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Impacting Team-based Learning of First-year Engineering College Students via the Creation of an Upperclassman Project Management Course

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Abstract

Engineering curricula excels at introducing students to technical information and engineering design thinking which is important for students to succeed in their future careers. However, "soft skills" such as teamwork is also an essential skill in engineering curricula. Generally, it is common for engineering courses to contain team-based projects ranging from first-year Introduction to Engineering courses to Senior Design/Capstone courses. However, students' experiences in teams vary greatly and when un-facilitated within large courses, students may have negative experiences which impact their future learning. To overcome this issue, a new course: *Applications in Project Management in Biomedical Engineering* was developed at the University of Massachusetts Lowell. This course is student-led where upper-class students serve as project managers (PMs) to first-year student teams in *Introduction to Biomedical Engineering* who are conducting semester long design projects. The upper-class students learn about a promising career in engineering project management while immersed in their role as PMs. They are responsible for setting agendas, ensuring quality of deliverables, setting deadlines, and managing conflicts. Several studies have revealed that in industry, the role project managers take have significant impact on project success [1], [2] and that teamwork was positively correlated with project performance. Project success can be achieved with stronger collaboration, team cohesiveness, and team communication [1]. However, project management is rarely discussed or taught in undergraduate engineering programs.

In this paper, we analyze how upper-class PMs influence first-year students' perceptions on team dynamics and stress as they go through their semester long design project. Half of the first-year students worked with upper-class PMs (PM group) and half worked traditionally in teams without PMs (Control group) as in previous years. At the end of the semester, a survey was conducted to study the students' perceptions on self-efficacy, confidence, teamwork, and stress. Survey consisted of 5-point Likert scale questions and analyzed with student's T-test. No significant differences were observed on students' self-efficacy, confidence, and stress when the course was taught both virtually and face-to face. However, statistically significant changes were observed when analyzing students' perceptions of teamwork in a face-to-face environment. This included higher ratings when asked about how well the group worked together ($p=0.013$), about whether the group had similar expectations (0.009), and about whether students supported each other ($p=0.019$). Further analysis showed that there were significant differences as reported by female and male students. Interestingly, while similar trends were observed when the course was conducted virtually, the data was not significant. Our data shows that incorporation of upper-level project managers in first-year courses can aid in their perceptions of team-based learning and that students with PMs worked better within their teams.

Introduction

Teamwork is an essential learning outcome for students in engineering which, by nature, is a collaborative process where new products and designs are formulated by teams working over long distances and over long periods of time[3]. This skill is highly sought after by employers

and is required for accreditation[4]. Many universities incorporate teamwork-based learning within their teaching philosophies and within their engineering curricula. It is common for multiple courses to contain team-based design projects ranging from first-year Introduction to Engineering courses to Senior Design/Capstone courses[5].

Courses that adopt teamwork-based methodology can aid students to experiment and acquire skills such as group problem solving, leadership, interpersonal communication, negotiation, and time management[6]–[9]. A positive teamwork experience can have a positive influence on academic performance, motivation, and attitudes towards learning[7], [9]. However, these courses merely provide an opportunity to participate in a team and often times little is done to teach students to develop or improve specific team-based skills. While smaller courses with dedicated teachers may incorporate specific modules or lessons to develop these skills, team-based projects are often un-facilitated in larger courses due to lack of time and resources. Thus, students' experiences in teams vary greatly within the same course and program. Ineffective teams can be characterized as teams that exhibit a lack of accountability and commitment, exhibit a fear of conflict, and are inattentive to results [10]. Of great concern is that research has shown that ineffective teams can actually negatively affect student's attitudes toward working in teams[11], [12]. In a recent study, it was shown that students that were dissatisfied with team-work practices had negative team-work learning experiences such as dominating team members, unequal workload contributions, and personality clashes in their groups [8]. These negative team-work learning experiences can potentially be alleviated through the use of Project Managers. In engineering, it is common to introduce teamwork early in the curriculum, often in first-year Introduction to Engineering courses which can be additional challenge. Aside from learning discipline specific information and working in un-facilitated teams for the first time, first-year students are overcoming obstacles in adjusting to college life itself, such as feeling isolated, home-sick, and learning to be independent and balancing their schedules alone[13]. In these introductory courses, students are expected to be more independent and work with a group of students they do not know which is very different from a typical high school project.

Project Management Course

At the University of Massachusetts Lowell, first-year biomedical engineering students are required to enroll in a two-credit hour Introduction to Biomedical Engineering course their first semester. In this course, students receive an introduction to their major and its applications and learn the engineering design process in a semester long team-based project. In teams of three to four, students find a real-world problem, research and evaluate this problem, design a solution, and finally prototype their solution using computer-aided design (CAD), 3D printing, or other prototyping strategies. The course is large with 60-120 students per semester divided into four or five sections of 24 students each. Typically, all students in the course attend one 50 minute weekly lecture with the professor and one 2-hour lab with a teaching assistant. Each student team chooses their own design problem to focus on and it can be difficult for the instructor to give individual feedback to all students. In addition, many student teams struggle with communication and organization within their teams.

In order to aid the first-year teams be more organized and productive, and to help them focus on the technical aspects of the project rather than navigating the social relationships, a second upper-level course was developed, *Application in Project Management and Mentorship in BME*. In this course, juniors and seniors in BME learn about project management as a possible career in engineering by serving as the project managers (PMs). This course is designed to mimic the industry processes. Students complete an application to "apply" for the job as PM and course meeting times are treated as business meetings. PMs are chosen based on academic performance in their STEM courses and an application essay which indicates their motivations and interest in managerial positions. Each PM is responsible for one team of first-year students in the Intro course; PMs are responsible for goal setting, assigning tasks, resource management, running meetings, and conflict management. The PMs also have the responsibility to manage the scope of the project in collaboration with the course instructor. Every week, the PMs met for a business meeting to discuss the progress of their team and to give each other advice. Throughout the semester, different resources are made available as the teams reached certain milestones. This included Gantt charts when teams are ready to assign tasks, conflict resolution protocols, meeting protocols, etc. These PMs provide valuable insight to the course and give feedback for their group over the semester long course. However, they are specifically instructed to only advise on the technical aspect of the project and not to help with the prototyping in any way besides asking questions and providing guidance. Both first-year students and upperclassmen can benefit through this collaboration, with first-year students gaining knowledge from experienced upperclassmen, while the upperclassmen gain leadership and organizational skills that can be useful in industry.

This paper aims to study the impact of upperclassmen PMs on first-year students engineering students' perceptions as they go through their first college level team-based design course in both a face to face and a virtual setting. The course was taught in person in Fall 2019 (5 sections) and virtually in Fall 2020 (5 sections). In both semesters, half of the student teams worked with a PM and half worked independently without a PM akin to a normal course. Through an end of semester survey, we analyzed the student's self-reported perceptions on self-efficacy, teamwork, and stress.

Methods

Participants: In the first-year Intro to BME course, Fall 2019 (face-to-face) had 118 students across five sections and Fall 2020 (virtual) have 80 students across 5 sections. In the course, students worked in teams of 3 to 4 students. For each semester, 2 sections were randomly assigned Project Managers, and the remaining 3 sections worked without a project manager. All students were in the same 50 minute lecture with the professor of the course, followed by designated 2-hour lab taught by TA. All 5 sections had access to the same TAs, the same professor, and the same resources.

Project Managers: Project managers consisted of upper-level BME students who had previously taken and passed Intro to BME with a grade of B or above. During each semester (Fall 2019 and Fall 2020), 12 students took the *Application in Project Management and Mentorship in BME* course. Fall 2019 was conducted face-to-face and Fall 2020 was virtual.

Survey: A survey was developed and conducted at the end of each semester. Survey contained questions about demographics followed by 5-point Likert questions broken down into 3 categories, self-efficacy, teamwork, and stress (1=Strongly Disagree to 5=Strongly Agree). 81 students (68.6%) and 45 students (56%) responded to the survey in Fall 2019 and Fall 2020, respectively. Survey questions were generated based on a literature search [14]–[17], however, a validated instrument needs to be used for further exploration.

Table 1: End of Semester Survey Questions for First-Year Students

Number	Question	Category
1	I was able to solve and overcome any problems that arose with this project.	Self-Efficacy
2	I was able to complete the project and all its components by the assigned deadlines.	Self-Efficacy
3	I believe that I could have completed this assignment without any outside resources.	Self-Efficacy
4	Even under stress, I knew that the project would turn out according to plan.	Self-Efficacy
5	If this project were an individual assignment, I would have been able to complete it on my own and to the same standards as it would be with a group.	Teamwork
6	I work well with my team.	Teamwork
7	I believe that my groupmates held the same expectations for the project as I did.	Teamwork
8	I believe that my opinions were heard and acknowledged in the group.	Teamwork
9	My group is supportive of each other.	Teamwork
10	I felt overwhelmed during the project.	Stress
11	I felt like I did not have an adequate amount of time to complete this project.	Stress

Data Analysis: Average and standard deviations was calculated for each question with Microsoft Excel. For each question, participants were subdivided into four groups: students who identify as women who worked with project managers, students who identify as women who worked without project managers, students who identify as men who worked with project managers, and students who identify as men who worked without project managers. P-values were calculated using student's T-test and p-values below 0.05 were determined to be significant.

Results and Discussion

In order to study the impact of upper-class PMs on teamwork skills of first-year engineering students as they go through their first college level team-based design course, a survey was conducted at the end of the semester in Fall 2019 (5 sections face-to-face) and in Fall 2020 (5 sections virtual). Both semesters were taught by the same instructor who used similar lectures and assignment materials. In both semesters, half of the student teams worked with a PM and half worked independently without a PM akin to a normal course.

Previous work has shown that there are asymmetrical experiences in project teams for different genders [18], [19] and that stereotypes alter perceptions of team member's abilities [20], [21]. Research has shown that women students often experience gender bias in engineering teams which may lead to negative experiences [22]. This includes differences in self evaluations, peer evaluations, and team presentations. Often times, women are rated lower in both self and peer evaluations. To account for this gender bias and to understand the impact of PMs on students of different genders, survey answers are presented as whole class, men, and women.

Self-Efficacy

Self-efficacy is the belief a person has in their own abilities in order to overcome challenges and successfully complete specified tasks. Students' efficacy beliefs are correlated with students' academic performance, motivation, and persistence in engineering programs[23]–[26]. To see whether having a PM influences students' reported self-efficacy in both face-to-face and virtual environments, students were asked four questions at end of semester survey on a 5-point Likert scale (1=Strongly Disagree to 5=Strongly Agree). In a face-to-face environment, results indicate no significant differences in perceptions of self-efficacy between men and women students with and without PMs (Fig. 1). In a virtual environment, results indicate no significant difference for questions 1, 2, and 4. For question 3 "*I believe that I could have completed this assignment without any outside resources*", men students without a PM rated significantly higher than both men students with a PM and women students without a PM. Men students without a PM had an average of 3.8 compared to women without a PM which had an average of 2.25 ($p=0.0023$) and men students with a PM of 2.636 ($p=0.022$), respectively. This trend can also be seen when the course is in a face-to-face environment, though it is not significant. It is possible that working with a PM helped men students have a more realistic expectation for the resources needed on a project.

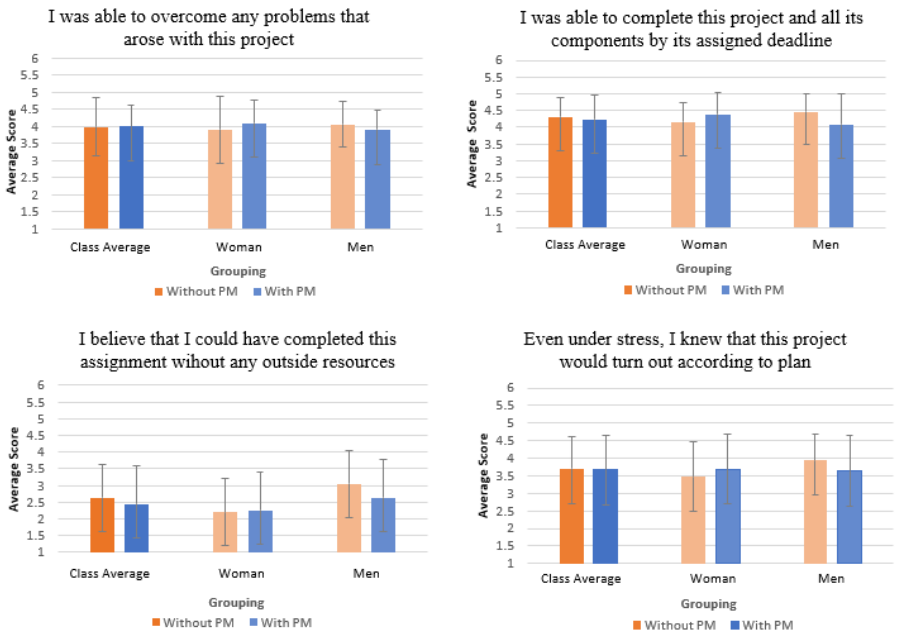

Figure 1. First-year engineering students with and without project managers show similar levels of self-efficacy in a face-to-face team-based environment. Student responses to end of semester survey containing questions on a Likert scale from 1=Strongly Disagree to 5= Strongly Agree. Error bars indicate standard deviation

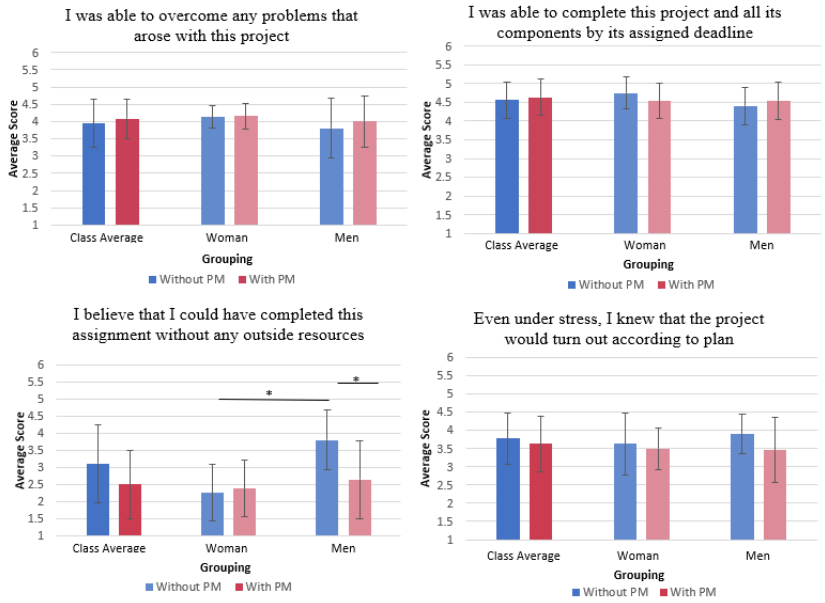

Figure 2. First-year engineering students with and without project managers show similar levels of self-efficacy in a virtual team-based environment. Student responses to end of semester survey containing questions on a Likert scale from 1=Strongly Disagree to 5= Strongly Agree. Error bars indicate standard deviation. "*" indicate a statistically significant difference, $p<0.05$ with student's T-test.

Teamwork

When students were asked several questions to rate their perceptions on their team dynamics, students with PMs generally rated their team more favorably than students without project managers (Fig. 3). When asked "*If this project were an individual assignment, I would have been able to complete it on my own and to the same standards as it would be with a group*", students without PMs significantly agreed with this statement more. Students with a PM had a class average of 3 compared to students without a PM who had an average of 3.6, ($p=0.0474$). This could indicate that students with PMs are more likely to recognize the need for teamwork.

For several questions, Q6 "*I work well with my team*", Q7 "*I believe that my groupmates held the same expectations for the project as I did*", and Q9 "*My group is supportive of each other*", students with PMs significantly agreed more with the statement. For question 6, students with a PM had an average of 4.5 compared to students without a PM which had an average of 4 ($p=0.0134$). Interestingly, women students with PMs rated Q6 significantly higher than women students without PMs. Women students with PMs had an average of 4.5 compared to women students without PMs that had an average of 3.8($p=0.0304$). For question 7, students with a PM had a class average of 4.2 compared to students without a PM that had an average of 3.5($p=0.009$). Similarly, women students with PMs had a significantly higher average than women students without PMs. Women students with PMs had an average of 4.3 compared to women students without PM's that had an average of 3.3 ($p=0.0190$). Lastly, for question 9, students with a PM had an average of 4.4 compared to students without a PM that had an average of 3.9 ($p=0.0191$), men students with PMs rated Q9 significantly higher than women students without PMs. Men students with PMs had an average of 4.5 compared to men students without PMs that had an average of 4.2 ($p=0.0242$). Combined, the data suggests that with a PM, groups were able to communicate better, set similar expectations, and be more supportive of each other. This trend is similar for both men and women students. This data is promising as the role of a PM is to keep their group focused, provide the overall scope and feasibility of the project, delegate tasks, and keep the team engaged. A few of the toughest obstacles when working with groups are unbalanced workloads, team conflict, and communication breakdowns. These issues challenge team processes, which can lead to conflict, along with determining how to approach a

critical decision, due to the fear of making the wrong decision [10]. Having an experienced PM can help improve team communication, team collaboration, and team cohesiveness[1].Through setting meetings and having an impartial third person for the group to communicate with, the PM can help minimize miscommunication and give their group confidence to express their own ideas about the project without feeling intimidated. The PM can also help to keep each group member accountable for their assigned tasks, ensuring that everyone is doing their share to create a healthier team-based environment. With the help of a PM outlining the focus of the project, the group shares the same ideas and expectations for the project, setting a realistic goal for their team to achieve. A project becomes more successful when the whole group is engaged, and all aspects of the project are clear to everyone. Overall, this shows that PMs have a large effect on the perceived teamwork dynamic of first-year students in engineering, creating a better working environment.

Interestingly, data from Fall 2020 when both the Intro to BME and the Applications in PM courses were taught in a virtual environment, there were no significant differences between the two courses. Men students' responses to Q9 actually decreased with a PM. It is possible that the inexperience of PMs with conducting meetings on zoom negated the overall positive affect.

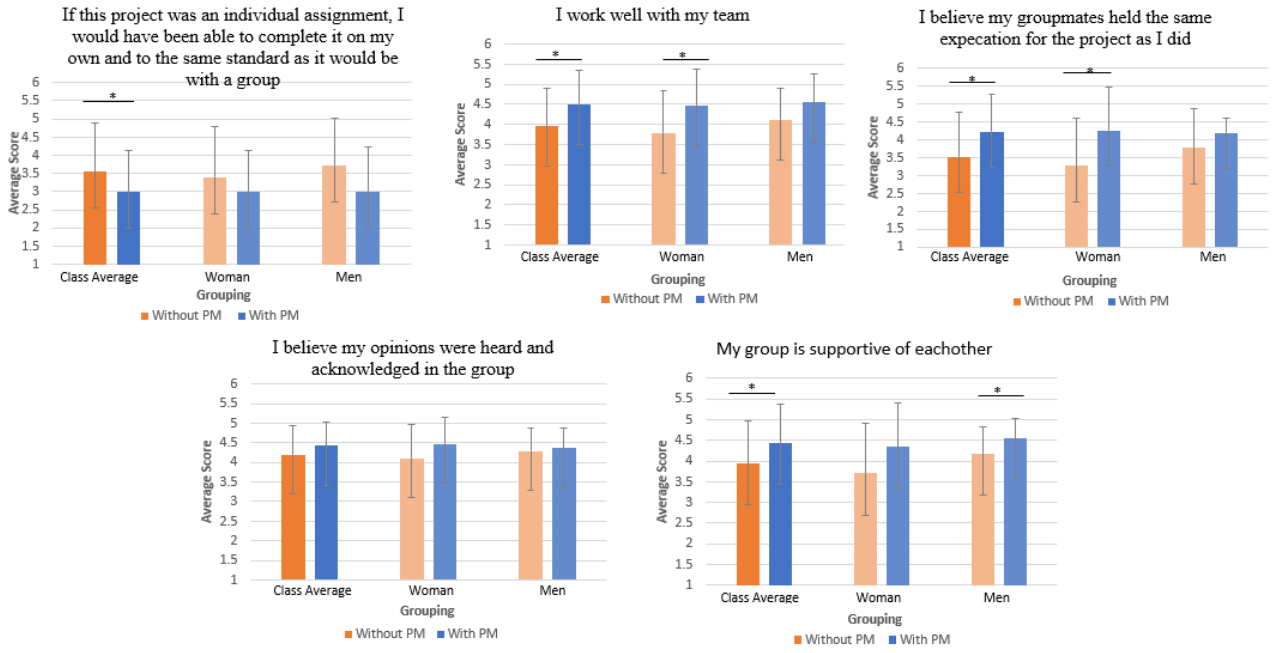

Figure 3. First-year engineering students with project managers rate increased teamwork skills in a face-to-face team-based environment. Student responses to end of semester survey containing questions on a Likert scale from 1=Strongly Disagree to 5= Strongly Agree. Error bars indicate standard deviation. "*" indicate a statistically significant difference, $p<0.05$ with student's T-test.

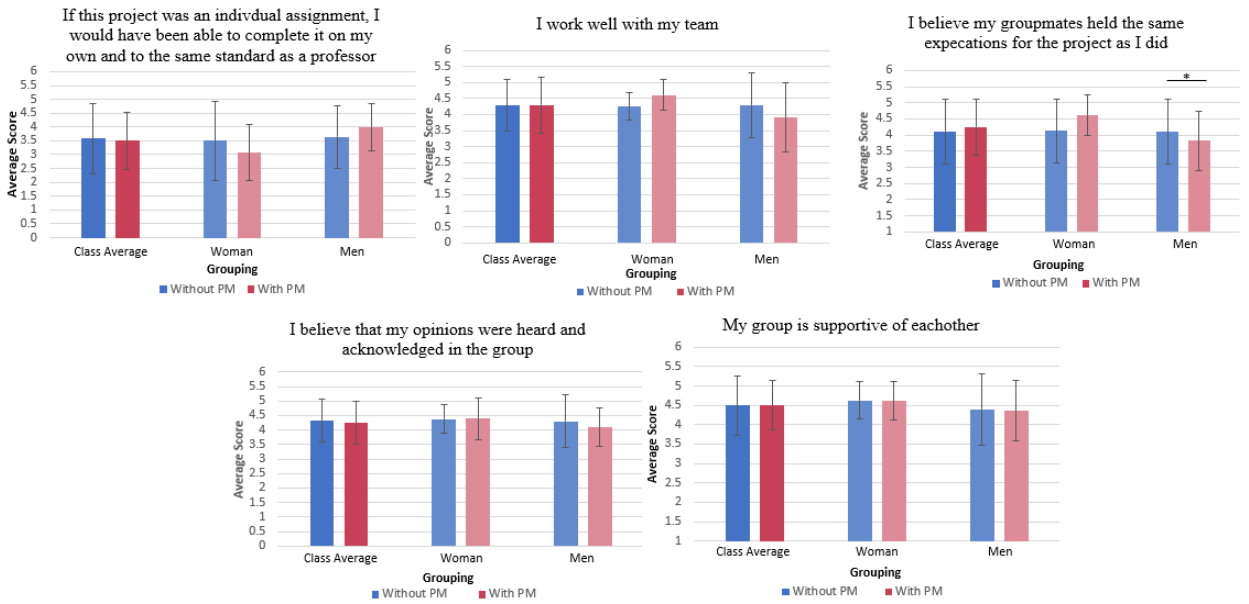

Figure 4. First-year engineering students with and without project managers rate similar teamwork skills in a virtual team-based environment. Student responses to end of semester survey containing questions on a Likert scale from 1=Strongly Disagree to 5= Strongly Agree. Error bars indicate standard deviation. "*" indicate a statistically significant difference, $p<0.05$ with student's T-test.

Stress

The final two questions of the survey asked students to rate whether they felt overwhelmed with the project and whether they had enough time to complete the project (Fig. 5). In the face-to-face course, when students were asked "*I felt overwhelmed during the project*", men students without a PM were significantly lower than men students with a PM and women students without a PM. Men students without a PM had an average of 2.5 compared to men students with a PM that had an average of 3.5 ($p=0.0144$). In addition, men students without a PM averaged 2.5 compared to women students without a PM that had an average of 3.3 ($p=0.0366$). This data is consistent with students answers to Q3 "*I believe that I could have completed this assignment without any outside resources*" where it is possible that men students may not see the full scope of the project without guidance from a PM and further exploration is needed. In general, students felt that they had enough time to complete the project and there were no significant differences between students with and without PMs.

When both the *Intro to BME* and the *Applied Project Management* courses were taught virtually, no significant differences were seen between the students with and students without PMs. Interestingly, students with PMs reported less feelings of being overwhelmed though it is not statistically significant. When asked "*I felt like I did not have an adequate amount of time to complete this project*", women students with a PM significantly rated lower than men students with PMs. Women students with a PM had a class average of 1.9 compared to men students with a PM that had an average of 2.7 ($p=0.0494$), indicating that adequate amount of time was given for the project.

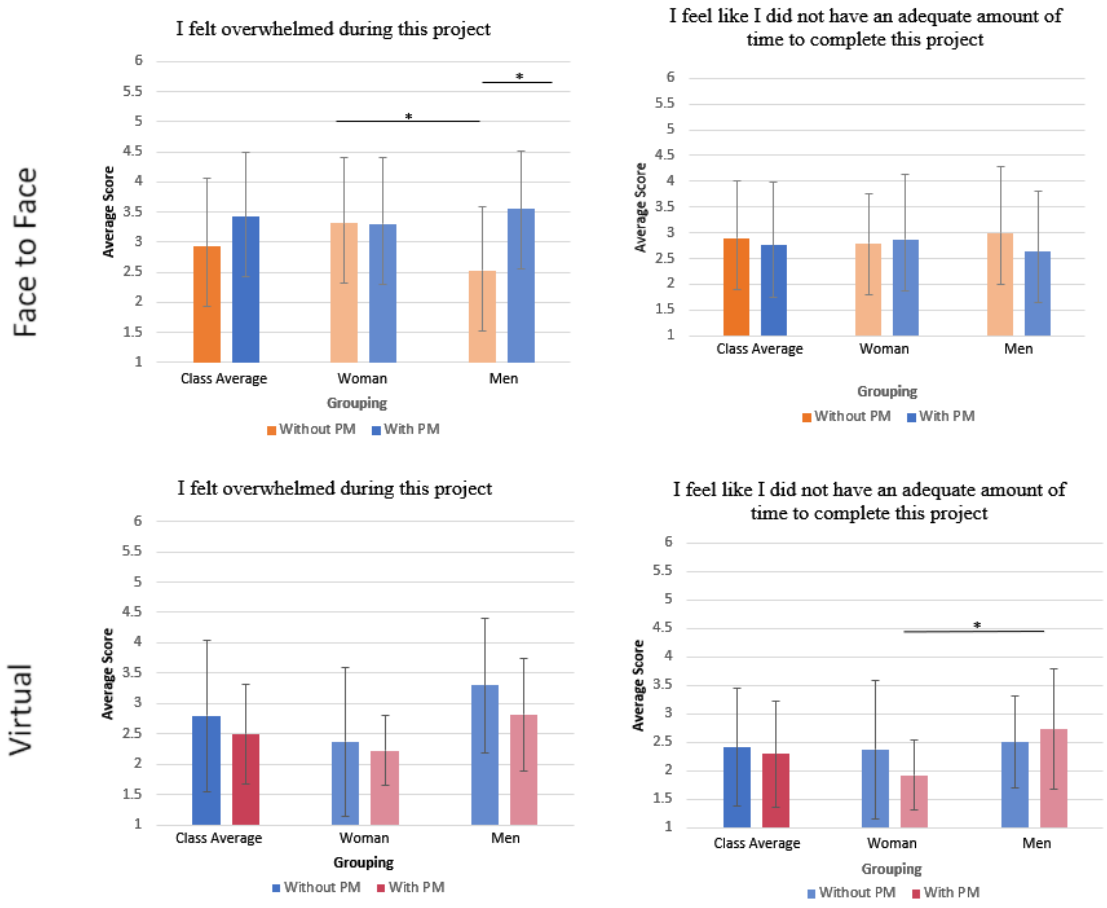

Figure 5. Stress levels of first-year engineering students with and without project managers in a face to face vs virtual team-based environment. Student responses to end of semester survey containing questions on a Likert scale from 1=Strongly Disagree to 5= Strongly Agree. Error bars indicate standard deviation. "*" indicate a statistically significant difference, $p<0.05$ with student's T-test.

Student Grades

The grade distribution in Figure 6 shows the average grades students received for their project. Regardless of having a PM, there was no difference in the grades received by the students for their assignment. This indicates that PMs did not impact the students' technical abilities and learning. This is an important distinction in that PMs were specifically instructed to not help with the technical portion of the students' projects. Anecdotally, many student teams competed in a college wide prototyping competition at the University of Massachusetts Lowell where both undergraduate and graduate students competed. In Fall 2019 (face to face), two teams from the course placed first (no PM) and third (had PM). In 2020, one team with a PM placed second.

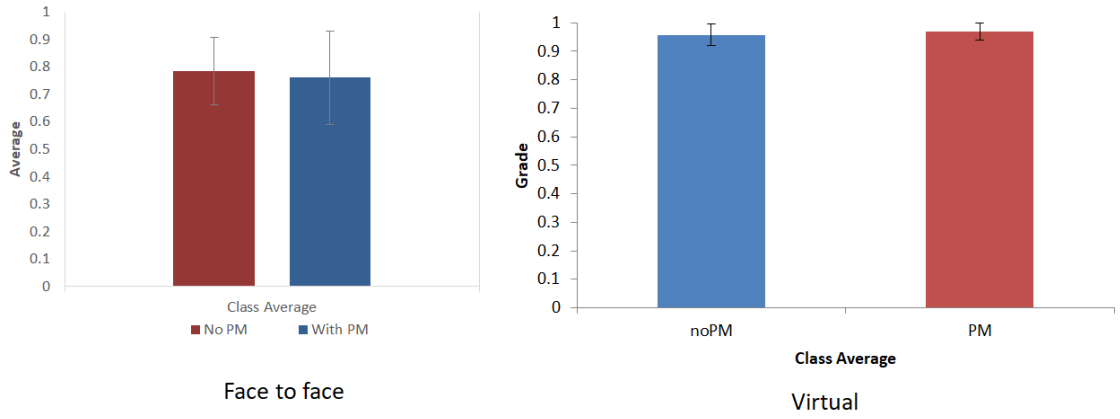

Figure 6. Average project grades for students with and without PMs. Error bars indicate standard deviation. "*" indicate a statistically significant difference, $p<0.05$ with student's T-test.

Project Manager Reflections

Upperclassmen Project Managers were given a reflection assignment following completion of the course. Assignment prompts were "*What were your group dynamics like*", "*What would you do differently if you were to be a PM again*", "*What advice do you have for a future PM starting out in your role*", and "*What do you think your strengths and weaknesses are as a PM?*". Project managers noted the importance of communication, organization, time management, and the ability to relate to team members. Most project managers struggled with the balance of being a friend versus a Project Manager. Some project managers felt they instilled the wrong dynamic by being too friendly. Students were able to realize the importance of leadership styles and team-dynamics on workflow through the creation of an experimental *Applied Project Management* course.

One student noted " *This class was a perfect way to learn about project management because we actually had hands on experience doing it. It was a much better dynamic than if we just had lectures every week learning about different leadership methods that some of us might not even like to use. This class was like a working trial and error to understand what leadership styles each of us like and don't like. We were able to experience first-hand how a project manager should work and how their role is very important to the success of a project. I am so glad I took this class and hope it is able to expand so more people can have this experience*". Data on PM experiences and leadership development can be found in reference [27].

Conclusion

Team-based projects are a common part of the engineering curriculum and can be harder to facilitate and manage in a larger classroom. The creation of an upper level Applied Project Management course have the benefit of allowing upper level students to experience and learn about a new career in project management while serving to facilitate and guide the students in

first-year engineering courses. Our work shows that in a face to face classroom, PMs can help to increase students' perceptions of teamwork ability including increasing communications, understanding the full scope of a project, and feeling more supported in a group. However, PMs may not change students' perceptions of self-efficacy, stress levels, or their grades within a course. This method may not be as effective in a virtual learning environment and adoption of this technique will require additional training on the use of virtual conferencing software.

There are still several limitations to the current study. The current data relies heavily on quantitative data and future work should utilize qualitative data to gain a better understanding of how students felt working with a project manager and their overall experience. It might be beneficial to study the development of team dynamics in these courses and study the influence of certain demographics of the PMs on similar demographics of their students. Further analysis of the grades for the course is also needed, including the frequency of late work and the amount of feedback needed from the instructor and TAs per group. In addition, further study is needed to understand differences in experiences between students of different genders, races, and ethnicities.

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