The emergence of the project manager role in student design teams: A mixed-methods exploratory study

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Abstract

Even though employing project management techniques has been found to positively impact project outcomes, capstone design project instructors do not typically formalize a project management role in teams, and when given the choice, students do not always designate a project manager. The objective of this research was to identify the project management models students followed during the capstone projects, how the project management model changed throughout the project timeline, and whether the project team shared a mental model of their project management approach.

To pursue these objectives, we conducted a two-phase exploratory mixed-methods study composed of a longitudinal cohort study of an inter-disciplinary class completing a capstone design project, followed by a large survey of over 319 students, representing 122 teams, across six engineering programs at the conclusion of their capstone design project. Both study phases concluded that student teams employ three dominant project management models: one designated project manager, a rotating project manager role, and no project manager. Teams make changes in project management model over time, both in the direction of stronger and weaker project management models. Increased uncertainty and group conflict lead teams toward a more deliberate project management model. It was also found that teams who identify a need for a project manager do so early in the project timeline. Finally, a designated project manager is most successful in uniting the team with a mental representation of the project and increasing the likelihood for project success. The results give insight into the behaviours of student capstone teams and could further direct the design of project management instruction in capstone project courses in order to better equip students for success.

1. Introduction

All senior Canadian engineering students must complete a team-based capstone design project in accordance with accreditation requirements [1]. Typically, these projects span the 8 months of the students' final year of undergraduate studies. In their teams, students share the responsibilities of all design-related and logistical management tasks. The intention of capstone projects is to challenge students to identify a problem, design a solution, and manage a long-term project - all of which are marketable skills in the labour market.

In order for students participating in capstone projects to be successful, they must receive proper guidance and training [2]. One of the most impactful pieces of training for high-performance teamwork is project management [3]. Capstone projects reinforce the training students receive in the classroom and may be one of the first opportunities students receive to practice their project management skills. Studies have shown that the use of project management techniques can nearly guarantee project success [4]. Designating a project manager (PM) in a student group ensures that at least one student is practicing project management skills, while the group, and overall project, benefits from the actions of the PM. In practice, student teams typically follow one of three PM models: choosing one designated PM, a PM role that switches

between team members, or no project management model at all [5]. Understanding how students come to choose a PM model can inform teaching practices that can improve student knowledge in project management and better ensure project success.

The faculty of engineering at the University of Waterloo is the largest engineering school in Canada. All 15 engineering programs, as well as a handful of other programs outside the faculty, culminate in a capstone design project [6]. The purpose of this project was to draw on the experiences of students completing their capstone projects in order to identify the factors that lead teams to select certain project management styles and understand the trends in this behaviour.

2. Background

While there is ample broader literature on project management, here we review research on project management in student capstone projects. Students who understand project management tools and principles are able to complete their projects in a more timely and cost-effective manner [7]. Including opportunities to apply project management techniques in courses prior to the capstone projects can drastically improve project success rate [4]. Therefore, there is evidence to suggest that project management frameworks used in real-world scenarios can be properly implemented into student capstone projects *and* those student groups will benefit from them.

Previous case studies analyzing the link between project management performance and project success have shown that there is, indeed, significant positive correlation between PM style and project success, and that an investment in proper project management frameworks would increase the likelihood of project success [8]. In student groups, successful adaptation of project management techniques, like the management of problem scope, time, cost, communication, risk, and quality, enhances students' abilities to complete their projects efficiently [9]. Groups with a designated peer PM can have higher levels of reported group success, fewer "slackers", higher grades, higher peer evaluations of performance, and higher project quality than groups without a PM [10]. This emphasizes the importance of teaching project management skills to undergraduate students prior to their capstone projects, and the need to encourage teams to use such models.

Capstone design projects often represent the first experience in which students complete a large-scale project from problem identification to solution building. It may also be the first opportunity for students to practice their project management skills. A recent large study of engineering capstone design teams found that while a majority of teams had a designated peer PM or rotated the role between team members, over a quarter of teams did not use a PM role at all [5]. The study also found that the majority of the PMs assumed the role on their own rather than having been selected by the team. A closer analysis on the correlation between PM style and group satisfaction showed that groups with a designated PM experienced higher group satisfaction than those with a rotating PM, and higher still than groups with no PM [5]. There were no insights on how teams used the models for the duration of the project, only a snapshot of the models teams used at the end.

Finally, it has been found that in order for teams to work successfully, they have to have a shared mental model [11]. Mental models are knowledge structures that help individuals describe, explain, and predict events while interacting with their environment [11]. In other words, in order for capstone project teams to be successful, team members have to have a shared understanding of their problem, their expectations of one another, and their goal, in order to be able to predict the actions of one another and work cohesively as a team. Of particular interest in this paper is capstone teams' shared mental model on their projects' project management.

3. Motivation

Based on previous studies, this study aims to explore if and how capstone design teams engage with project management models. This knowledge can inform project management instruction in order to advance student knowledge and better ensure capstone project success. Building on work previously discussed, we seek to answer the following research question:

1. What project management models do students use for their capstone design projects?
2. How do these models change over time?
3. Do teams have a shared mental model of their project management models?

To answer these questions, we employed a two-phased mixed-methods study. Since the research aims to study project management models over time, a longitudinal method was employed in the first phase to collect qualitative data. The second phase then aims to confirm and further advance findings from the first phase using quantitative data.

The rest of the paper is structured as follows. Sections 4 and 5 describe the methods and results of the two phases of the study. Section 6 provides a discussion of the combined findings, relating them back to the research questions. Study conclusions are summarized in Section 7.

4. Phase 1 of the study

4.1 Method

In order to study the process of PM emergence, we conducted a cohort, longitudinal study over six months. Study participants were third-year students enrolled in an interdisciplinary program at the University of Waterloo, who were completing a team-based, two-term capstone design project. While this is not an engineering program, it is nevertheless very design-oriented.

The capstone problem assigned to these students was to design a museum exhibit on a topic of their choice, with the aim of educating visitors on a topic aligned with the United Nation's Sustainable Development Goals [12]. Teams were created by the instructor. Students were not explicitly encouraged to designate group roles until the second term, and even then, the roles were not formally outlined. Thus, the emergence of a PM is a result solely based on group actions and decisions.

The study consisted of five cycles of semi-structured interviews, spread out throughout the project duration, as shown in Figure 1. The general progression of the project is as follows. Teams were created in September, and the beginning of the project was focussed on developing collaborative norms for the group to follow throughout the project. By the beginning of October, teams were required to have come up with a topic for their projects, which they pitched in November. At that time, they were in a retrospective phase and working towards their implementation plan. In December, all teams had to submit a storyboard of a completed visualization of their museum design, with a draft of all content, and justification for all design decisions. Teams built their projects in January and February, and installed the final display in mid-March.

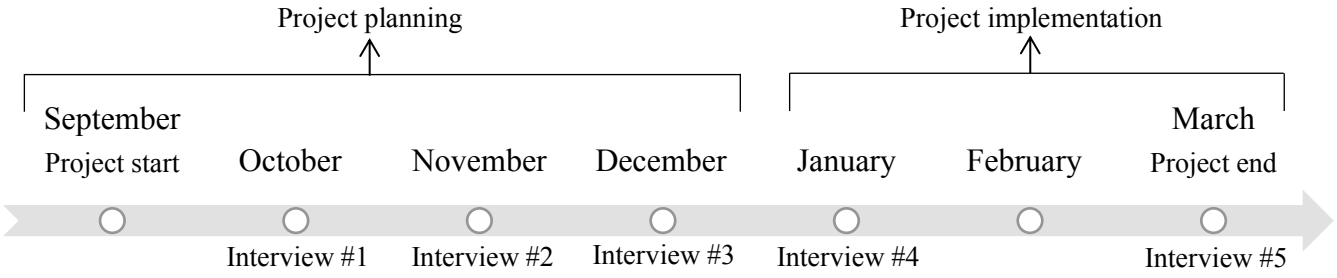

Figure 1: Timeline of interviews during phase 1.

The interview questions focussed on understanding how teams were managing their projects and evaluating the success of these techniques. Five prompting questions were used:

1. *How does your team manage your tasks?*
2. *How do you manage your tasks?*
3. *Does your team use any project management tools, like Trello, Asana, etc.?*
4. *In your opinion, how is your group functioning overall?*
5. *How satisfied are you with your group's performance thus far?*

These questions guided the interviews, but others were asked during the interview to further inquire about a relevant point. Interviews were audio recorded and transcribed for the purposes of summarizing and identifying key themes.

There was a total of 5 teams enrolled in the class, of which all participated in the study. Only one student from each team participated in each interview round. As it was a cohort study, team members rotated, such that a different team member participated in each interview. Some participants were interviewed more than once based on voluntary participation. This design was chosen as an efficient way to gain the perspective of each team member and to avoid sample bias, while minimizing the number of one-on-one interviews conducted. For each team, findings from previous interviews were compared with subsequent ones; aggregate group responses gave insight on the teams' mental models and changes in PM model over time.

4.2 Results

In interviews with the five groups throughout their project, it was found that after teams were formed, four possible PM models had emerged. Teams may have entirely lacked a PM; had an "unofficial" PM – a student who assumed the PM role without being designated as such; had a rotating PM role among team members; or had a single designated student serve as PM. Figure 2 provides a visual representation of the changing PM models for the phase 1 teams over the project duration. Overall, the majority of groups changed PM models during the first term of their project (September – December). It was during this time that they were planning their project and it was before they received any project management lectures. Eventually, by the beginning of the second term (January), all groups converged to the highest level of project management model - a single PM, and remained consistent with a designated PM role during the second term of their projects.

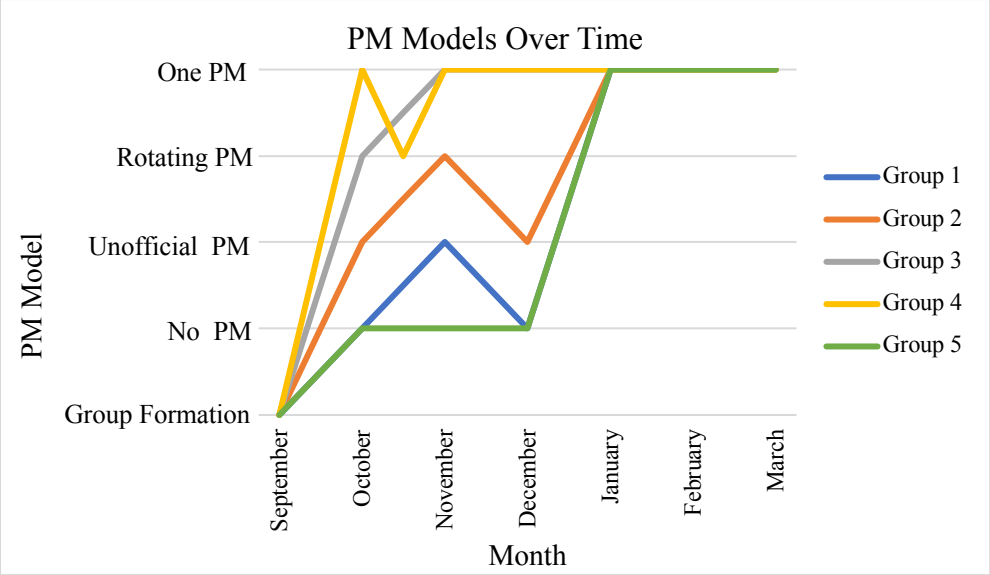

Figure 2. Diagram of PM emergence from study 1 participants.

Below we summarize some key patterns that are observed in how the different PM models emerged in teams.

Project management without a PM

By the time of the first interviews (October), only two groups were operating without a PM role. In these cases, the project management tasks were either completed collaboratively, or the teams divided them across all members.

Emergence of the "unofficial" PM.

For two of the groups, the PM role was, at some point, assumed by one of the team members "unofficially". In this model, a single team member is completing project management tasks, effectively acting as the PM, without the recognition for the role. For example, by the 1st interview (October), group 2 reported that one group member had stepped up to take on the roles of a PM without the title and without the group discussing it. This particular scenario caused

some group conflict due to the perception of the person in the PM role as “bossy” and the rest of the group as “lazy”.

Similarly, group 1 reported a member stepping into an unofficial PM position during November. The rationale that the group gave for this arrangement was a reported natural inclination of this member to lead, and a need from the other group members for direction and organizational management. The team was hesitant to designate a PM but was content with the member completing the tasks unofficially.

The rotating PM

Another interesting PM model that emerged was that of the rotating PM. For example, group 3 decided to regularly change the PM every month. Similarly, in November, group 2 changed to rotating roles from an unofficial PM as an attempt to reduce group conflict. The group had agreed that the PM was to change weekly.

Designated PM

By the mid-point of the first term, only two of the groups had designated a formal PM. For group 4, a designated peer PM had emerged due to delays and discomfort within the group caused by communication issues. In this case, a PM emerged due to necessity, with the specific PM chosen based on personality traits (presumably favourable to project management).

Group 3 had a rotating PM role previously, but designated a peer PM in November because the rotating role was not working as they anticipated. They identified the difficulties in dividing tasks in comparison to one person organizing all the project management. They felt a designated PM would be especially important as the project progressed, more decisions were made, and they got busier.

“Regression” in PM model

An interesting phenomenon that was identified with three of the teams was a “regression” from a higher form of PM model to a lower. For example, group 4, having designated a peer PM in October, changed to a rotating role in early November. Interestingly, after trying the rotating PM model for a couple weeks, the group did not find this technique to be effective, so it reverted back to a designated PM role.

Another example is that of group 2, which, in December, gave up their rotating PM model and reverted to their previous PM model of an unofficial PM. The December interviewee reported that the group had not officially discussed changing models, but that rotating was not working and the past unofficial PM stepped back into that role.

Finally, also in December, group 1, which at this point had an “unofficial” PM due to some group organizational issues, reverted back to having no designated peer PM. This individual felt as though the group was functioning efficiently and no longer needed a PM.

Project management in the implementation phase of design

Perhaps the most interesting pattern that was observed is related to the convergence of PM models in the second term of the project. In January, the project focus shifted from planning to implementation. A fascinating observation from the fifth round of interviews was that every design group, regardless of their formation previously, had decided to designate a peer PM. In all cases, if a group had an informal or rotating PM at some point during their project, it was the same team member who was designated as the PM in January. A likely explanation for this choice is that the student was already doing project management tasks, so they had the needed expertise.

In this phase of the project, the attitudes of team members toward the PM role also changed. Students in the designated PM role reported receiving larger recognition for their work and experiencing less group conflict as a result of it. The PMs felt that the project team responded better to the PM's direction.

The final round of interviews, which occurred after the students had completed their capstone projects, confirmed that the PM model had persisted. Every group reported having the same PM for the entire second half of the project. Every group also reported that the one PM model had worked well. Finally, there was agreement between the groups that having a designated peer PM contributed to that success, and respondents reported that the team would agree with this statement, indicating a shared mental model.

5. Phase 2 of the study

5.1 Method

Phase 2 of the study consisted of a survey targeted to engineering capstone design project teams. The purpose of the survey was to gather quantitative data on the project management model the team used, how peer PMs were chosen, when the PM role emerged, and if/how the PM model changed. The survey questions and multiple-choice options were, in part, based on questions and responses from the first phase of this study, as well as adapted from surveys with sections on project management [5], and research done on how group success has been measured [9]. A flow chart of the full survey is presented in Figure 3.

The survey was administered to fourth-year engineering students at the University of Waterloo, near the completion of their capstone project [13]. Participants were recruited via email or during class lectures. All members of the project team were encouraged to complete the survey. While in some of the disciplines students are instructed on project management tools and techniques, which has increased their success rate since implementation [14], [15], the instructors do not require students to formalize a PM model of any kind. The topics of capstone projects vary significantly based on the discipline of the teams, but all teams must follow the design processes linking problem finding to solution development.

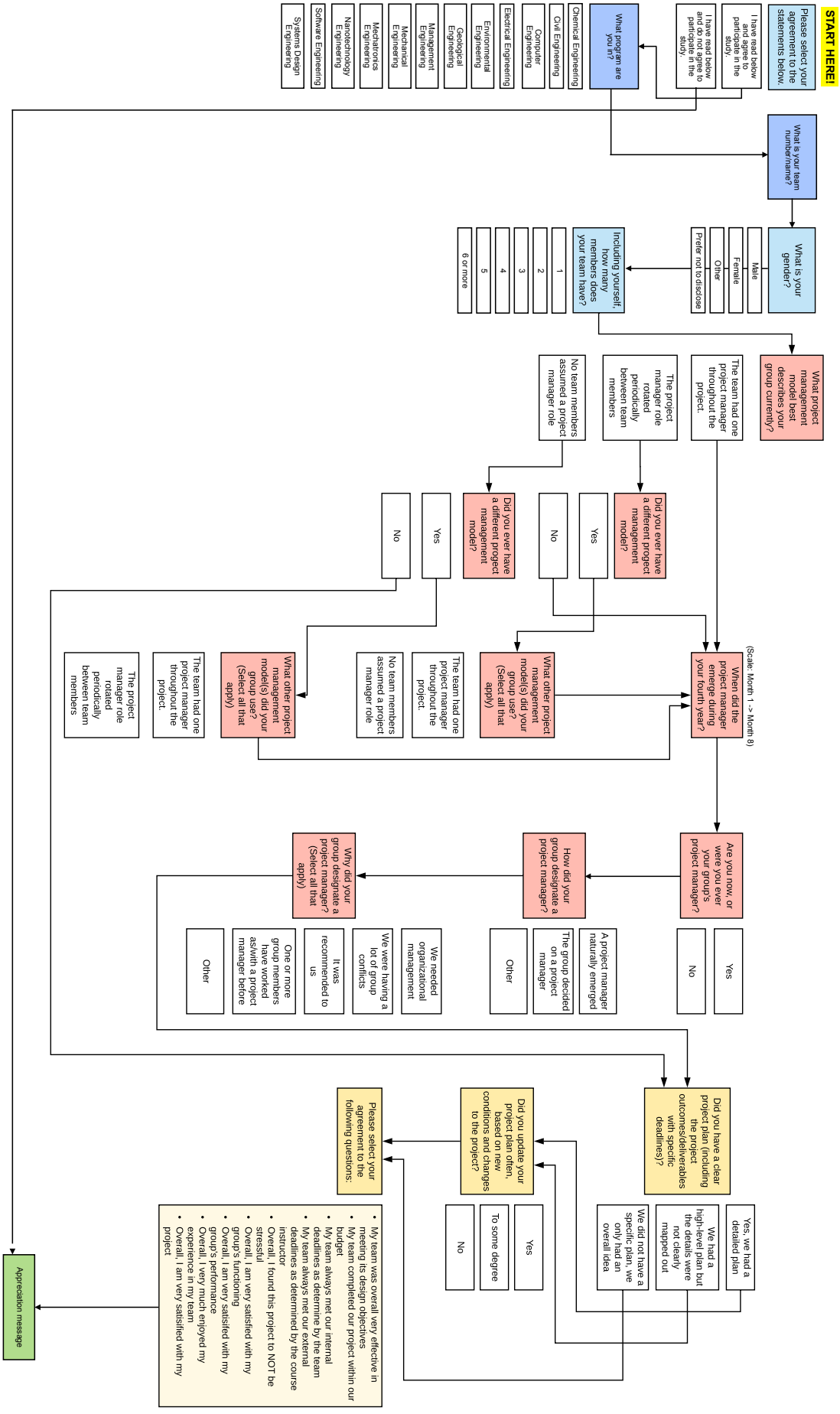

Figure 3. The survey administered in phase 2, displayed as a flowchart.

5.2 Results

The survey was completed by 319 individual students, representing 122 teams across six engineering programs. The individual responses were aggregated based on project team in order to extract team data.

The average group size of surveyed teams was 4.04. Each team had an average of 0.88 survey respondents who self-reported as PM per group; this ranged from a minimum of zero to a maximum of three. Of all student respondents, 121 self-reported as acting in a PM role at some point of the project, compared to 149 who reported not acting as the PM, and 49 who did not answer the question. Since the number of PMs per group is significantly smaller than non-PMs per group, yet the proportion of PM to non-PM respondents is comparable, we can infer that if the group had a PM, that individual was more likely to complete the survey than the other team members.

The survey also collected demographic data, including gender. Of all male-identifying respondents, 45% self-reported as having served as their teams' PMs at some point of the project. For female-identifying respondents, that figure was 53%. There are proportionally more male-identifying students than female-identifying enrolled in undergraduate engineering programs, including at the University of Waterloo, where women make up just 29.0% [16]. Yet, in our survey, proportionally more female-identifying students self-reported as PMs than male-identifying. This data suggests that female-identifying individuals in capstone teams were more likely to be the PM than their male-identifying teammates.

A question in the survey directly prompted students to identify the time at which the PM role emerged in their team (if it ever did). On average, it was found that if a team had a PM, either designated or rotating, the PM emerged within the second month of the project, and no later than the sixth month. Figure 4 is a histogram displaying the distribution of PM emergence by month. Due to the co-op system at the University of Waterloo, some cohorts of students may have begun their project in September and others in May. For this reason, the months have been quantified according to the location of the month in the project timeline.

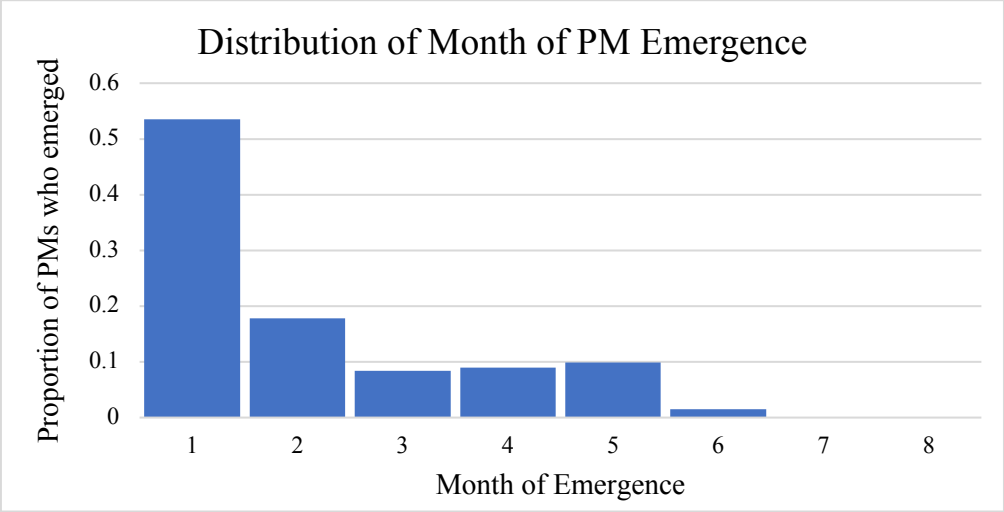

Figure 4. The distribution of PM emergence by month.

By the time the project was completed (when the survey was administered), the most popular project management model used was that of one designated peer PM (88 teams), followed by a rotating PM (57 teams). Only 31 teams reported having no PM at the time of the study. Interestingly, teams were often lacking agreement on their project management model. Since the individual response data was aggregated into project groups, when we look at responses for groups with at least two individual responses, we expect the answers to match. However, in this data subset, 56% of teams had contrasting reports about their PM model. This implies that the majority of teams, for which at least two members are represented in the data, do not agree on the project management model used at the time of the survey. The different responses to the same question within a team indicates that the teams do not have a shared mental model of the project.

Further investigation into the shared models of teams revealed that of the teams that *did* have a shared mental model, 90% had one designated PM. In other words, teams that have a shared mental model are also very likely to have one designated PM. It is possible that a causal effect exists between these two factors.

In addition to the PM model at the time of the survey, students were also asked about whether their teams had had any other PM models in the duration of the project. A minority (13%) of respondents reported that their team had used a different project management model prior to the one used at the time of study. We cannot, however, extract how these project management models changed over time.

6. Discussion

This study aimed to investigate the project management models students use during capstone projects and how they change over time. This was accomplished through a two-phase mixed-methods study that consisted of a longitudinal cohort study of an inter-disciplinary class completing a capstone design project, followed by a large survey of over 319 students across six engineering programs at the conclusion of their capstone design project.

6.1 Main findings

In the motivation for this study we presented three research question. In what follows, we summarize our study findings as they relate to each research questions and highlight key takeaways.

1. *What project management models do students use for their capstone design projects?*

We first aimed to find the project management models students follow. In both study phases, the models could be summarized into three categories: one student acting as the designated peer PM, the PM role rotating periodically between team members, and no PM role; with one PM being the most popular model. These findings confirm those from previous studies on project management in student capstone projects, where the same three models were listed [5]. We can now confidently say that the project management models students use for capstone projects are one of: a designated PM, a rotating PM, or no model.

In addition to confirming prior studies' results about the type of PM models capstone design teams follow, we were also able to provide new insight into *when* the PM role emerged. The interviews in phase 1 of the study revealed that all teams had designated one PM by month 5, when teams began building their project, but on average, the PM emerged in the 3rd month, when teams began developing the details of their project. A similar timeline emerged in phase 2 of the study: on average, the PM role for engineering capstone design teams emerged in the 2nd month of the project. These results are comparable and suggest that **students who identify a need for a PM do so early in the project timeline**.

2. How do these models change over time?

The next area of research interest was to determine how project management models changed over time, if at all. The results from the interviews in phase 1 show that it is typical for teams to fluctuate models, with all 5 teams following at least two different models. Groups would increase the degree of PM involvement during times of high stress or confusion. In other words, after a group conflict, or in preparation for a demanding deliverable, a student would step into a higher level of PM model (if PM models are ranked by degree of formalization, from no PM to one PM). For example, if a team was operating with an unofficial PM, during a time of conflict they would decide to rotate an official PM role. Once the conflict had subsided, or the deliverable was completed, the group would return to their previous PM model.

Research has shown that increased subjective uncertainty in the cognition of designers catalyses a more elaborate reasoning strategy [17]. It has also been found that uncertainty during a design project may lead to 'micro-conflicts' [18]. These pieces of research may explain the phenomenon observed from the interviews. **When teams were facing increased uncertainty they would also experience an increase in group conflict and an inclination towards a more deliberate reasoning strategy; that is, a more deliberate project management model.** This is a key finding, which needs to be further explored.

The changes in models were found to be less drastic in the survey results. Only 13% of respondents reported using different models, representing 31 teams (25%). While all teams in the first phase converged to the highest level of project management, this was not true for teams captured in the survey. Nevertheless, the dynamism of PM models suggests a need for a more complex understanding of how capstone project teams utilize project management in order to reflect real practice in their education. The lack of consensus on using one PM in the survey data, and the research which indicates this model to be superior in terms of encouraging project success, suggests **capstone design instructors may need to increase their emphasis on this model prior to students beginning their capstone projects**.

3. Do teams have a shared mental model of their project management models?

The final question researched asked if teams had a shared mental representation of their project management model. In this case, the two phases of the study seem to provide contradictory results. While the interview phase concluded that yes, teams do have a shared mental model, the survey concluded otherwise; 56% of engineering capstone design teams, with

respondent size of at least two, responded differently to the question, "What project management model best describes your group currently?". We can thus conclude a lack of shared mental model in teams from phase 2. We know from previous studies that a shared mental model is positively correlated with project success [11], so this finding is a concern which needs to be addressed.

Interestingly, the survey found that 90% of teams with a shared mental model had one PM. This finding lends further support for the need to increase instructional emphasis on project management in student capstone teams. **Our data suggests that the designated PM model is most successful in uniting the team with a mental representation of the project.** Additionally, since a shared mental model increases the likelihood for project success [11], we can infer that **as a designated PM model unites a team mental model, it also increases the likelihood of team success.**

6.2 Limitations and Future Work

The interviews conducted in phase 1 of the study provided rich and in depth information about the PM models of participating teams, as well as helped guide the development of the survey in phase 2. As is common with this methodology, the small sample size poses a limitation to the generalizability of the findings. Additionally, the interdisciplinary program in which the phase 1 study was conducted is unique, further limiting the ability to compare the findings with other capstone projects. Nevertheless, the majority of the findings in phase 1 were confirmed by the phase 2 survey study, validating the interview results.

For any survey study, limitations include missing responses, dishonest answers, differences in the interpretations of questions, and survey fatigue. These increase the noise in the data and limit the validity of conclusions. In the phase 2 survey, open-ended responses were limited. Since the survey was informed by the interview study, responses were often closed-ended with options found from the interviews and an "other" option. This may have skewed respondents into choosing an option that best fit, rather than the most accurate response. This decision was made for the benefit of categorical data analysis.

There is a need for future exploration on the correlations between shared mental model, project management model, and project success. Past research has shown project success to be positively correlated with PM model and shared mental models separately [11], but the research presented here has demonstrated a relationship between all three factors.

7. Conclusion

The findings of this study point at the importance of a peer PM in student capstone design projects. In both phases of the study, a majority of the groups interviewed/surveyed used a peer PM, whose role was established early in the project timeline. A surprising finding of this research was the tendency for teams to change project management models during their projects. The reasoning for this phenomenon is unclear, but one suggested explanation is linked to the concept of increased cognitive uncertainty and the desire for more deliberate reasoning strategies. Other findings include the lack of shared mental model with the need for future

exploration on how this affects capstone project success. The findings from this research indicate a need for further education on project management models, and the advantages of utilizing them properly, prior to students beginning their capstone projects.

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