

# Implementation of a System Prototype Readiness Milestone in Senior Capstone Design

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Students frequently view prototyping as a final deliverable rather than as an iterative learning process. Furthermore, overconfidence in theoretical analyses, the belief that interim prototypes are a waste of time, and optimism about first-pass success can lead to prototyping procrastination. When system prototypes are completed with little time remaining for prototype refinement and system validation, the results can be disappointing. To address this issue, Texas A&M University's mechanical engineering department has instituted a System Prototype Readiness Milestone assignment. This milestone assignment grades students on their ability to put forth a nearly functional prototype 30 days before the end of their capstone project. Such a shift emphasizes the iterative nature of design by forcing them to begin construction earlier, the importance of early testing with a functional prototype, and the need for comprehensive validation and documentation at the conclusion of an engineering project.

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## Background and Motivation

Prototyping is necessary in engineering design, but students often lack a proper understanding until it is too late<sup>1</sup>. In senior capstone design programs, many student teams build a working prototype of their solution. However, when students treat this prototype as an end goal rather than an iterative process<sup>2</sup>, the result is often a prototype that lacks some desired functionality or does not satisfy all the project requirements. Prior studies have shown that earlier prototyping can help avoid design fixation<sup>3</sup> and lead to better designs<sup>4,5</sup>.

At Texas A&M University, the mechanical engineering department has a two-semester senior design sequence. Student teams complete conceptual design in the first semester and then build and validate their designs in the second semester with (often physical) prototypes. In this second semester, there are only two key course milestones: a progress report halfway through the semester and the completion of all final project deliverables at the end of the semester. Despite lectures on types of prototyping<sup>6</sup> and the importance of doing so early<sup>7</sup>, student prototypes are often completed just before the final deadline. Students often expressed overconfidence that their system would work as expected based on their analyses, only to learn about integration issues and incorrect assumptions too late. In the final weeks of the semester, students put in additional effort to address newly identified issues and complete their projects. During this time, students' concern about impending deadlines often led them to make decisions and design changes quickly, with little analysis or

documentation. Even when teams could produce a functioning prototype, they frequently did not have time for adequate systematic testing and refinement. Despite timeline recommendations and reminders from instructors, this prototyping procrastination, while improving overall, continues to be an issue from cohort to cohort. This reinforces earlier observations in published research that novice and expert designers still fail to fully leverage prototypes throughout design<sup>8</sup>.

## Design of Intervention

To address this issue, a new System Prototype Readiness Milestone assignment worth 10% of the final grade was added to the second-semester course in Spring 2025. This milestone takes place approximately thirty days before the final deliverables are due and provides interim feedback on a team's progress. To receive full credit, students need to present a complete prototype demonstrating most of the desired functionality with a clear path forward for full functionality. They are thereby ready to begin validation testing and fine-tuning their systems. The instructional goal is for student teams to spend their final month focusing on validation testing, documentation, and minor improvements, rather than correcting design mistakes. Teams receiving full credit for the milestone assignment are viewed to be on track toward completing their final deliverables in the next month.

Teams who are unable to secure the full milestone credit can only receive half or zero credit. Half credit is given if the prototype is mostly complete, demonstrating

only some functionality. The team may have a design plan but are still waiting for parts for confirmation. At this point in the semester, these teams are considered behind and would require significant effort in the following weeks to be able to complete the requisite validation testing. Zero credit is given to teams with an incomplete prototype (e.g., parts are still being ordered, manufactured, or designed). These teams are typically unsure of their final design and do not know when they would be able to begin validation testing. These teams are considered severely behind and unlikely to complete their final deliverables.

### Facility Usage

In addition to the expectation that the new milestone assignment would increase project quality, we hypothesized that the intervention would encourage earlier prototyping. At Texas A&M University’s mechanical engineering department, students primarily utilize two maker spaces: the department’s Rapid Prototyping Studio (RPS) and the College of Engineering’s Fischer Engineering Design Center (FEDC). When the milestone was implemented, staff at both maker spaces noticed and remarked on the changes to how senior design was using their facilities early in the semester. To supplement these anecdotal observations, we reviewed facility data from both the RPS and the FEDC. To put the following data in context, Texas A&M’s mechanical engineering department supports approximately 70 capstone design teams every year, including some competition teams.

### RPS Usage

Figure 1 illustrates the change in RPS 3D printer usage for the entire capstone program from Spring 2024 (top) before implementing the milestone assignment to Spring 2025 (bottom) after the addition of the assignment. Although these numbers include the first semester capstone students, we believe that almost all prints come from the second semester course. One item to note is that the RPS changed their procedure from 2024 to 2025. In 2024, students would submit print requests with computer aided design (CAD) files and the RPS would prepare the print. In 2025, the RPS moved toward a self-service model once students have been trained on the machines.

From 2024 to 2025, the total Spring semester prints increased from 406 to 832. This statistic does not take into account information about material usage and print timing. However, Fig. 1 shows more prints in January of 2025 and more consistent usage leading up to Spring Break (early March) and toward the milestone assignment (end of March). Notably, the RPS usage did not sharply drop after the milestone assignment (March

30) indicating that teams continued to make progress and updates until the end of the semester.

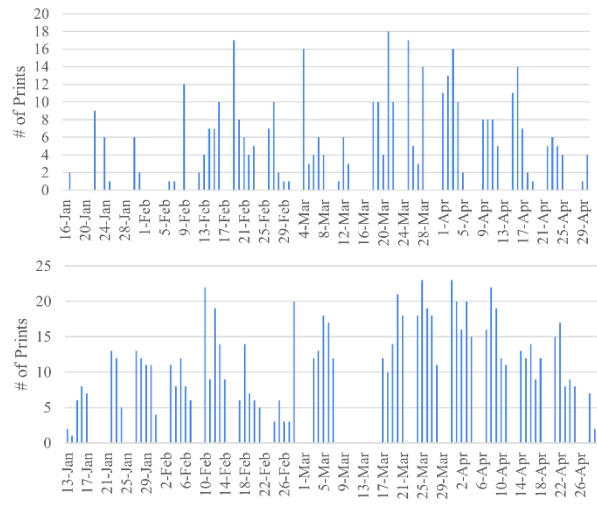


Figure 1: RPS 3D printing usage for all capstone students from (top) Spring 2024 without the milestone and (bottom) Spring 2025 with the milestone.

### FEDC Spring 2025 Usage

The FEDC offers a wide range of capabilities to all engineering students including 3D printing, manufacturing services, and build spaces. Since 2021, the FEDC has tracked the number of requests for 3D printing and fabrication requests. Spring trends for second semester capstone students during these years are shown in Fig. 2 with fiscal year (FY) 2025 being the first and only semester with the new milestone assignment.

Interestingly, the FEDC usage data in Figure 2 does not fully support the hypothesized trend. Although there is more usage in January, there is still a significant amount of work being done in April after the milestone deadline. This could include 3D printing and fabrication requests for the original prototype or for fine-tuning and improving it. Surprisingly, the data from FY 2024 follows a more expected trend with most requests occurring in February and March – leaving little to be done in April. Since the milestone assignment was not implemented in 2024, we cannot gather direct conclusions from this data. There are a number of nuances to be considered with this data, which is composed of several categories of requests that are not directly affected by the introduction of this new milestone. For example, our design competition teams, like the FSAE teams, continue to work well into April in preparation for the official competitions in May and June. Unfortunately, we are currently unable to separate this data from that of the full capstone program. We plan to inspect the data more closely to observe only the general capstone project trends.

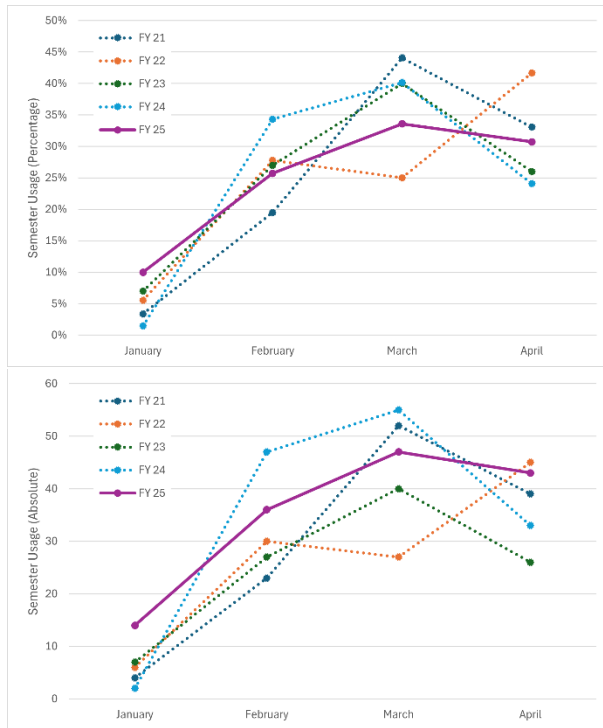


Figure 2: Total 3D printing and fabrication requests by second semester capstone students scaled by (top) percentage within one semester and (bottom) absolute number.

### Implications and Plans for Future Work

Although the FEDC data did not show a trend in line with our hypothesis, the RPS data and overall increase of work in January is encouraging. Maker space (RPS and FEDC) staff noticed increased general usage early in the semester before being informed about the new milestone. Among the recurring instructors who taught before and after the milestone introduction, the overall sentiment toward the new milestone assignment was positive. In general, prototypes were completed earlier than previous semesters, and the new milestone seemed to provide additional motivation for the students. Instructors indicated that the overall work quality was similar or better compared to previous semesters, and most recommended that the milestone assignment be continued. However, there were some recommended changes to the assignment and rubric.

Some students and instructors found the scale of 0, 5, and 10 percentage points toward students' final grade to be too restrictive. Teams with a prototype falling between a 5 and 10 were either rounded down to a 5 – which could be seen as harsh – or rounded up to a 10 – which serves as a distorted view of their current readiness to complete final deliverables. Beginning in Fall of 2025, the scale was adjusted to include the possibilities: 0, 3, 5, 7, and 10. The rubric for point values of 0, 5, and 10 remained unchanged whereas values of 3 and 7 are given when an instructor believes that a team falls between the

surrounding rubric items. We hope that this will allow a realistic scoring of their prototype readiness with only one month left on the project.

Another observation was that some teams who received their full milestone credit of 10 points, reduced their effort during the last month. They seemed to think that receiving full credit on the prototype milestone meant that they were already fully successful with their project. Some teams may have incorrectly believed their prototype to be their main final deliverable, leading to limited additional testing and design iteration after the milestone assignment. Teams who failed to complete all final deliverables would have seen their final grade penalized despite the full milestone assignment credit.

Since the Spring 2025 semester, we have been communicating that the new milestone deliverable is a step along the way and not an end in itself. We have added the following note to the milestone assignment to emphasize the message in future semesters: *“This milestone provides an indication of whether the team is on track with their project progress. However, receiving full credit on this milestone does not indicate that the project is complete or that Project Success has been achieved. The final Project Success will be assigned at the end of the semester based on the team’s fulfillment of the items in their Project Success Agreement.”* Instructors were asked to stress that the milestone score is an indication of likelihood of project success if the team continued with the same effort level through the remainder of the semester.

Including this Prototype Readiness Milestone in the second semester capstone course is an important step toward improving the quality of student projects. By pushing students to complete their prototypes sooner, we give them the opportunity to learn about the iterative nature of design. This structure may also provide more time for documentation at the end of the semester – compared to teams who complete their prototype right at the conclusion of the semester.

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