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The Benefits of Internal Design Reviews in an Engineering Capstone Course

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The Benefits of Internal Design Reviews in an Engineering Capstone Course

Abstract

In a large engineering capstone course, it is important for the instructors (Engineering Directors) to connect with each student team to ensure individual student success as well as overall project success. A way we have incorporated this into our curriculum is via a sequence of three internal design reviews: a Design Approval Review (DAR) held near the end of the first semester, a Project Readiness Review (PRR) scheduled eight weeks before the end of the project, followed four weeks later by the presentation of a Mandatory First Prototype (MFP). During the DAR and PRR, each team meets individually with the Engineering Directors to present their project's status. If a team is at risk of falling behind, this is an opportunity for the Engineering Directors to intervene and help them find a way to achieve a completed project at the conclusion of the course. Additionally, at the PRR, the team and Engineering Directors establish a set of measurable deliverables for the MFP. These deliverables are chosen to ensure that all required prototype features are at least functional a month before the end of the project. To understand the effect of the PRR/MFP process on project outcome, 41 mechanical and biomedical engineering students from three different semesters were surveyed. Overall, the students found the PRR/MFP process to be a beneficial process because they believed they received useful feedback from the Engineering Directors and that it helped their project outcome. We further validated the positive effects off the PRR/MFP process by examining the effect of the MFP grade on the technical evaluation of the team's final project for 147 teams over 8 semesters. From these results, we believe the PRR/MFP process is a useful process to promote team preparedness and increase project success in engineering capstone courses. The process not only encourages mentorship from course Engineering Directors, but also allows students another opportunity to learn to present and defend their work.

1. Introduction

In the concluding year of an engineering student's undergraduate career, ABET requires a major design experience which uses knowledge and skills learned in previous courses and involves application of engineering standards and handling of multiple constraints. Typically, this is accomplished in a capstone (senior) design course or course sequence [1].

In the two-semester engineering capstone course sequence at the University of Texas at Dallas (UTD), we provide students with the opportunity for "real world" experience [2] through partnerships with companies which sponsor projects. During the first semester, students focus on the project definition and design phases and attend weekly lectures while the second semester primarily consists of prototype fabrication and testing. The benefits of providing students with a multidisciplinary experience [3], [4] and the natural overlap in required skill sets has led us to combine the Biomedical and Mechanical Engineering departments into a single capstone course, co-taught by instructors from each department (known as the Engineering Directors).

With UTD's growth has also come an influx of students into the engineering school, leading to a steadily increasing enrollment in capstone classes. For example, in the joint Biomedical and Mechanical Engineering capstone course, we typically have 50-60 teams per year, each consisting of 5-6 students. This growth has presented new challenges [5] for the Engineering Directors, including how to monitor project status and intervene when needed to help ensure student and project success. To address this, we have integrated into our curriculum a sequence of three internal design reviews that complement the external design reviews held with the project sponsor [6]. 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 the effects of two of these checkpoints on project outcome are examined.

Most capstone courses are organized in the following fashion: Problem Definition, Concept Generation, Preliminary Design, Detailed Design, and Communication of Results [7]. Two main models for engineering capstone courses are the Problem/Project Based Learning (PBL) and Conceive-Design-Implement-Operate (CDIO) frameworks [8] , which overlap by sharing Design-Implement stages [9]. In each, there are variations with regards to course length, milestones, and review criteria by which students are advanced.

One such example of a course using the CDIO framework in practice is a Design-Build-Test electronics course at Linköping University in Sweden [10]. In this semester-long course sequence, a project was assigned to cover idea via design and implementation to evaluation of a product or system. The course in this case was organized into three stages of "Before" (receiving assignment and brainstorming), "During" (design and testing), and "After" (delivery and evaluation). Milestones are present during and between each of these stages, and approval is given by the "sponsor", or course examiner in this case, to move forward.

Another example is the PBL-based, interdisciplinary engineering capstone course developed for the University of Toledo and University of California, Merced [6]. The single semester course is split into three 5-week sections for each design phase, each punctuated by a Preliminary Design Review (PDR), a Critical Design Review (CDR), and Final Design Review, respectively. The design reviews are presented to a "general audience" consisting of clients, faculty, and student peers. Each team receives anonymized feedback from the audience members according to assessment criteria established at the beginning of the course.

The capstone course described in [11] is a single semester course with two main phases. The first phase consists of defining the project and selecting a few possible design concepts, while the second phase is for students to build and test prototypes to meet the project requirements. There is only one design review, which takes place in between these design phases. The review is held between the team, an advisory committee (consisting of two faculty members, a non-faculty member, and possibly a graduate student), and the client. Details of this review were not elaborated upon, but it was noted that there were weekly meetings with the advisory committee to discuss progress and deliver feedback. Similarly, a two-semester, industry-sponsored mechanical engineering capstone course is described in [12]. In this case there is a total of four design reviews conducted, three in the first semester (System Requirements Review, PDR, and CDR), and one in the second semester (System Verification Review). Oral presentations in the first three design reviews are given by the team to the faculty and clients involved in the project, while the final design review is open to all faculty and clients.

In the following section, we will detail some of the major milestones and design reviews present in the PBL-based capstone course at UTD. In section 3, the methodology by which the efficacy of the internal design reviews we have implemented are measured will be described. While there is much time, energy, and logistics involved with conducting individual design review meetings between the Engineering Directors and each of the teams, it is evident from the survey responses and Expo technical evaluation scores reported in section 4 that the process is beneficial to both students and project outcomes.

2. Capstone course milestones

The flow of our two-semester capstone course is shown in Fig. 1 [13]. 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 [14]. Each team is provided with a sponsor point-of-contact (known as the Client), and an experienced engineering advisor not affiliated with the Client's 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 design on paper that is suitable for fabrication. For deliverables such as the Project Definition and PDR, students are provided with a set of written guidelines that explain in detail what is expected for the particular deliverable.

While teams are required to meet weekly with their assigned TM, it is still important to have the Engineering Directors provide a uniform and consistent review of all teams and projects. Near the end of the first semester, the Engineering Directors meet with each student team individually in a first internal design review called the Design Approval Review (DAR); all team members are required to attend, bur no other project personnel such as the Client or TM are in attendance at 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. Besides material costs, the budget is expected to include written price quotations for any fabrication services the team will need such as machining, welding, and circuit board manufacturing/assembly. Requiring these quotes has the added benefit of forcing teams to consult with the on-campus machine shop staff on the manufacturability of their design. The outcome of DAR 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 DAR. If the design is deemed complete by the Engineering Directors, the team is permitted to schedule their CDR with their sponsor. 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 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 fully prepared before presenting their completed design to their sponsor.

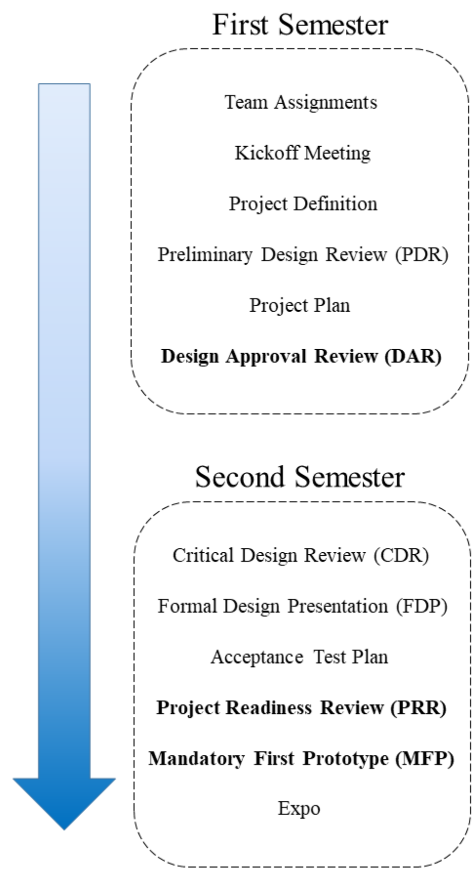

Figure 1: Flowchart of selected major milestones for the two-semester capstone course. Bolded items refer to internal design reviews.

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. This is usually the first time the Client will see the design and justification in such detail. 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. The FDP is done to provide students with experience presenting formally to a large audience. It is not intended to be an opportunity for in-depth critical evaluation of designs; however, students are provided with instructor and peer feedback on the quality and content of their presentation. The next 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 project exposition (Expo). Similar in format to the DAR 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 deliverables to be demonstrated four weeks later at the MFP. The purpose of the MFP is for the team to show evidence of all required prototype functionality. The hardware and software are expected to be assembled and integrated to the extent that the team can show that all required system functionality is present. 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 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. Between the time of the PRR and MFP, we do not change MFP deliverables (except in very rare instances). Teams are expected to manage their projects effectively and develop solutions to any obstacles they encounter so that they meet their MFP goals and schedule.

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 fails if they miss even one of these. (In a few instances, the Engineering Directors have given a team half-credit when they came very close to completing all deliverables.) 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 before 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.

At the conclusion of the second semester, teams present their final deliverable at Expo. Here teams prepare a short oral presentation and demonstration of their device to judges consisting of faculty members and local engineers not involved in the projects. Judges rate the teams on their presentation and technical achievement, and those with the highest scores are awarded at the end of the event. After official judging has taken place, the projects are then exhibited to the general public.

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 DAR, 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 projects.

We observed improvements in team preparedness for the CDR following implementation of the DAR 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 DAR meeting would be an interesting direction for future research.

3. 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 (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. As a result, the questions fall into one of three categories further elaborated on in Section 4.2: effect of time between each milestone, amount of work input by the team, and the outcome of the final deliverable. 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 following order:

1. The PRR/MFP process helped my team have a better project outcome.

2. My team received useful feedback from the Engineering Directors at the PRR.

3. We worked harder earlier in the semester because of the deadlines set by the PRR/MFP process.

4. The milestones set by PRR/MFP motivated my team.

5. The time between PRR, MFP, and Expo were reasonable for my team.

6. Our team's MFP deliverable was reasonable.

7. My team had to work more hours between PRR and MFP than I thought we would.

8. My team had adequate time to fix any problems that were discovered during testing.

9. My team was able to complete our prototype without making any compromises on quality and/or features.

10. My team had time to tweak or polish our final prototype for Expo.

11. My team had time to include features in our final prototype to meet one or more of our stretch goals.

12. My team had to work much harder than we expected after MFP to complete our final prototype.

In this survey, valid responses were obtained from a total of 41 students. In the sample, there were 31 students who identified as male and 10 who identified as female. The departmental distribution was 24 MECH and 17 BMEN. Finally, there were 28 students who passed and 13 students who failed their MFP.

4. Results and discussion

4.1 Overall 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 [13] (the percentages may not add to 100% due to omitting the neutral responses).

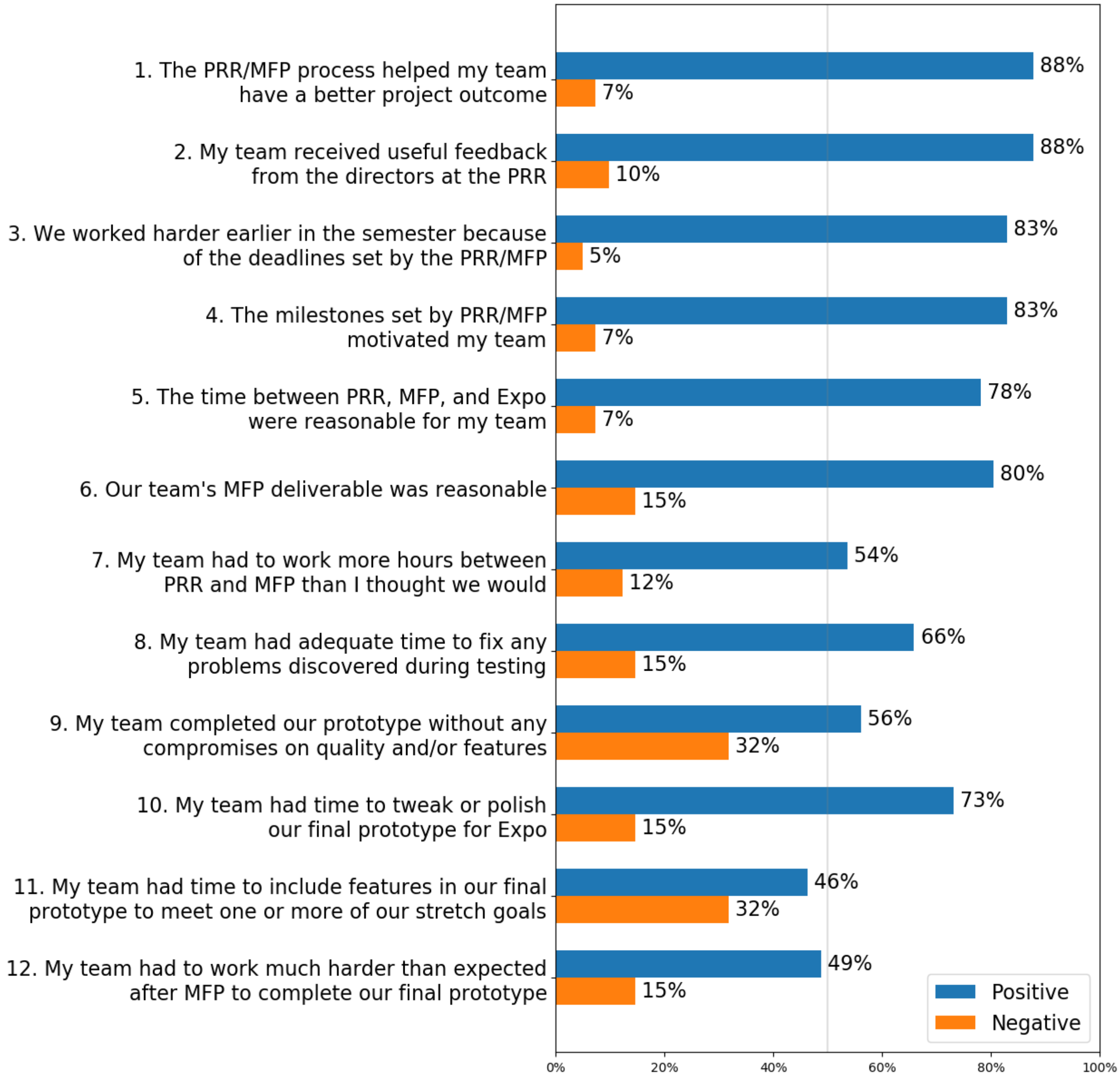

Figure 2: Percentages of positive and negative responses for each survey factor.

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.

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 appropriate, 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 had input in the process 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 more accurately planning their workload across the semester.

4.2 Detailed results

While we have been able to uncover some interesting findings from the overall results, it is useful to examine the results in more detail by splitting the factors into three categories of "Time", "Work", and "Outcome", as seen in the following three subsections. The factors related to "Time" are mainly concerned with the effect of time on the project between each milestone. Factors in the "Work" category examine the amount of effort exhibited by the team throughout the PRR/MFP/Expo milestones. Finally, the "Outcome" factors examine the resulting deliverable following the internal design review process.

We believe the most pertinent parameter of this study to be the result of the MFP. As stated in section 3, students passed the MFP if they met all of the agreed upon deliverables and failed if they missed even one of these; however, in some instances, the Engineering Directors have awarded teams with partial credit if they came very close to achieving the MFP deliverables. Here we are considering teams who <u>did not</u> meet all of the agreed upon deliverables to be in the "failed MFP" category, which includes teams who only received partial credit.

In Figs. 3-5 we show the percentage of students who passed MFP (green) and percentage of students who failed MFP (red). In both cases, we are reporting only the fraction that had a <u>positive</u> response (sum of *Somewhat Agree* and *Strongly Agree*) to the factor.

4.2.1 Results for factors related to time

Fig. 3 shows the responses for the four factors in the "Time" category. "The time between PRR, MFP, and Expo were reasonable for my team" was highly positive from both groups of students; even students who failed their MFP felt the assignments were adequately spaced throughout the semester. The factors "My team had adequate time to fix any problems discovered during testing" and "My team had time to tweak or polish our final prototype for Expo" were both more positively rated by students who passed MFP than those who failed. Students who failed MFP required more time to finish their basic requirements, leading to less time to execute their Acceptance Test Plan and fix any issues discovered. For the same reason, these students may not have had much time to improve the quality of their prototype. Teams who passed their MFP fulfilled the basic requirements decided on during the Project Definition phase, and thus could focus on perfecting portions of their prototype. "My team had time to include features in our final prototype to meet one or more of our stretch goals" had a lower positive response than the other factors in the "Time" category due to the nature of stretch goals. As stated previously, these are not a requirement for the completion of the project, but usually proactive teams are able to complete at least some of them. Those who fail their MFP are required to work on an action plan with the Engineering Directors to get their project back on track, and are most likely focused on just finishing the minimum requirements.

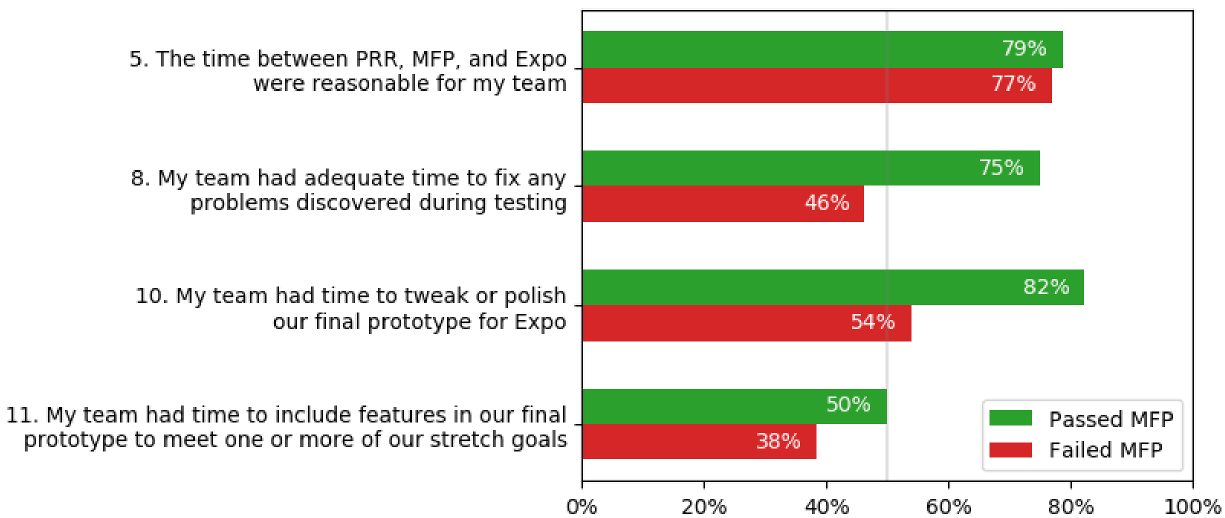

Figure 3: Positive (sum of *Somewhat Agree* and *Strongly Agree*) response percentages of students who passed (green) and failed (red) their MFP for factors in the "Time" category.

4.2.2 Results for factors related to work

Fig. 4 shows the responses for the four factors in the "Work" category. "We worked harder earlier in the semester because of the deadlines set by the PRR/MFP" and "The milestones set by the PRR/MFP motivated my team" had positive response rates higher than 50% for students who passed and failed, but the percentages were significantly higher for those who passed (93% and 89%, respectively). Respondents who passed their MFP were both highly motivated by the deadlines and worked harder earlier in the semester. The fact that more that 60% of respondents agreed with these two statements regardless of MFP outcome confirms that the PRR/MFP process is having the intended effect. "My team had to work more hours between PRR and MFP than I thought we would" and "My team had to work much harder than expected after MFP to complete our final prototype" both show the students who failed their MFP agreed with this statement more than those who passed did. This makes sense, as the teams that failed MFP were normally the teams that were the farthest behind schedule when meeting with the Engineering Directors for PRR.

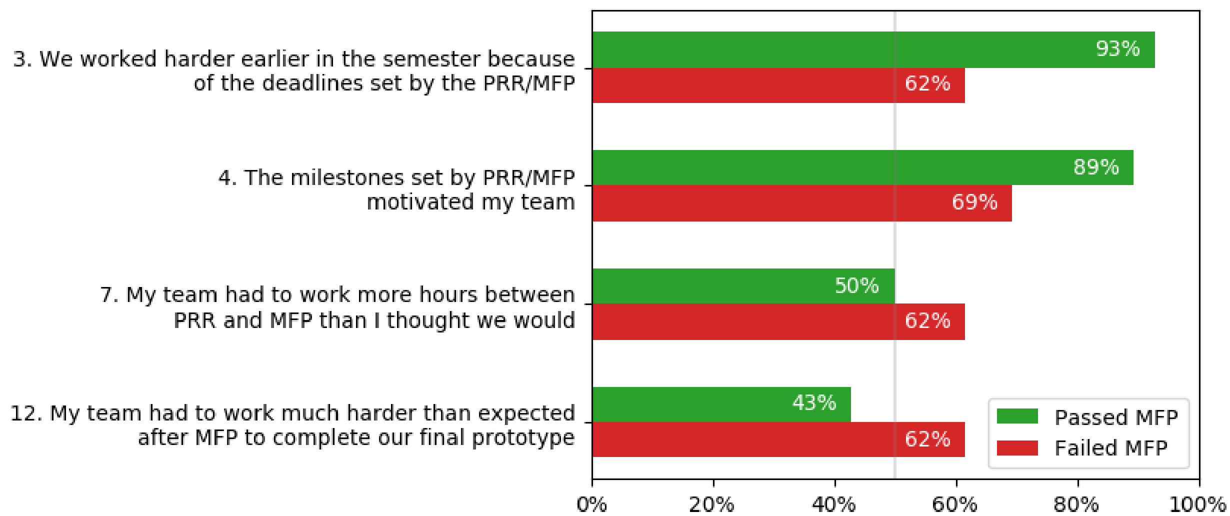

Figure 4: Positive (sum of *Somewhat Agree* and *Strongly Agree*) response percentages of students who passed (green) and failed (red) their MFP for factors in the "Work" category.

4.2.3 Results for factors related to outcome

Fig. 5 shows the responses for the four factors in the "Outcome" category. "The PRR/MFP process helped my team have a better project outcome" and "My team received useful feedback from the directors at the PRR" both received highly positive responses from respondents regardless of whether they passed or failed MFP. This shows the PRR is a useful meeting for each individual team, and they found the input from the Engineering Directors to be helpful. It is encouraging to see that students who did not pass the MFP still believed that the process was beneficial to their team. "Our team's MFP deliverable was reasonable" had positive responses of over 60% from both groups. Respondents who failed their MFP may have still felt their deliverable was reasonable because they had a part in creating it and ultimately agreed to it in writing. As expected, "We completed our prototype without any compromises on quality and/or features" had a much higher positive response from students who passed than those who failed their MFP. Since the MFP is a checkpoint for each team to have all of their basic functionality in the prototype, those who passed should have more time to meet project requirements in terms of quality and features compared to those who failed and had to work harder to catch up.

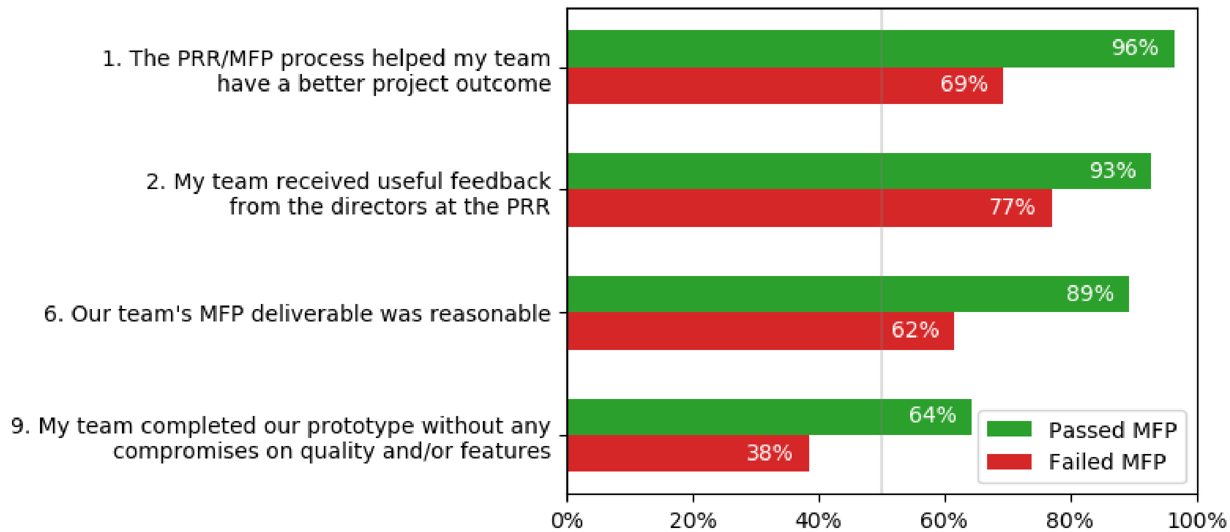

Figure 5: Positive (sum of *Somewhat Agree* and *Strongly Agree*) response percentages of students who passed (green) and failed (red) their MFP for factors in the “Outcome” category.

4.3 Effect of MFP outcome on Expo technical evaluation score

In addition to student opinion, we also quantitatively analyzed the effect of the MFP outcome on project success as measured by how the final protype was evaluated at Expo. The final prototype is presented at Expo where it is judged by faculty and local engineers not involved in the project. The judging rubric is as follows:

1. Presentation:

1.1 Content: Initial description of project ("elevator speech") is concise and thorough; Includes project background & motivation, key requirements, and overview of design features.

1.2 Delivery: Speakers project confidence and understanding of the material; Delivery is enthusiastic and persuasive; Unfamiliar terms or concepts are defined and explained.

1.3 Questions: Questions are handled with confidence; Answers demonstrate an understanding of the project and issues involved.

1.4 Exhibit: Team effectively uses prototype, example items, video, etc. to deliver their message.

1.5 Dress & Appearance: Team members are dressed and behave in a professional manner.

2. Technical:

2.1 Solution: Design presented has the features and capabilities necessary to solve the given problem; Design has a high probability of successfully working as intended.

2.2 Performance: Design meets the project specifications; Acceptance test results verify that the project meets requirements.

2.3 Challenges: Team has successfully managed challenges and developed effective ways to solve unexpected problems.

2.4 Craftsmanship: Rating of the overall quality of the final prototype.

The two general Expo rating categories are presentation and technical. The former measures how well the team was able to communicate their solution to the judges, while the latter is a measure of the quality of the solution. For that reason, we only examined the technical ratings given by the judges to each team. For subcategories 2.1-2.4, judges rated the team on a four-point scale (*Far Below Expectations* - 1, *Below Expectations* - 2, *Meets Expectations* - 3, *Exceeds Expectations* – 4). The total technical evaluation score reported here is calculated by taking the average of the scores in each subcategory (2.1-2.4) for each team.

The MFP and Expo technical evaluation scores received by 147 BMEN and MECH teams were recorded from Spring 2017 to Fall 2019 (for a total of 8 semesters). Fig. 6a shows the distribution of the Expo technical evaluation scores received by 95 teams who passed MFP. The average score received was 3.40 and the standard deviation was 0.29. Fig. 6b shows the histogram of Expo technical evaluation scores of 52 teams who failed MFP. The average score was 3.16 and the standard deviation was 0.40. Students who passed their MFP had a higher average technical evaluation score average and less score variability than those who had failed their MFP.

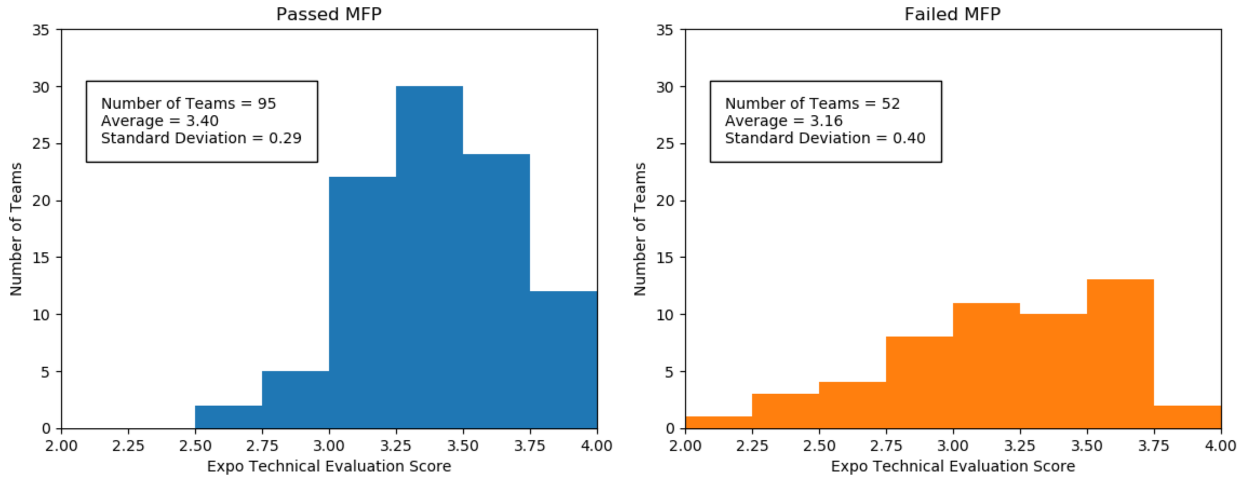

Figure 6: Distributions of Expo technical evaluation scores given to teams who (a) passed and (b) failed their MFP. Note the bottom axis ranges from 2.0 to 4.0.

For purposes of this analysis, we set the threshold for "passing" the Expo technical evaluation at a score of 3.0, which corresponds to at least "meeting expectations". Table 1 shows the number of teams in the categories of Pass/Fail MFP and Pass/Fail Expo technical evaluation, and we can view it as a binary classifying confusion matrix [15]. The "true positive" is the upper left entry, which corresponds to when teams passed both MFP and the Expo technical evaluation. The "true negative" is the lower right entry, which corresponds to when teams failed both MFP and the Expo technical evaluation. We can calculate the accuracy of this classification by summing the "true positive" and "true negative" categories and dividing them by the total number of teams, which we find to be 70.7%.

Table 1: Expo technical evaluation score data for each team split into different conditions.

N = 147	Pass Expo Technical Evaluation	Fail Expo Technical Evaluation
Pass MFP	88	7
Fail MFP	36	16

Table 2 shows the calculation of the conditional probabilities. It is evident that passing MFP will aid in passing the Expo technical evaluation (92.6% probability). From this, we can make the following logically equivalent statements:

1. Given that a team failed MFP, they are more likely (by 23.4 percentage points) to fail the Expo technical evaluation than if they had passed MFP.

2. Conversely, given that a team passed MFP, they are more likely (by 23.4 percentage points) to pass the Expo technical evaluation than if they had failed MFP.

Table 2: Conditional probabilities of the Expo technical evaluation outcome given the MFP outcome.

N = 147	Pass Expo Technical Evaluation	Fail Expo Technical Evaluation
Pass MFP	92.6%	7.4%
Fail MFP	69.2%	30.8%

5. 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 status and offer feedback at important checkpoints during the semester, the Design Approval Review (DAR), Project Readiness Review (PRR), and Mandatory First Prototype (MFP). We previously reported on the overall student survey responses in [13], but here we explore the data deeper and examine Expo technical evaluation scores to confirm our observations that the PRR and the MFP demonstration have been a beneficial addition to our capstone course. 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.

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