PDPC) to identify the most attractive concept to develop further. This process was viewed by both students and industry representatives as unnecessarily elaborate and overly rigid. Therefore, the decision was made to loosen the requirements within the assignment to allow the student teams to identify appropriate tools, such as decision matrices and others, to properly evaluate their developed concepts and justify why their chosen design is the best according to those criteria. Within the design presentation that was Assignment 2, student teams were expected to highlight the necessary functions (subsystems) of their device, present three design concepts, then using appropriate evaluation criteria, evaluate the three concepts and select the concept that would move forward for prototyping.

Assignments 3 and 4 were the analysis and creation of the physical prototype; Assignment 3 focuses on utilizing visualization tools including SolidWorks CAD and ANSYS FEA to ensure the viability of their device, and Assignment 4 is the actual demonstration of their device, where teams have the opportunity to demonstrate their devices twice with a two-week period in between demonstrations for device alterations. Assignment 3 was largely unchanged from previous years, where students were able to leverage their CAD and FEA skills from a previous course to identify issues with their designs by developing a full CAD assembly of their prototype and performing FEA on selected parts. The demonstrations in Assignment 4 proceeded as they had in previous years, but changes were made to how they were scored. In previous years with this project, each team earned points in three areas: time, payload weight, and balloon popping bonus. In the first two categories, teams' scores were normalized based on maximum performance within the class; the highest performing team in each subscore category received the maximum score, then others received points based on their performance relative to the highest performing team. When total scores were tabulated, an additional normalization was done to adjust scores based on overall demonstration success – devices that completed the task with no issues were awarded "A" grades, minor issues "B," failed demonstrations "C," and no demonstration "D" or "F." This method created some uncertainty among the students as what their grades would be for different performance levels, so this year a task completion-based scoring system was adopted, with different performance levels guaranteed a specific grade. This scoring system can be seen in Figure 3; the highest possible score is 100 points.

| Criteria | Points |
|---|---|
| Successful Climb to the Surface with no Touches, carrying 100 g payload, under 90 seconds | 70 |
| Popping all 6 balloons | 10 |
| Popping 1-5 balloons | 2 |
| Touching your system, for each touch | -5 |
| Build Violations, including overweight or oversized, each | -10 |
| Successful Climb to the Surface with no Touches, carrying 100 g payload, under 30 seconds | 10 |
| Successful Climb to the Surface with no Touches, carrying 400 g payload, under 90 seconds | 10 |
| Unsuccessful Climb to the Surface (either stuck or fall mid-climb) | 60 |
| Functional Prototype (functionality demonstrated), but unable to climb | 50 |
| Non-functional Prototype | 40 |
| Incomplete Prototype | 30 |

*Figure 3: Scoring for Device Demonstrations*

Assignment 5 focuses on reviewing and reflecting upon the overall process and results of their project. This assignment was transitioned into a poster instead of a written report, and students were graded by alumni and supporters of the academic program. The poster requirements included detailing the highlights of their design and prototyping process, the details of their device, and their demonstration results. In addition, the team was asked to discuss how they would have altered both their design and process to achieve better performance in their demonstrations, whether their devices were ultimately successful or not. The teams presented their posters in a poster fair during class time with faculty, other students and other supporters in attendance.

Assignment 6 is the formal beginning of the capstone project for the students; the projects all feature design work and processes as required by ABET and the majority of the projects are industry or faculty sponsored. Prior to the due date, the students have indicated their preference of projects and have been placed onto teams and had the opportunity to meet their project mentor and learn more about their assigned project. Mirroring Assignment 1, the teams are asked to create a team contract and project schedule along with detailing the specific objectives and requirements of their project. Microsoft Planner was again used to create the project timelines so they may be easily updated throughout the project.

## 2.6 Post-Project Survey

Near the conclusion of the semester, the students of the course were invited to participate in a survey offering their opinions on the updates to the course; the survey had been approved by the University's Institutional Review Board. The 31 questions were grouped into several categories: engineering self-efficacy, teamwork efficacy, course assignment satisfaction, and course lecture satisfaction. Thirty of the questions utilized a 5-point Likert scale, and the final question was a free response. The questions can be seen in Figure X. The students were provided access to the survey through an online link, and of the 101 students in the course, 56 chose to complete it.

| Question Group | Questions |
|---|---|
| Engineering Self-Efficacy (Blue) | 1. I can identify problems requiring engineering solutions.<br>2. I can interpret data when solving engineering problems.<br>3. I can articulate the solutions to engineering problems.<br>4. I can communicate the solution to an engineering problem in written form<br>5. I can communicate the solution to an engineering problem in spoken form |
| Teamwork Efficacy (Red) | 6. I can work well with other students on an engineering project.<br>7. I can be a valuable team member on an engineering project.<br>8. I can work with team members to ensure all aspects of a project are completed to my satisfaction.<br>9. I can work with team members to resolve conflicts in completing an engineering project. |

| | |
|---|---|
| Course Assignment Satisfaction (Yellow) | 10. I found the team contract to be valuable to overall team success.<br>11. I found the project timeline using Microsoft Planner to be valuable to overall team success.<br>12. I found Assignment 1 to be valuable for preparation for capstone.<br>13. I found Assignment 1 to be valuable for preparation for my future career as an engineer.<br>14. I found the design presentation (Assignment 2) to be valuable to overall project success.<br>15. I found the design presentation (Assignment 2) to be valuable for preparation for capstone.<br>16. I found the design presentation (Assignment 2) to be valuable for preparation for my future career as an engineer.<br>17. I found the expectations in the design presentation (Assignment 2) to be clear.<br>18. I found the CAD/FEA assignment (Assignment 3) to be valuable to overall project success.<br>19. I found the CAD/FEA assignment (Assignment 3) to be valuable for preparation for capstone.<br>20. I found the CAD/FEA assignment (Assignment 3) to be valuable for preparation for my future career as an engineer.<br>21. I found the poster (Assignment 4) to be valuable for preparation for capstone.<br>22. I found the poster (Assignment 4) to be valuable for preparation for my future career as an engineer. |
| Course Lecture Satisfaction (Green) | 23. I found the communication styles lecture to be valuable for preparation for capstone.<br>24. I found the communication styles lecture to be valuable for preparation for my future career as an engineer.<br>25. I found the discussion on Team Contracts and Teamwork to be valuable for preparation for capstone.<br>26. I found the discussion on Team Contracts and Teamwork to be valuable for preparation for my future career as an engineer.<br>27. I found the Lean Engineering lectures to be valuable for preparation for capstone.<br>28. I found the Lean Engineering lectures to be valuable for preparation for my future career as an engineer.<br>29. I found the lecture on FEA and Electronics led by the teaching assistants to be valuable for preparation for capstone.<br>30. I found the lecture on FEA and Electronics led by the teaching assistants to be valuable for preparation for my future career as an engineer. |

| | |
|---|---|
| Open Response | 31. What additional items would you like to see discussed or presented in this course in the future? |

*Figure 4: Survey Questions*

## 3. Results and Discussion

### 3.1 Industry Priorities for Course Structure

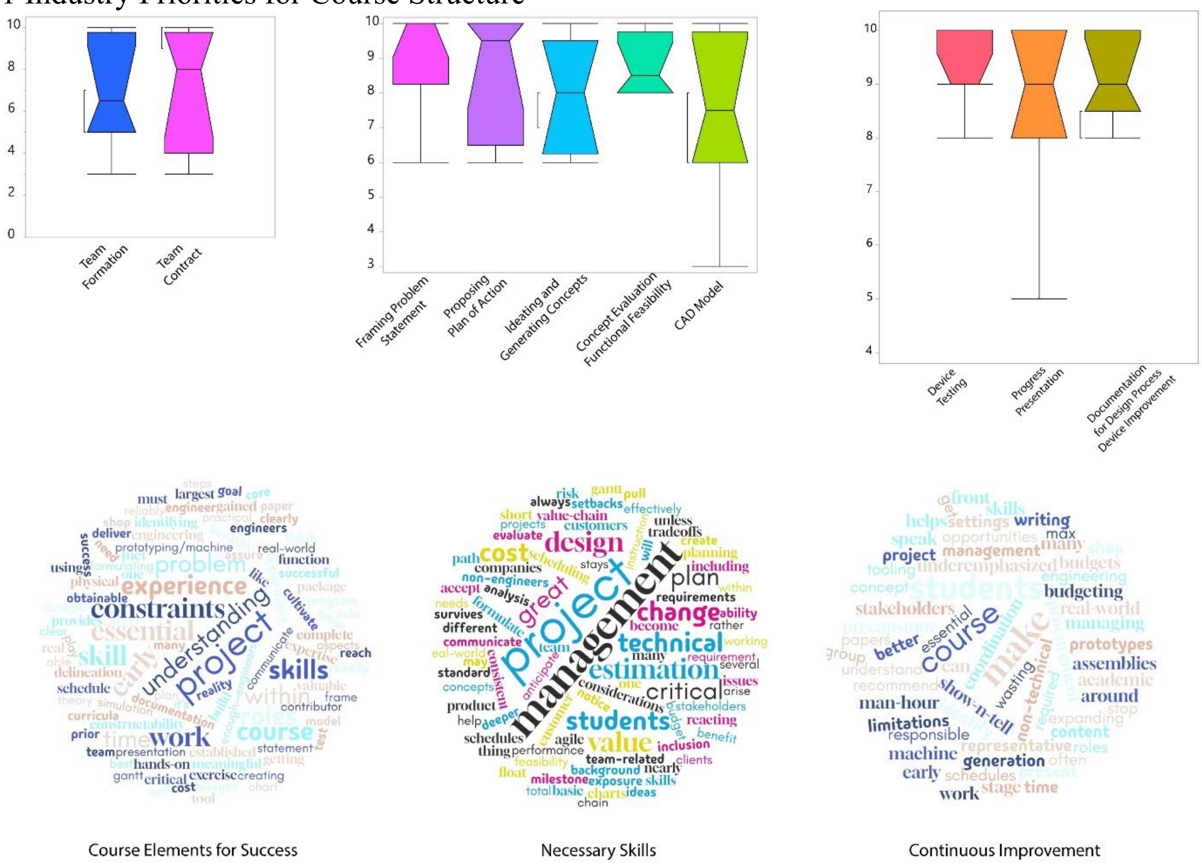


*Figure 5: Industry ratings (1–10 Likert scale) of the importance of three core course elements: (1) team formation and team contract, (2) execution of the engineering design process (problem framing, planning, ideation, concept evaluation, and CAD modeling), and (3) device testing, progress presentation, documentation, and iterative improvement. Box-and-whisker plots show high median ratings across all elements, with greater variability observed for team formation compared to the tightly clustered ratings for design execution and testing. The accompanying word cloud summarizes open-ended responses, highlighting recurring themes such as project-based work, design rigor, technical skills, planning, communication, and experiential learning.*

The industry survey evaluated the importance of three core structural components of the course:

3.1.1 Team Formation and Team Contract - Ratings for team formation and team contract ranged from 4 to 10, showing the widest distribution among the three elements. Although the median lies in the upper range of the scale, indicating that most respondents consider structured team formation important, the broader interquartile range and lower minimum score suggest variability in how strongly this component is prioritized. This spread indicates that while industry recognizes the value of formal team contracts and intentional team structuring, it may not be viewed as uniformly critical across all professional contexts. Some respondents may see team dynamics as something that develops organically in practice rather than requiring structured academic emphasis.

3.1.2 Engineering Design Process - The second boxplot assessed the importance of the engineering design process, including problem framing, planning, ideation, concept evaluation, and CAD modeling. This distribution is tightly clustered near the upper end of the scale, with a high median and limited variability. Compared to team formation, the engineering design process shows stronger consensus and higher perceived importance. The narrow interquartile range indicates broad agreement that systematic execution of the design process is foundational to engineering education. Industry stakeholders appear to consider structured problem definition, solution generation, and model-based implementation as indispensable competencies.

3.1.3 Device Testing, Progress Presentation, Documentation, and Iterative Improvement - The third boxplot represents the importance of device testing, structured progress presentation, documentation of the design process, and iterative improvement. Similar to the engineering design process category, this element shows a high median and relatively tight clustering of responses.
This strong consensus suggests that industry places substantial value on validation and refinement activities. The inclusion of testing and iterative improvement reflects real-world engineering workflows, where prototypes are evaluated, performance is measured, and designs are modified based on documented results. The importance assigned to progress presentations and documentation further highlights expectations around accountability, communication, and traceability in engineering practice

The open-ended responses, represented in the word cloud, reinforce the quantitative findings from the boxplots. Prominent terms such as project, design, technical, experience, skills, planning, and communication align directly with the highly rated structural elements. The frequent appearance of design and technical supports the strong emphasis seen in the engineering design process boxplot. The prominence of project and experience reflects the importance placed on applied, hands-on workflows involving testing and iteration. The presence of communication aligns with the high ratings for progress presentations and documentation. References to planning and execution further reinforce the structured, process-driven expectations industry holds for engineering training. Notably, while teamwork-related terms may appear in the word cloud, they do not dominate the qualitative responses to the same extent as design and technical execution terms. This observation is consistent with the greater variability observed in the team formation boxplot compared to the tighter clustering seen in the design and testing categories.

3.1.4 Overall Interpretation - Taken together, the box-and-whisker plots and the word cloud indicate that industry prioritizes:

- Rigorous execution of the engineering design process,
- Validation through testing and iterative improvement,

- Clear documentation and structured communication,

while viewing formal team contracts and structured team formation as important but somewhat more context-dependent. The figure collectively demonstrates that industry expectations are strongly centered on technical rigor, structured design methodology, and validated implementation—hallmarks of professional engineering practice.

### 3.2 Perceived Value Addition of Professional Skills to Design Presentation Performance

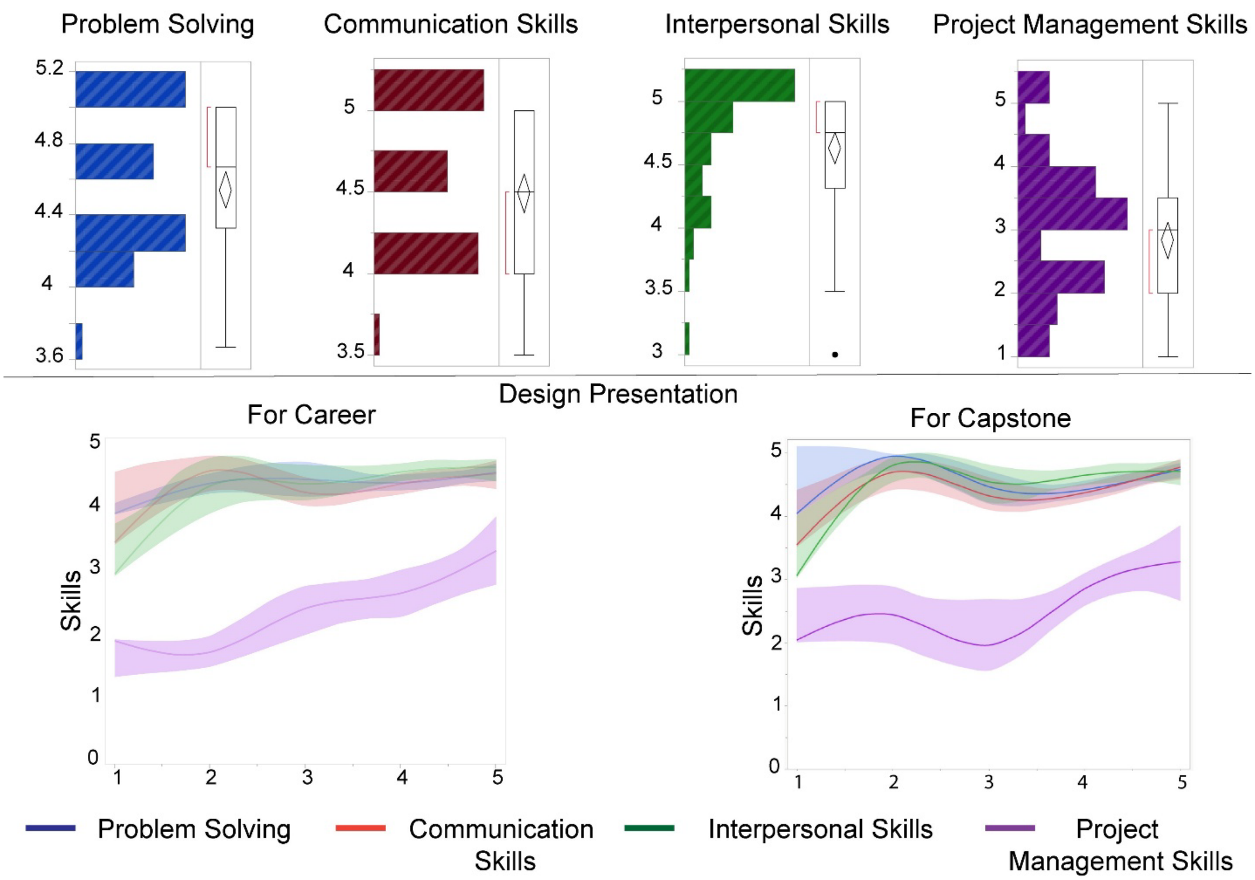


*Figure 6: Correlation between perceived value of professional skills (problem solving, communication, interpersonal, and project management) and (a) design proposal presentation performance, (b) perceived overall engineering career success, and (c) anticipated capstone project performance. Problem solving, communication, and interpersonal skills show high mean perception scores and consistent positive correlations across all contexts. Project management, despite lower mean ratings, exhibits a steeper correlation slope, indicating strong performance gains among students who highly value this skill.*

As shown in figure 6, students' perceptions of the value added by four professional skills—problem solving, communication, interpersonal skills, and project management—were analyzed in relation to performance in the design proposal presentation assignment. Descriptive statistics indicate that problem solving, interpersonal, and communication skills were perceived as highly important contributors to presentation success, whereas project management received comparatively lower ratings. Problem solving demonstrated a maximum score of 5.0, a minimum of 3.67, and a mean of 4.50, indicating a consistently strong perception of its importance with limited variability. Interpersonal skills showed the highest mean (4.62), with a maximum of 5.0 and a minimum of 3.0, suggesting that students perceive team dynamics and collaborative effectiveness as critical to successful design presentations. Communication skills yielded a mean of 4.49 (max = 5.0, min = 3.5), reinforcing the recognized importance of clarity, organization, and persuasive technical delivery. In contrast, project management skills exhibited a substantially lower mean score of 2.83, with a wide distribution (max = 5.0, min = 1.0), indicating heterogeneity in student perception. While some students strongly valued structured planning and coordination, many perceived it as less directly influential on presentation outcomes.

### 3.2.1 Correlation Between Skill Perception and Performance

Correlation analysis was conducted to examine the relationship between perceived skill value and (i) performance in the design proposal presentation, (ii) anticipated performance in the subsequent capstone project, and (iii) perceived relevance to overall engineering career success. For the design presentation assignment, problem solving, interpersonal, and communication skills demonstrated positive correlations with performance, consistent with their high mean perception scores. These findings suggest alignment between student perception and measurable presentation outcomes. Project management, although rated lower overall, exhibited a steeper correlation slope compared to the other skills. This indicates that students who highly valued project management tended to demonstrate disproportionately stronger performance gains. Thus, while not universally perceived as critical, project management appears to function as a high-leverage skill when effectively recognized and applied.

Importantly, correlation analyses for the subsequent capstone project and for overall engineering career readiness demonstrated similar trends. Problem solving, communication, and interpersonal skills remained strongly associated with anticipated future performance, and project management continued to show a steeper slope despite lower mean ratings. This consistency across immediate academic performance, near-term project work, and long-term professional outlook suggests that students' perceptions are stable and transferable across contexts.

### 3.2.2 Interpretation and Educational Implications

The consistently high ratings for problem solving, interpersonal, and communication skills indicate that students clearly recognize these competencies as central to both academic and professional engineering success. These skills are highly visible during presentations and collaborative work, making their impact more tangible. The lower average rating for project management may reflect its less visible or less explicitly taught nature. However, the stronger correlation slope across presentation, capstone, and career contexts suggests that structured planning, coordination, and execution may serve as performance multipliers. Students who internalize project management principles appear to translate that awareness into measurable gains.

The wide distribution in project management perception (min = 1.0) further indicates uneven exposure or confidence in formal project management practices. This points to an opportunity for curricular enhancement through earlier and more explicit integration of planning tools, milestone tracking, and risk management frameworks. Overall, the findings reveal a distinction between perceived importance and performance leverage. While problem solving, communication, and interpersonal skills are widely acknowledged as essential, project management—though undervalued by many—demonstrates strong potential to amplify both academic outcomes and long-term professional readiness.

### 3.3 Impact of Instructional Modules on Project Proposal Presentation and Career Readiness Perception

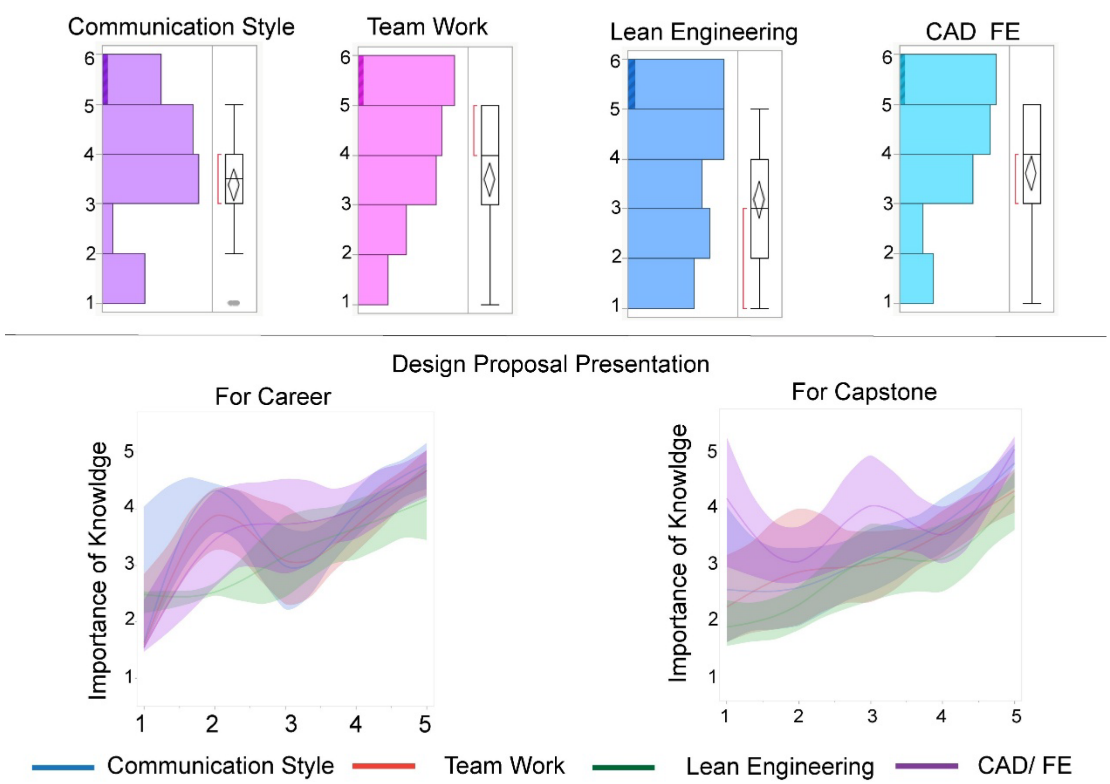


*Figure 7: Correlation between perceived knowledge gain from instructional modules (communication style workshop, team contract lecture, lean engineering sessions, and CAD/FE lectures) and (a) project proposal presentation performance, (b) anticipated next capstone course performance, and (c) perceived overall engineering career readiness. CAD/FE shows high mean perception scores and strong positive correlation across contexts. Lean engineering, communication style, and team contract demonstrate increasing or steep correlation slopes, indicating amplified performance and career readiness perception among students who highly value these components.*

To evaluate the perceived value addition of specific instructional modules, correlations were examined between individual knowledge components and (i) project proposal presentation performance, (ii) anticipated performance in the subsequent capstone course, and (iii) perceived overall engineering career readiness. As shown in figure 3, the instructional components analyzed included: communication style workshop, team contract lecture, lean engineering active-learning sessions, and CAD/FE (computer-aided design and finite element analysis) lectures.

3.3.1 Distribution of Knowledge Scores

All four instructional modules demonstrated a full scoring range (min = 1, max = 5), indicating diverse levels of perceived mastery or impact among students.

Communication style workshop: mean = 3.50

Team contract lecture: mean = 3.38

Lean engineering sessions: mean = 3.17

CAD/FE lectures: mean = 3.60

CAD/FE received the highest mean score, suggesting strong perceived relevance and confidence in technical skill acquisition. Communication style and team contract modules showed moderate mean scores, while lean engineering had a slightly lower average despite covering applied systems-level thinking.

3.3.2 Correlation with Project Proposal Presentation Performance

Correlation analysis between these instructional modules and project proposal presentation performance revealed positive relationships across all four components. Communication style and team contract modules exhibited increasing correlation slopes, indicating that students who rated these components more highly tended to demonstrate improved presentation outcomes. This trend suggests that structured communication strategies and clearly defined team expectations contribute to improved proposal organization, delivery clarity, and collaborative coherence.

Lean engineering demonstrated a steeper slope compared to communication and team contract modules, suggesting a stronger performance amplification effect among students who internalized lean principles. Although its mean perception score was lower (3.17), students who strongly valued lean engineering concepts showed disproportionately stronger presentation performance. This finding indicates that systems thinking and process optimization may enhance proposal structuring and design justification.

CAD/FE also exhibited a steep correlation slope, with high overall mean scores. This suggests that technical competency in modeling and simulation directly strengthens design credibility and technical depth in proposal presentations. The combination of high average scores and strong slope indicates both broad recognition and measurable performance benefit.

3.3.3 Correlation with Capstone and Career Perception

When correlations were examined for anticipated performance in the next capstone course, CAD/FE maintained high perception scores and strong correlation trends. The remaining three modules—communication style, team contract, and lean engineering—showed similar correlation patterns, with all four instructional components demonstrating steep slopes. This indicates that students perceive each module as influential for sustained project execution beyond the initial proposal stage.

For overall engineering career readiness perception, CAD/FE again received high scores, reinforcing its perceived importance as a core technical competency. Communication style and team contract maintained increasing slope trends, highlighting the perceived long-term value of interpersonal clarity and structured collaboration. Lean engineering exhibited a steep slope in career perception as well, suggesting that students who recognize the importance of efficiency, workflow optimization, and value-stream thinking associate these principles strongly with professional success.

#### 3.3.4 Interpretation and Educational Implications

The results reveal a consistent pattern across academic and professional contexts. Technical depth (CAD/FE) is both highly valued and strongly associated with performance outcomes. However, non-technical instructional modules—particularly lean engineering and team structuring—demonstrate high-leverage effects, as indicated by steeper correlation slopes.

The discrepancy between mean scores and slope strength is particularly notable for lean engineering. Despite a moderate average rating, its strong slope suggests that when students meaningfully integrate lean principles, measurable gains occur in presentation quality and perceived career readiness. This highlights the importance of reinforcing systems-based and process-oriented thinking in engineering curricula.

Similarly, communication style and team contract modules function as structural enablers. Their increasing slopes indicate that mastery of communication frameworks and explicit team governance mechanisms translates into improved collaborative execution and professional preparedness.

Overall, the findings suggest that while technical competency (CAD/FE) is widely recognized as foundational, integrative skills such as structured communication, team governance, and lean systems thinking act as performance multipliers across project-based learning environments and professional trajectories.

### 3.4 Relationship Between Design Proposal Presentation Performance and Project, Capstone, and Career Perceptions

To further examine the predictive value of early design communication performance, Assignment 2 (design proposal presentation) was correlated with students' perceived preparedness for (i) the current project, (ii) the subsequent capstone course, and (iii) overall engineering career readiness.

This correlation was performed to evaluate whether measurable performance in a structured presentation setting serves as an early indicator of broader academic and professional development. Since the design proposal presentation integrates technical reasoning, communication clarity, team coordination, and design justification, it represents a composite demonstration of engineering competency. Correlating Assignment 2 performance with project, capstone, and career perception allowed us to assess whether this early milestone reflects transferable skills beyond the immediate assignment context.

3.4.1 Distribution of Perception Scores

Students reported relatively high perceived alignment between presentation performance and broader outcomes:

Project readiness: max = 5, min = 1, mean = 3.9
Capstone preparedness: max = 5, min = 1, mean = 4.0
Engineering career readiness: max = 5, min = 1, mean = 4.0

The similar mean values across all three domains suggest that students consistently view the design proposal presentation as relevant to both near-term and long-term engineering development.

3.4.2 Correlation Trends

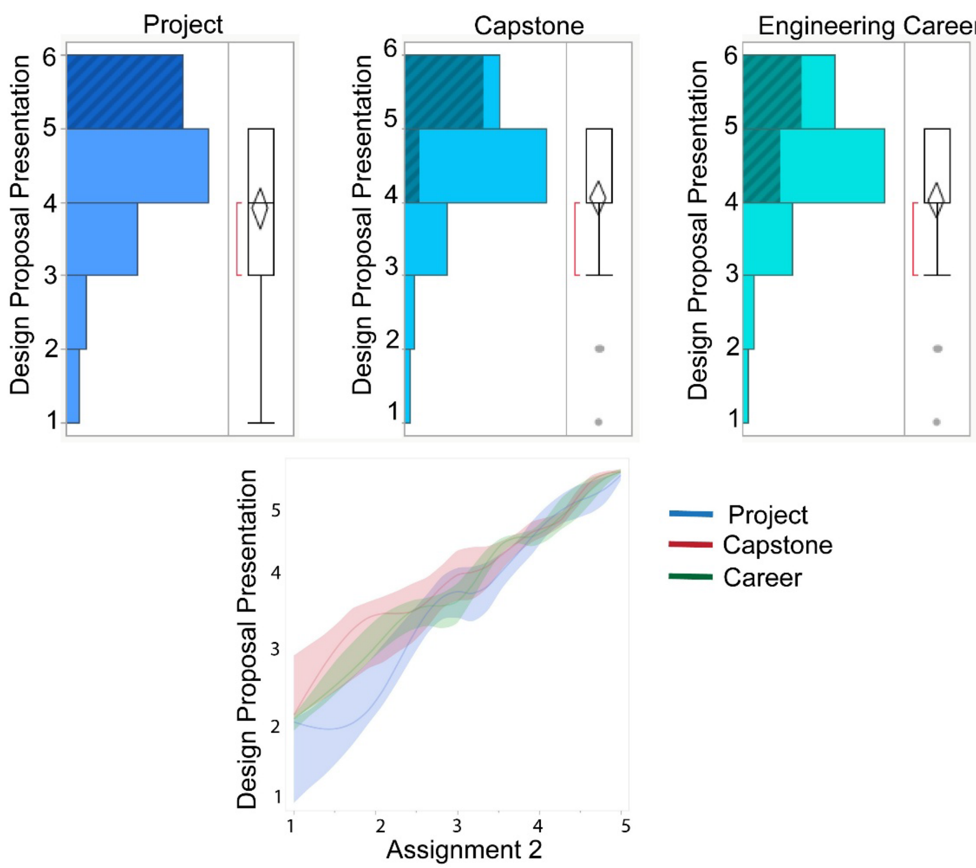

*Figure 8: Correlation between Assignment 2 (design proposal presentation) performance and perceived (a) current project readiness, (b) capstone preparedness, and (c) overall engineering career readiness. All three domains demonstrate steep positive slopes, indicating that higher presentation performance is strongly associated with increased confidence in academic progression and professional engineering development.*

As shown in figure 8, correlation analysis demonstrated steep positive slopes across all three domains when plotted against Assignment 2 performance. Students who performed strongly in the presentation assignment tended to report higher confidence and preparedness for their ongoing project, the next capstone course, and their future engineering careers.

The steep slope observed in all three cases indicates a strong association between demonstrated presentation success and perceived broader competency. Unlike earlier analyses where certain skills showed differential slopes, here the trend was uniformly strong. This suggests that Assignment 2 functions as an integrative assessment capturing multiple competencies simultaneously.

#### 3.4.3 Interpretation and Educational Implications

The consistent steep correlation slopes across project, capstone, and career perceptions indicate that design presentation performance may serve as an early proxy for engineering readiness. The presentation assignment required students to synthesize technical content, defend design decisions, coordinate team contributions, and communicate effectively—skills that are foundational across engineering education and professional practice.

The near-identical mean perception scores for capstone (4.0) and career (4.0) further suggest that students recognize continuity between academic performance and professional identity formation. The slightly lower but still high project mean (3.9) indicates immediate applicability within the course context. By correlating Assignment 2 with broader outcomes, we assessed whether performance-based evidence aligns with student self-perception of growth. The strong and consistent slopes suggest that early structured presentation milestones may serve as formative checkpoints for longitudinal skill development. These findings support embedding high-stakes, integrative communication assignments early in project-based curricula. Such assignments not only assess technical design thinking but also reinforce transferable competencies that extend into capstone experiences and professional engineering practice.

## 3.5 Association Between Assignment 3 (Report) Performance and Student Perceptions of Project, Capstone, and Career Readiness

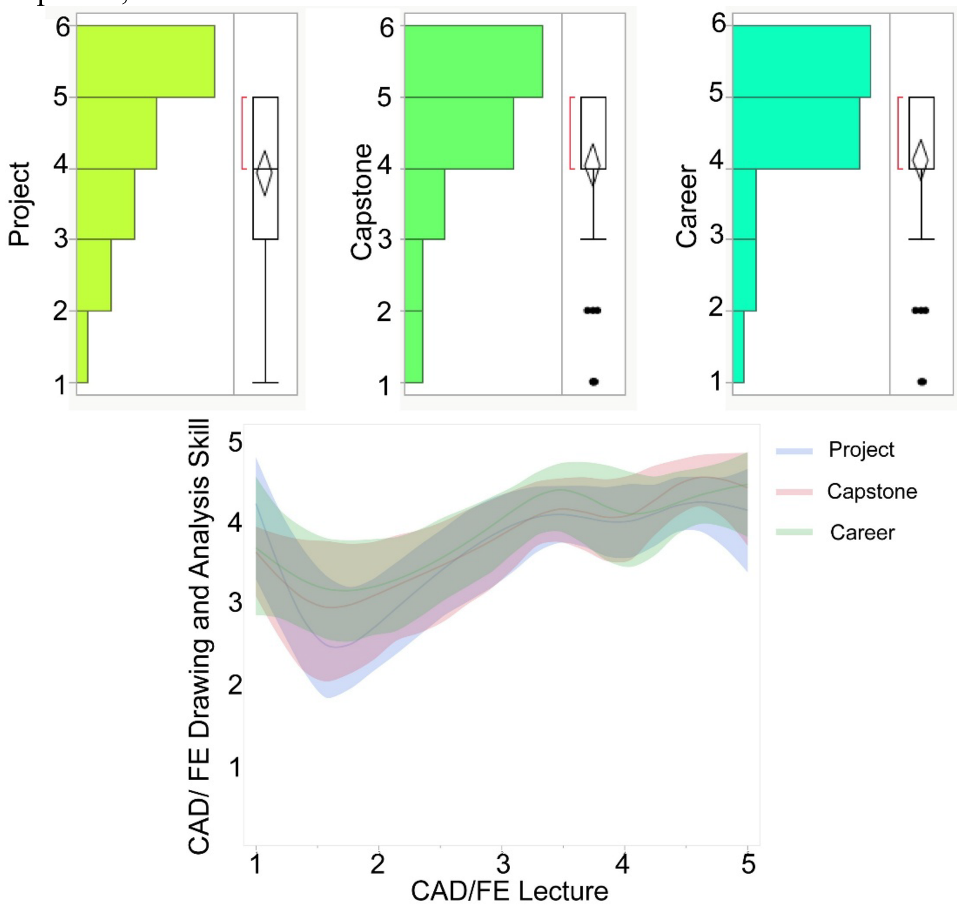


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*Figure 9: Relationship between Assignment 3 (report) performance and three outcome domains: Project preparedness, Capstone readiness, and Career confidence.* ***Top panel:*** *Score distributions (scale 1–5) for each domain, showing skew toward higher ratings (4–5) with moderate variability and few extreme outliers.* ***Bottom panel:*** *Smoothed trend lines illustrating positive associations between CAD/FE lecture and perceived readiness across all domains, indicating that stronger report performance corresponds with higher confidence and preparedness for project work, capstone completion, and career development.*

Figure 9 illustrates the relationship between student performance on Assignment 3 (report) and three outcome domains: Project preparedness, Capstone readiness, and Career confidence. The top panel presents the distribution of scores for each domain using a 1–5 scale. Across all three measures, responses are skewed toward higher values (4–5), indicating that students generally perceived themselves as well-prepared and confident in each area. Mean scores were relatively high—Project (~3.9), Capstone (~4.0), and Career (~4.0)—with relatively few low ratings (1–2). The corresponding boxplots show moderate variability in scores but limited extreme outliers, suggesting a consistent pattern of perceptions across students rather than being driven by a small subset of high or low performers.

The bottom panel displays smoothed trend lines illustrating the relationship between individual report scores and perceived outcomes in Project, Capstone, and Career domains with relation to the lecture. All three curves show a positive slope, indicating that students who performed better on Assignment 3 also reported higher levels of preparedness and confidence across all domains. Notably, the slopes are relatively steep, particularly for Project and Capstone readiness, suggesting that report quality is strongly associated with students' perceptions of their ability to execute projects and engage with capstone work effectively. Career confidence also shows a clear upward trend, implying that the skills reinforced and demonstrated through the report—such as technical communication, analysis, and synthesis—may translate into broader professional self-efficacy. Assignment 3 serves as an integrative assessment that not only evaluates technical and analytical competencies but also supports students' broader academic and professional development. The consistency of the positive association across all three domains highlights the value of report-based assignments in fostering confidence, readiness, and skill integration. These findings underscore the importance of well-designed, structured assessments in bridging technical proficiency with real-world preparedness, reinforcing the role of written reports as a critical tool for both learning and self-evaluation.

## 4.4 Relationship Between Poster Performance, Skill Development, and Design Presentation Success

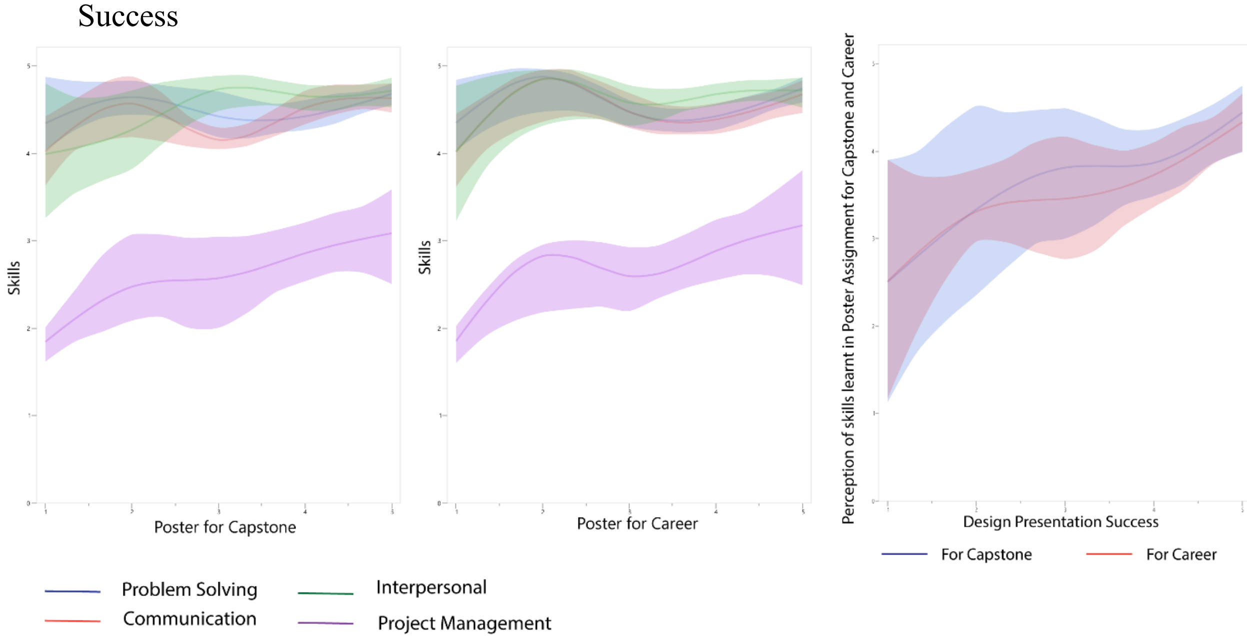


*Figure 10: Poster assignment performance is positively associated with perceived development of problem solving, communication, interpersonal, and project management skills (left and middle panels), and higher perceived skills correspond to increased design presentation success for both capstone readiness and career confidence (right panel).*

Figure 10 illustrates the association between poster assignment performance and perceived development across four core skills—problem solving, communication, interpersonal skills, and project management—as well as its relationship to overall design presentation success for capstone and career readiness.

In the left and middle panels ("Poster for Capstone" and "Poster for Career"), higher poster performance scores are consistently associated with increased self-reported skill development across all four domains. Problem solving, communication, and interpersonal skills begin at relatively high baseline levels and show modest upward trends as poster performance improves, indicating that students who performed better on the poster assignment perceived incremental strengthening of these competencies. In contrast, project management displays a more pronounced upward trajectory. Although it starts at comparatively lower perceived levels, it increases steadily with improved poster performance, suggesting that structured poster preparation may particularly enhance students' ability to organize, coordinate, and manage project components.

The right panel demonstrates a positive relationship between perceived skills and overall design presentation success, for both capstone readiness and career confidence. The slopes for both outcomes trend upward, indicating that as students report stronger skill development, their perceived success in design presentations also increases. The overlapping confidence bands suggest similar patterns for capstone and career outcomes, though the upward trajectory remains consistently positive in both cases. This pattern supports the interpretation that poster-based assignments function not only as communication exercises but also as integrative learning experiences that reinforce transferable professional skills. Poster performance is meaningfully associated with multidimensional skill development and that these skills, in turn, align with improved design presentation success. The particularly strong growth in project management skills highlights the role of structured, deliverable-driven assignments in preparing students for capstone projects and professional environments.

### 4.5 Student Feedback Emphasizes Hands-On Learning and Applied Robotics/Electronics Integration

Figure 11 presents a word cloud generated from aggregated student feedback, where word size reflects frequency of occurrence within the dataset. The most prominent words include *"course," "lectures," "electronics," "robotics," "lab," "fabrication," "design," "learn,"* and *"use."* The prominence of these terms indicates that students primarily framed their experience around technical content integration and hands-on learning components.


*Figure 11: Thematic Distribution of Terms in Aggregated Student Feedback- Word cloud of aggregated student feedback indicating that hands-on laboratory work, electronics integration, robotics design, and course structure were the most frequently referenced aspects of the learning experience.*

Frequent references to *"electronics," "robotics," "mechanical,"* and *"design"* suggest that students strongly associated the course with interdisciplinary system integration. The simultaneous visibility of *"fabrication," "build,"* and *"projects"* highlights the applied, experiential structure of the course. These patterns indicate that learning was perceived not solely through lectures but through active construction, prototyping, and implementation. The word *"solve", "see" and "work"* further implies that students emphasized practical application of tools, software, and hardware rather than abstract theoretical exposure.

Instructional elements are also clearly represented through frequent mentions of *"lectures," "class," "taught,"* and *"assignments."* This suggests that while the course was hands-on, structured instructional delivery remained central to the student experience. Positive descriptors such as *"good," "valuable,"* and *"helpful"* appear alongside more critical terms including *"confusing," "behind,"* and *"gaps,"* reflecting a range of perceptions. This distribution indicates that although students valued the applied learning environment, variability in background preparation or pacing may have influenced individual experiences.

The word frequency distribution demonstrates that students perceived the course as technically immersive and application-driven, with strong emphasis on robotics, electronics integration, and fabrication-based learning. The findings support the effectiveness of a project-based engineering model while also highlighting the importance of instructional clarity and foundational scaffolding to ensure consistent learning outcomes across diverse student backgrounds.

4. Instructor Observations

In addition to the feedback from the student survey, the instructors also reflected on the overall success of the course. Within the primary goals of the course redesign, the instructors felt they were successful in reducing the amount of written work for the students as well as focusing more on items that would align with expectations for them as practicing engineers. The feedback in the industry survey prioritizes rigorous execution of the engineering design process, validation through testing and iterative improvement as well as clear documentation and structured communication, and the assignments specifically address these items. The addition of more active learning elements within the lectures was a success, and the design presentation and poster fair were highlights of the semester.

The immediate feedback from the instructors within the design presentations (Assignment 2) allowed students to move forward with their designs with confidence or make changes to their designs with specific guidance from the instructors as well as a reasonable amount of time to complete the changes. The strong and consistent slopes for assignment 2 related analysis suggest that early structured presentation milestones may serve as formative checkpoints for longitudinal skill development. These findings support embedding high-stakes, integrative communication assignments early in project-based curricula. Assignment 3 serves as an integrative assessment that not only evaluates technical and analytical competencies but also supports students' broader academic and professional development. The consistency of the positive association across all three domains highlights the value of report-based assignments in fostering confidence, readiness, and skill integration.

The overall success of the students' devices was in line with previous years with the same project. The use of CATME allowed the instructors to observe team dynamics much earlier and with more detail; the intention is to not only require CATME in future semesters, but also to integrate it within the course grading.

With respect to areas of improvement, the instructors felt that there were still opportunities to reduce the written work by students, but a refocus on specific critical design evaluation tools was necessary. The design presentations delivered by the students were sometimes lacking in concrete justifications for design decisions, but rather focused more on personal experience or comfort with certain techniques rather than objective use of tools such as evaluation matrices. Additional attention on these tools will be a focus in future semesters.

While the use of Microsoft Planner for project planning simplified the process for students to create project timelines, the limitations of the software and the students' unfamiliarity led to weaker scheduling than in previous semesters. The instructors plan to become more familiar with the capabilities of Microsoft Planner to either offer more guidance and instruction to the students, or potentially identify a different cloud-based scheduling tool that might be more appropriate.

Despite a moderate average rating, our analysis suggests that when students meaningfully integrate Lean principles, measurable gains occur in presentation quality and perceived career readiness. This highlights the importance of reinforcing systems-based and process-oriented thinking in engineering curricula. In future semesters, there will be efforts made to tether the principles of Lean Engineering more to the project so that students can see the impact of the principles on their project success.

The word frequency distribution demonstrates that students perceived the course as technically immersive and application-driven, with strong emphasis on robotics, electronics integration, and fabrication-based learning. The findings support the effectiveness of a project-based engineering model while also highlighting the importance of instructional clarity and foundational scaffolding to ensure consistent learning outcomes across diverse student backgrounds. Future improvements in the course will address the issues above as well as continue to focus on preparing students both for their capstone project and for their futures as practicing engineers.

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