Implementation of Internal Design Reviews in a Capstone Course

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In a large engineering capstone course, it is a challenge for instructors to connect with each team to monitor status and provide input when needed to help ensure student and project success. To combat this, we have established a sequence of three internal design reviews located at important checkpoints during the project cycle. These internal design reviews consist of a Detailed Design Approval (DDA) review held near the end of the first semester and a Project Readiness Review (PRR) followed by the demonstration of a Mandatory First Prototype (MFP) held in the latter half of the second semester. Each of these reviews provides an opportunity for the instructors to meet each team individually, assess their status, and provide feedback. If a team is found to be at risk, this is an opportunity to provide individualized guidance. To gauge the effectiveness of the PRR/MFP process, we conducted a survey of 41 mechanical and biomedical engineering students from three different semesters. The results indicate the PRR/MFP process is a useful tool to promote team preparedness and increase project success in engineering capstone courses. As an added benefit, the design reviews provide students with additional opportunities to practice presenting and defending their work.

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Introduction and Background

In the engineering capstone courses at the University of Texas at Dallas (UTD), we provide students with the opportunity for "real world" experience[1] through partnerships with nearby companies which sponsor two-semester projects. The benefits of providing students with a multidisciplinary experience[2] and the natural overlap in required skill sets has led us to combine students from the Biomedical and Mechanical Engineering Departments into a single capstone course, co-taught by instructors from each department (known as the Engineering Directors).

With the growth of our university has also come an influx of students into the engineering school. For example, in the aforementioned capstone course, we typically have 50-60 teams per year, each consisting of 5-6 students. This growth has presented new challenges[3] for the Engineering Directors, including how to keep track of project status and intervene when needed to help ensure student and project success. To combat this, we have integrated a sequence of three internal design reviews that complement the external design reviews held with the project sponsor[4]. These internal reviews take the form of individual meetings between each team and the Engineering Directors at important checkpoints during the project. In this paper, the internal design review process is explained and students' opinions about two of these checkpoints are examined.

The flow of the capstone course is shown in Fig. 1. When students enter the first semester of the course, they rank the available projects they would like to work on and the Engineering Directors form teams according to students' preferences and self-reported skills[5]. Each team is provided with a sponsor point-of-contact (known as the Client), and an experienced engineering advisor not affiliated with the company (known as the Technical Manager, or TM). The project begins with a kickoff meeting between the team, TM, and Client to introduce and familiarize all parties with the project requirements. Following the kick-off meeting, the team prepares a Project Definition document which acts as a record of the agreed upon scope and requirements. Next, the team enters the conceptual design phase which culminates in an external presentation to the sponsor in a Preliminary Design Review (PDR). The outcome of the PDR is the Client's selection of a single conceptual design option. At this point, the team has an adequate understanding of their project to proceed with developing a Project Plan consisting of a work breakdown structure and a Gantt chart. The remainder of the first semester is spent in the detailed design phase with the team working to prepare a completed prototype design that is suitable for fabrication.

Even though teams are required to meet weekly with their assigned TM, we have found that it is still useful to have the Engineering Directors provide a uniform and consistent review of all teams and projects. Therefore, at the end of the first semester, the Engineering Directors

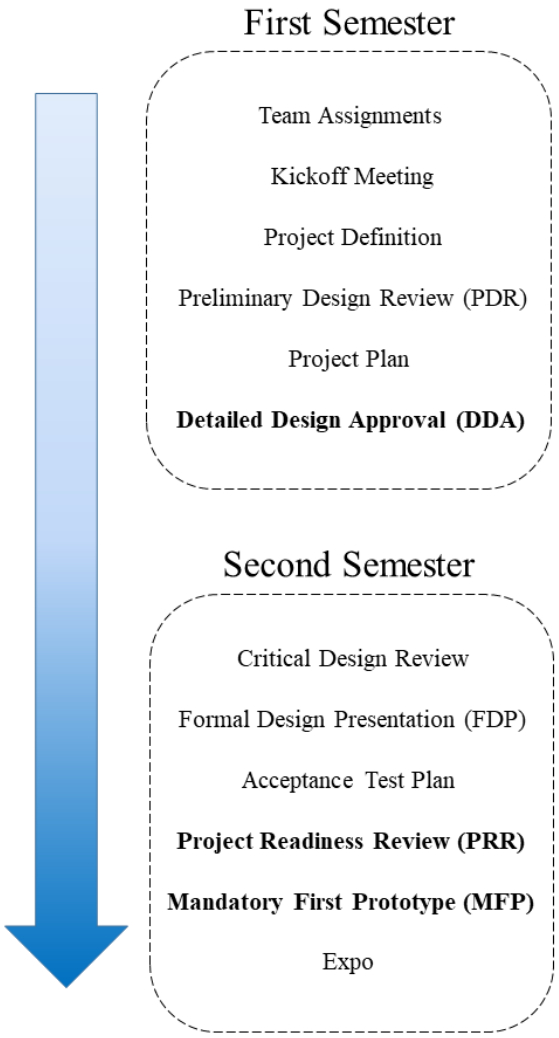

Figure 1: Flowchart of selected major milestones for the two-semester capstone course. Bolded items refer to internal design reviews.

meet with each team individually in the first internal design review called the Detailed Design Approval (DDA) meeting. No other project personnel (e.g., Client or TM) attend these meetings. The Engineering Directors offer a set of 45-minute appointment time slots spread throughout the week that teams can choose from. The meeting consists of the team presenting their problem statement, final design, the engineering justification for their choices, a final bill of materials, and a budget. The outcome of this meeting is a determination of the completeness of the team's design and its readiness to be presented to the sponsor in the Critical Design Review (CDR). There is no direct grade assigned for the DDA. If the design is deemed complete by the Engineering Directors, the team is permitted to schedule their CDR. If there are minor issues, the team is provided with a list of action items and follow-up is handled through email. More serious issues are handled in a follow-up DDA meeting. Although time consuming, these meetings have proven to be a valuable tool to assess team progress, head off major issues, and ensure that teams are prepared before presenting their completed design to their sponsor.

The second semester of the course begins with the CDR, an external meeting with the Client used to review the completed design, finalize key project decisions, and identify any design deficiencies. The outcome of this meeting is an agreement by all stakeholders to proceed with prototype fabrication. The teams then prepare and deliver internally a Formal Design Presentation (FDP) showing their approved final designs to their peers. This is another opportunity for teams to practice presenting technical information. Another key deliverable in the second semester is the Acceptance Test Plan. Teams are expected to validate the performance of their prototype against the project requirements and this is formalized in a written test plan that is reviewed and approved by the Client.

The latter half of the second semester includes the second and third internal design reviews, the Project Readiness Review (PRR) and the Mandatory First Prototype (MFP) demonstration, respectively. The PRR and MFP are two additional opportunities for the Engineering Directors to meet with each individual team. Teams must schedule a 30-minute appointment with the Engineering Directors for the PRR which is held two months prior to the final public exposition (Expo). Similar in format to the DDA meeting, the goal of this meeting is to assess the team's status with regard to scope, schedule, and budget and determine if the team is on track to successfully complete their project. If there are issues that put the team at risk of not completing their project, this is an opportunity for the Engineering Directors to work with the team to create an action plan to get them back on track. Scheduling this meeting two months prior to the Expo has been found to provide adequate time for teams to recover if serious issues are discovered.

A second critical part of the PRR is the establishment of a set of quantifiable and measurable MFP deliverables to be demonstrated at a later date. The purpose of the MFP is for the team to show evidence of all required prototype functionality. In other words, every required feature must be at least operational at MFP. Perfected operation, attainment of performance goals, and aesthetic touches are not required at this point. It is important not to confuse MFP deliverables with acceptance testing. For example, an MFP deliverable might be to show that an actuator or motor can be operated by the control system. Whether the motion, force, etc. of these devices meets project requirements is a matter of testing and is not the focus of the MFP demonstration. With this understanding of the MFP expectations, teams are required to bring a list of their proposed MFP deliverables to the PRR. The list is discussed with the Engineering Directors and

modified if necessary to ensure that it includes demonstration of all required features. Having the teams create this list first provides buy-in and eliminates disputes about misunderstood or unfair requirements later at the MFP demonstration. Because the MFP is a major portion of a team's final grade (see below), the finalized checklist of MFP deliverables is emailed to each team for their review and approval.

When a team signs up for a PRR time slot, they are automatically assigned an MFP demonstration time slot on exactly the same day and time four weeks later. This ensures all teams have an equal amount of time to work on their project between PRR and MFP. The MFP is demonstrated by the team in an individual meeting with the Engineering Directors. Teams have only their 30-minute appointment time to show all items on the MFP deliverables checklist. Out of fairness to others, teams are not permitted a "make-up" later if something fails to work during their appointment time. The result of the MFP is binary and accounts for 10% of a team's semester grade: The team passes if they meet all of the agreed upon deliverables, and fail if they miss even one of these. In the event of failure, this is again an opportunity for the Engineering Directors to aid the team in creating an action plan and hold one or more follow-up meetings to ensure project completion.

The penalty for failing to meet MFP requirements is intentionally harsh (i.e., a full letter grade) to motivate teams to work hard early so that they will have several weeks left for execution of the Acceptance Test Plan and improvement of the prototype prior to the Expo. Prior to implementation of the PRR/MFP process, we too frequently witnessed teams hopelessly trying to finish projects the night before Expo. The result was often a poor-quality prototype, sponsor dissatisfaction, and a bad student experience. Post-implementation, we have seen numerous instances where teams have discovered major problems at their MFP and then had time remaining to adequately address them resulting in a more successful project.

Other benefits of the three internal design reviews described above include additional opportunities for students to gain experience presenting and defending their work as well as more fixed milestones to help students manage their projects. While there is a significant time commitment required on the part of the Engineering Directors, the DDA, PRR, and MFP meetings help balance tracking performance of a large group of teams without having to be involved in every minute detail of the project.

We observed improvements in team preparedness for the CDR following implementation of the DDA meeting, and we also saw improvements in the quality of the final prototype at Expo following implementation of the PRR/MFP process. These observations lead us to believe that the series of internal design reviews we implemented in our capstone curriculum has improved the student experience and increased project success. To confirm this, we conducted a survey of several cohorts to gather data on students' opinions about the PRR/MFP process. We have chosen to focus here on evaluating the PRR/MFP process since it has a more direct impact on project outcome, but gathering student opinions about the DDA meeting would be an interesting direction for future research.

Methodology

In this work, a voluntary online survey of Mechanical (MECH) and Biomedical (BMEN) Engineering students in the Summer 2017, Fall 2017, and Fall 2019 semesters was conducted (UTD IRB Approval No. MR 17-126). The survey was sent soon after Expo so the PRR, MFP, and project outcome would be clearly remembered by the respondents. Students were asked to identify their engineering major, gender, and the pass/fail outcome of their MFP. The factors investigated in the survey were generated based on the authors' experience and perceptions of possible connections between the PRR/MFP and project outcome. Respondents were asked to "rate [his/her] level of agreement with each of the following statements regarding [his/her] personal experience with the PRR/MFP process in [his/her] capstone course," using a 5-point rating scale (Strongly Disagree - 1, Somewhat Disagree - 2, Neither Agree Nor Disagree - 3, Somewhat Agree - 4, Strongly Agree - 5). The 12 included factors were asked in the top-to-bottom order seen in Fig. 2. In this survey, valid responses were obtained from a total of 41 students. In the sample, there were 31 male and 10 female students. The departmental distribution was 24 MECH and 17 BMEN. Finally, there were 28 students who passed and 13 students who failed their MFP.

Results

To create a useful metric for judging a student's response with the factors presented regarding the PRR/MFP process, the percentage of *Somewhat Agree* and *Strongly Agree* answers were summed as a positive response, while the *Somewhat Disagree* and *Strongly Disagree* were summed as a negative response. The overall results of the survey are presented in Fig. 2 (the percentages may not add to 100% due to omitting the neutral responses).

Two of the most promising findings of the survey are that 88% of students agreed that the PRR/MFP process helped their team have a better project outcome, and similarly 88% believed their team received useful feedback from the Engineering Directors at PRR. These results show that most students found the PRR/MFP process to be valuable and it supports our assumption that these internal design reviews are beneficial.

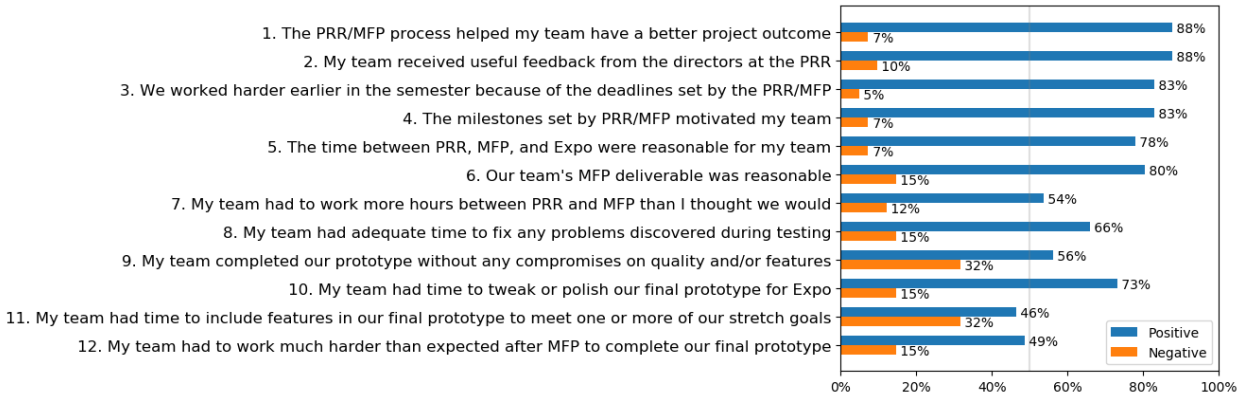

Figure 2: Percentages of positive and negative responses for each survey factor.

Another important finding was that students agreed they worked harder earlier in the semester because of the deadlines set by the PRR/MFP process and they were motivated by these milestones. A majority of students also felt that they had adequate time to fix any problems discovered during testing and to tweak/polish their final prototype before Expo. Together, these results provide strong evidence that the PRR/MFP process has made the distribution of project effort more uniform across the semester and provided extra time at the end of the project. Both of these outcomes were key reasons for implementing the internal design reviews and their associated milestones.

The PRR/MFP timeline seems to be good with 78% of students agreeing that the time between the PRR, MFP, and Expo milestones were reasonable for them. The responses also show it has been useful to allow students to propose and discuss the MFP requirements, because 80% of respondents agreed that what they were required to show at MFP was reasonable. This aligns with our experience that students are more accepting of the MFP objectives and outcome because they were a partner in creating it and had agreed in writing to the deliverables.

The last two factors had the lowest agreement from students, but these continue to support the benefits of the PRR/MFP process. The nature of stretch goals is an important reason why only 46% of students agreed they had enough time to include them in their final prototype at Expo. These are not a requirement for the completion of the project, but are usually completed by teams willing to go the extra mile. Additionally, students who fail their MFP are focused on getting their project back on track, and are more likely to aim for just finishing the minimum requirements. Only 49% of students agreed their team had to work much harder than expected after MFP to complete their final prototype. This is an indication that the implementation of the internal design reviews and their associated milestones is working, since approximately half of students are accurately planning their workload across the semester.

Conclusion

In capstone courses with a large number of students, instructor-team interaction can dwindle and allow issues to go unaddressed, potentially affecting the student experience, project outcome, and client satisfaction. To combat this, we have implemented a series of three internal design reviews to gauge team statuses and offer feedback at important checkpoints during the semester. This process also provides additional milestones to help the team manage their effort. The student survey responses examined here confirm our observations that the Project Readiness Review (PRR) and the Mandatory First Prototype (MFP) demonstration have been beneficial in our capstone courses. The most positive responses from students were that the feedback they received from the Engineering Directors at the PRR meeting was useful to them and the PRR/MFP process helped them to have a better project outcome. The data obtained from our survey will be further analyzed and explored in future publications.

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