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Development of Teamwork Skills in a Project-based First-year Engineering Subject: A Comprehensive Framework

Huey Yee Chan; Lionel Lam.
University of Melbourne
Corresponding Author Email: huey.chan@unimelb.edu.au

ABSTRACT

CONTEXT

Teamwork skills are extremely important for engineering students, given the increasing complexity and scale of the types of problems that engineers must solve. Fostering good practice around communication and teamwork should start early with first-year engineering students, with continued reinforcement throughout the later years of their degree. At the University of Melbourne, this is accomplished through a semester-long real-world design project that requires students to work in teams. However, many first-year students who are transitioning from high school, some of them without any prior experience working in teams, often find themselves ill-equipped with the skills required to handle the significant teamwork demands of the project.

PURPOSE

This paper presents the implementation of a comprehensive framework for teaching teamwork in a project-based first-year engineering subject, consisting of a suite of activities spanning the semester. These include online delivery modules that serve as an introduction to teamwork concepts, structured workshop-based team building activities and team management planning, and lastly peer assessments to evaluate team performance. Collectively, these aim to develop and assess teamwork skills at different stages of the semester within student teams working on a semester-long design project.

APPROACH

Two surveys were conducted, one in the middle of semester and the other at the end of semester to collect feedback on the student experience as they progressed through the series of activities. The outcomes of these surveys were evaluated to assess the effectiveness of the activities and provide insights into the perceptions of teamwork among first-year engineering students.

OUTCOMES

Survey data indicated that a significant majority of respondents (83%) agreed that working with their team in the subject has helped them appreciate the importance of teamwork in an engineering project. The team management plan and workshop-based team building activities were identified as the most helpful components in the development of teamwork skills when compared to the other activities within the framework. Across the various types of team-based activities in the workshops, students largely preferred activities that involved physical engagement and problem-solving. For instance, activities like the Lego Activity and the Escape Room were favoured over activities that focused more on reflection and discussion.

CONCLUSION

The implementation of the teamwork framework has been successful in providing a structured learning approach in developing teamwork skills in first-year engineering students. The authors will continue to refine the framework by identifying and revising activities to maximise student engagement around the learning and assessment of teamwork skills.

KEYWORDS

Teamwork, project-based, first-year engineering

Introduction

Teamwork skills are extremely important for engineering students, given the increasing complexity and scale of the types of problems that engineers must solve. A study by Passow (2012) shows that teamwork and communication skills are regarded by engineering graduates and industry as key attributes in the professional practice of engineering. To foster the development of teamwork skills, Felder et al. (2000) recommend a cooperative learning approach where team learning tasks should be structured to feature:

1. **Positive independence:** team goals and member responsibilities must be clearly defined
2. **Face-to-face promotive interaction and appropriate use of interpersonal and teamwork skills:** student teams must be given the opportunity to interact and work together on tasks
3. **Regular self-assessment and individual accountability:** teams should periodically be required to evaluate their performance and identify areas for improvement

Various teamwork development approaches relevant to the recommendations above have been explored by researchers. According to Strom and Strom (2011), peer assessment is one of the recommended strategies to enhance cooperative learning. Shishavan and Jalili (2020)'s evaluation of the implementation of peer assessment to individualise team marks showed that the peer assessment process improved the cooperation of team members which enhanced the students' teamwork experience. Tichon and Seat (2004) introduced a series of short class exercises to promote teamwork development in a year-long first-year engineering project design course, from icebreaker activities, to brainstorming as a team, to progress evaluations. Oakley et al. (2004) described the importance of establishing expectations early (from team formation and initiation) through a Team Agreement document that outlines the different team roles and responsibilities, the process for completing work, strategies for dealing with conflicts, and the use of peer ratings to help develop teamwork skills and adjust team grades for individual performance.

At the University of Melbourne, fostering good practice around communication and teamwork starts early with first-year engineering students, with continued reinforcement throughout the later years of their degree. This is accomplished through a project-based learning model in an introductory engineering subject that requires students to work in teams. However, many first-year students who are transitioning from high school, some of them without any prior experience working in teams, often find themselves ill-equipped with the skills required to handle the significant teamwork demands of the project. Providing them with the necessary resources and tools to work effectively in teams is an important aspect of the subject. This paper outlines the consolidation of various teamwork development practices that have been explored in different combinations, subsets, and settings by researchers into a comprehensive Teamwork Framework in accordance with the cooperative learning approach by Felder et al. (2000). This is catered to effectively deliver the teaching of teamwork skills to first-year engineering students in a large diverse cohort. Survey feedback on the effectiveness of various activities within the framework was analysed to provide insights into students' perceptions of teamwork that could be used to improve teamwork instruction.

Background

At the University of Melbourne, the general first-year engineering subject, "Engineering Technology and Society" (ETS), is structured around a semester-long real-world design project that requires students to work in teams to design a water pumping, disinfection, and distribution system to supply drinking water sourced from an underground well to a remote community. By employing a project-based learning model, the subject provides students with a foundational curriculum that introduces them to the engineering profession and important professional practices such as teamwork and communication skills.

Students are free to form project teams of three to four members in the second week of semester. They continue to work within the same team for the duration of the semester, collaborating on various team-based assessments, such as a project and team management plan, weekly project

design tasks, a video presentation, a mid-semester preliminary report, and an end-of-semester final report. These assessments collectively contribute 64% to the overall subject grade.

With this high dependence on collaboration, the development of teamwork skills is a major priority. Weekly three-hour workshops are an integral part of the subject, during which students actively collaborate with their team members to complete a series of progressive tasks leading up to the final project outcome. These workshops provide an ideal environment for fostering teamwork skills and they have therefore been structured to include various types of activities, such as non-project-related team building activities, technical hands-on experiments, and project-related design tasks, all of which require active team-based participation. Teamwork and collaboration, however, are not only limited to the confines of the workshops. Outside of class, teams are responsible for organising their own meetings and coordinating their efforts to complete tasks or assessments.

Teamwork Framework

In this subject, the Teamwork Framework provides the structure to facilitate effective teamwork, both within and outside of scheduled class activities. The most recent implementation of the framework in Semester 1 2023 (Table 1), consists of (1) a set of online self-paced modules to introduce teamwork concepts, (2) a series of workshop-based team building activities that allows teams to put concepts into practice, and (3) assessment tasks to monitor and evaluate team progress. By integrating these components, the framework aims to develop and assess teamwork skills at different stages of the semester.

Table 1: Teamwork Framework

Week of Semester	Online Modules	Workshop-based Activity	Assessment
2	Teamwork Modules ***1 & 2***	Team Building Activities: ***Puzzle Problems & Lego***	
3		Team Building Activity: ***Moon Landing***	
4	Teamwork Module ***3***	Team Building Activity: ***Hula Hoop***	Team Management Plan
5		Team Building Activity: ***Escape Room I***	Peer Assessment **#1**
8	Teamwork Modules ***4 & 5***		Peer Assessment **#2**
9		Team Building Activity: ***Team Health***	
10		Team Building Activity: ***Escape Room II***	
Exam Period			Peer Assessment **#3**

Online Self-paced Teamwork Modules

Five self-paced online modules are introduced across Weeks 2, 4 and 8 to deliver general teamwork concepts. Each module focuses on specific aspects of teamwork and is designed to provide students with an understanding of effective team dynamics. In the first four weeks of semester, this begins with the importance of teamwork in Module 1, followed by effective team practices in Modules 2 and 3. As teams progress further into the semester when challenges tend to arise, Modules 4 and 5 address team conflicts and offer strategies to navigate and resolve them. Each module is presented as a video consisting of a series of narrated slides, with durations ranging from three to seven minutes, accessible at students' convenience via the subject's Learning Management System (LMS) page. Overall, the combination of short and concise videos with flexible unlimited access aims to optimise student engagement and retention of the material.

Team Management Plan

The **positive independence** element of cooperative learning emphasises the importance of teams having clearly defined goals and individual members understanding their role and responsibilities within their team. To this end, project teams are required to complete a Team Management Plan worth 5% in Week 4 to establish their project goals, expectations, team member responsibilities, project task distribution, and risk assessment prior to commencing the semester-long project. Project teams are provided with a template to draft their Team Management Plan during the relevant week's workshop with guidance and supervision from their tutors. Teams are then expected to independently review and finalise their document outside of class before submission.

Workshop-based Team Building Activities

In line with the **face-to-face promotive interaction and appropriate use of interpersonal and teamwork skills** element of cooperative learning (Felder et al., 2000), the ETS workshops provide students with the opportunity to apply theoretical teamwork skill development concepts to practice. In a typical 3-hour workshop, students work within their project teams to complete prescribed workshop tasks, some of which constitute assessed subject components, such as conducting experiments, executing design tasks, and drafting documents that build towards the final project outcome. While activities like hands-on experiments and design tasks require collaboration, their primary emphasis is on assessing technical outcomes rather than skill development. To shift the focus of learning towards teamwork skill development, a set of six team building activities are introduced over the semester, from icebreakers at team inception, progressing to conflict identification and resolution later in the semester, as outlined in Table 1. These short activities (typically lasting less than an hour) are conducted at the beginning of workshop sessions, prior to any technical tasks, to promote engagement and encourage bonding within teams. Each activity follows a structured format, commencing with a briefing by tutors outlining the objective(s) and teamwork skill(s) that the activity aims to demonstrate, followed by the activity's instructions. Upon completion of the activity, tutors conduct a debriefing session where students share feedback on their experience with the activity and discuss any observations, insights, and lessons learned. This is important as it allows students to meaningfully reflect on the objectives of the activity as well as their own learning experiences. There is no assessment associated with any of the team building activities, as they are implemented as a means of learning support rather than obligatory tasks.

The team building activities can be classified into three broad categories: (1) activities that are physical in nature, such as Lego and Hula Hoop, requiring team members to work cooperatively on a physical activity to achieve a common goal, (2) activities that are reflection or discussion-based, like Moon Landing and Team Health, requiring team members to discuss and address a given topic, and (3) activities with a problem-solving element, such as Puzzles and Escape Rooms, requiring analytical thinking and teamwork. This diverse range of team building activities, staggered over the semester and each with their own learning objectives, provide the necessary exposure to a variety of collaborative scenarios outside of what is offered by the project-related tasks.

The first workshop of the semester in Week 2 is dedicated to team-based icebreaker activities that facilitate student interaction prior to project team formation. Because students are free to form their own teams, it is important to give them the opportunity to get to know their peers with whom they might potentially be collaborating for the entire semester. In the first activity, students are rotated into different random groups for specific durations to devise solutions to simple puzzle problems: an example of a puzzle problem is the "chicken and foxes crossing the river" scenario. This activity allows random groups of students to propose ideas, deliberate on different possible solutions, and eventually reach a consensus on a final solution. The second activity is Lego-based and requires student groups to collaborate on the construction of a block structure following a prescribed set of rules. Engaging in this Lego-based activity, students can showcase their ability to work collaboratively, communicate effectively, and coordinate their efforts towards common goals. The opportunity to observe and interact with their peers through these icebreaker activities provides students with a basis to make informed decisions when selecting team members, maximising the chance of cohesive and productive team dynamics throughout the semester.

The Moon Landing activity is a discussion-based activity introduced in Week 3 following team formation. It aims to facilitate informal and relaxed interaction and communication within the newly-formed teams before they embark on actual project work. Here, project teams are presented with a survival scenario that requires team members to individually assess their own survival strategy before coming together to deliberate on a team-wide agreement on the most viable approach for survival. When effectively conducted, this activity offers insight into the dynamics of a team, in terms of how members justify their decisions, handle differences in opinions, achieve group consensus, and navigate authority within the team (for example, whether or not there are dominant member(s), or passive member(s) who struggle to assert their opinions). This awareness is beneficial in laying the foundation for effective teamwork moving forward.

In Week 4, a change in activity type is introduced with the Hula Hoop activity. This purely physical activity requires team members to work together towards the common goal of setting a hula hoop down from a specific height while maintaining it parallel to the ground. The rapid but controlled manner of the activity challenges students to understand the importance of setting a reasonable pace for a particular action, as well as the necessary coordination and synchronisation required to ensure that all members keep up with the pace. Additionally, the activity also highlights the importance of effective communication to ensure a situation remains under control.

In Week 5, teams are presented with an educational Escape Room activity as a form of active learning where students discuss, problem-solve, reason, collaborate, and synthesise knowledge. The tabletop Escape Room format adopted in the workshop was adapted from Ross, Hall, and Ross (2022) and involves the use of electronic decoder boxes where students solve a set of three pen-and-paper-based puzzles that revolve around technical concepts covered in the subject, such as fluid mechanics and MATLAB programming. Students then validate their answers by inputting them into the decoder box. Completing this activity requires a combination of aptitude and cooperation and sheds light on the different skill sets and strengths that each member might bring to their team, such as organisation and delegation skills or technical competence in specific topics – this is helpful when it comes to the division of tasks within a project team.

The structure of the Teamwork Framework, consisting of the online delivery modules and team building activities, supported by the Team Management Plan, directly addresses the initial lack of knowledge and experience around teamwork in our first-year engineering students. By the end of Week 5, students are theoretically equipped with necessary basic teamwork skills that serve as a foundation for their ongoing development as a team. No team building activities are scheduled for the workshops between Weeks 6 to 8 to allow students some flexibility to focus on other subject assessments due during that period, such as the video presentation and a preliminary report.

In the second half of semester, the team building activities shift in focus to anticipate issues arising from team conflict. With the majority of teams established and well underway with the project, this is the stage of the semester when teams begin undertaking higher-stakes team-based assessments, highlighting differences in working styles, unfair division of tasks, and unsatisfactory team member contributions. The Team Health activity in Week 9 is a reflective exercise that promotes conflict resolution skills, self-reflection, and accountability among team members. Team members respond to a series of questions based on team conflict scenarios to assess the effectiveness of their team's processes to deal with conflict. Team members then discuss any concerns that arise and propose approaches to address these issues. The activity motivates students to come to terms with conflict within their teams and to take responsibility for their actions by working together towards a resolution. This activity has the added advantage of helping to identify teams with more serious issues that might require external intervention from instructors.

The final team building activity in Week 10 is a repeat of the tabletop Escape Room activity from Week 5, this time focusing on different technical topics of image processing and MATLAB programming. With the semester and project coming to an end, this repeat activity serves mainly as a fun challenge for students to apply their technical knowledge and problem-solving skills, with less of a focus on the teamwork aspect.

Peer Assessments

In addition to developing teamwork skills through practice, the Teamwork Framework also includes the assessment of team performance. Three Peer Assessment exercises are conducted over the semester (Weeks 5, 8, and the Exam Period) to evaluate and monitor team progress at different stages of the semester and to generate a scale factor based on individual contribution. This is used to moderate team-based assessment marks, in accordance with the **regular self-assessment and individual accountability** element of the cooperative learning approach (Felder et al., 2000). Self- and peer-evaluations are set up using the Feedback Fruits platform and serve as checkpoints that allow students to provide feedback on themselves and to their team members, as well as to receive feedback on their collaborative efforts. Peer Assessment #1 (Week 5) is a practice round for students to familiarise themselves with the Feedback Fruits interface and the evaluation process. Ratings and outcomes from this first evaluation are solely for feedback purposes and have no bearing on marks, as teams have just started out. Peer Assessments #2 and #3 (Week 8 and the Exam Period) provide contribution feedback and are used to generate scale factors that moderate the video presentation and final report, respectively. Students are reminded to view the feedback from these evaluations constructively, and to reflect more deeply on team dynamics and their own contributions to their team, identifying areas for improvement as necessary. From an instructor's perspective, the Peer Assessments provide an effective way of tracking and monitoring team performance across a large cohort.

Outcomes and Discussion

Two surveys were conducted on the Semester 1 2023 cohort to understand their experience with the activities in the Teamwork Framework and the impact on their teamwork skill development. 342 students completed the mid-semester survey covering activities from Weeks 2 to 5, while 206 students completed the end-of-semester survey covering activities from Weeks 8 to the exam period. Responses to survey questions focusing on student experience were scored on a 5-point Likert scale ranging from "Strongly disagree" to "Strongly agree". Outcomes from both surveys were combined as aggregate data across the whole semester and summarised in two separate figures, Figure 1 - representing student perceptions of the various activities in the Teamwork Framework and Figure 2 - representing student experience on specific team building activities.

From Figure 1, Questions 1 and 2 revealed that a lower-than-expected proportion of students (average of 60%) found the online modules effective in helping them understand the importance and challenges of effective teamwork. With the self-paced online modules, there was no associated assessment component; this lack of enforcement around completion may have contributed to this outcome. Additionally, feedback from students who completed the modules indicated that some content covered in the videos was perceived as redundant and were largely based on common sense. To address these concerns, it may be beneficial to explore ways to increase student engagement and accountability around completing the modules. This might be achieved by enforcing follow-up quizzes, and regularly reviewing and updating content for relevance.

Positive responses to Question 3 from 81% of the respondents indicated that the Team Management Plan (Week 4) was effective in helping teams establish team goals and expectations. Aligned with this, an encouraging 82.5% of respondents agreed in Question 4 that their teams have achieved the goals they had set out to achieve.

Responses to the general statement on the team building activities in Question 5 indicated that the activities had a positive impact in encouraging students to work within their teams for approximately 74.3% of the students. However, from this single question alone, it is not entirely clear how the different weekly workshop activities impacted learning. Further evaluation into the individual team building activities, as shown in Figure 2, provided further insights into students' perceptions of, and preferences for, certain types of activities.

From Figure 2, a significant majority of students (nearly 85%), agreed that the Puzzle Problems and Lego activities in Week 2 were effective in helping them meet peers prior to team formation. 68% of students managed to form their project teams with peers they met through these activities.

This outcome was particularly encouraging, as it demonstrated that the first round of workshop-based activities had a positive impact on team formation within the cohort.

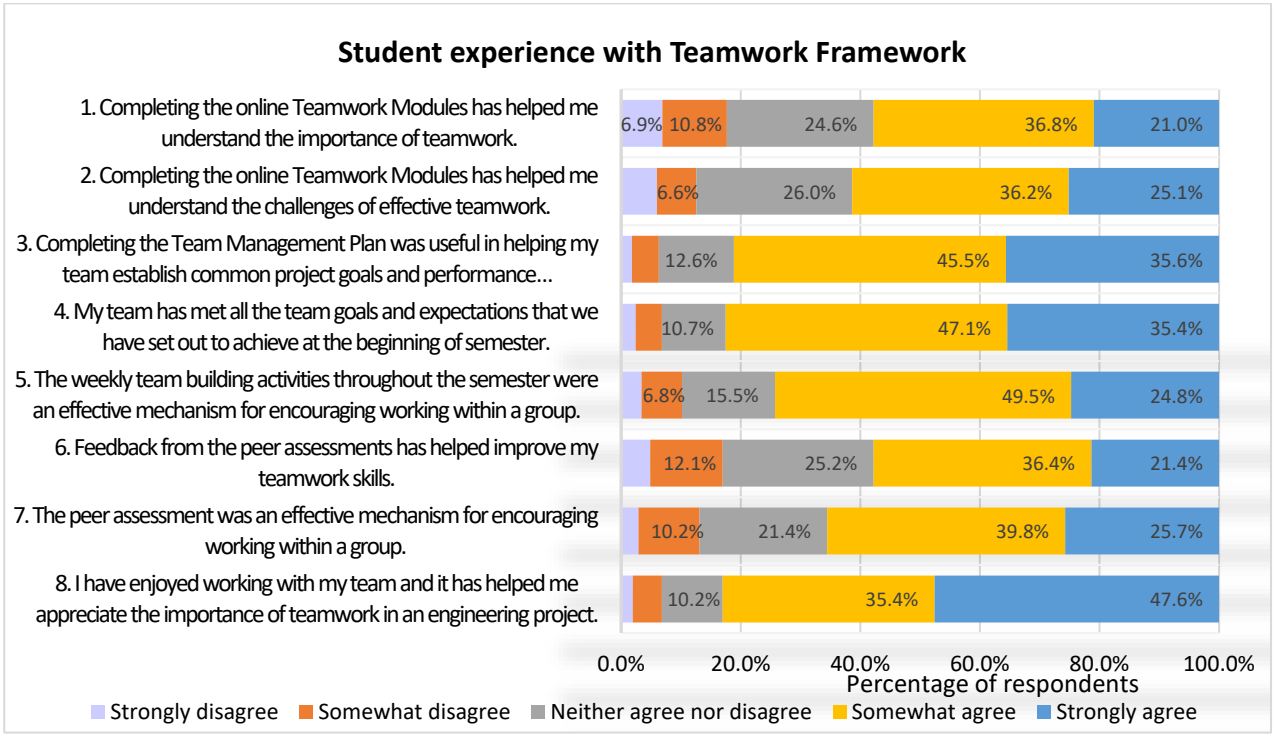

Figure 1: Student experience with the Teamwork Framework (responses <6% not indicated).

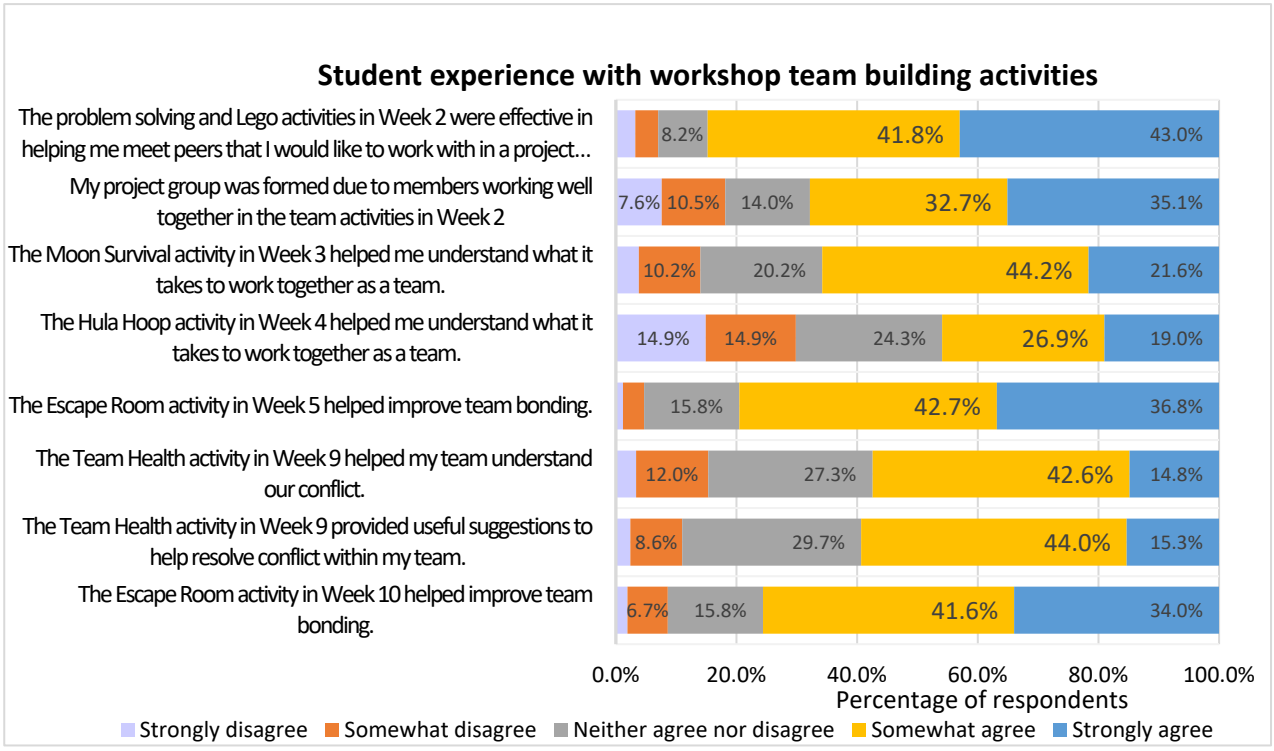

Figure 2: Student experience with workshop-based team building activities (responses <6% not indicated).

Outcomes from the surveys in Figure 2 also revealed that, of all the workshop team building exercises, the Hula Hoop activity in Week 4 was the least popular with less than 50% of students finding it relevant. During the activity, it was observed that groups were more focused on trying to set the hula hoop down as quickly as possible, rather than paying attention to the objective of maintaining a controlled pace. The competitive atmosphere in the class may have contributed to this shift in focus and misalignment of the intended learning objective behind the activity. In contrast, the Escape Room activities in Weeks 5 and 10 were the most preferred. The combination of time constraints, technical puzzles, and the use of a physical tool (the decoder box) in these content-driven team building exercise created an interactive and immersive environment that proved to be effective in generating positive engagement in more than 75% of students. While the overall response was positive, mixed free-form comments indicated that students at different levels of technical competency had different experiences and perceptions of these activities. It appears that technically competent students may have benefited more from the Escape Room activities while students who were not as well-versed with the technical content felt excluded watching their technically proficient peers take the lead in decoding the puzzles. Some students expressed concerns that their teammates were overly fixated on trying to solve the puzzles rather than working as a team, causing individual puzzle-solving abilities to overshadow the importance of teamwork and effective communication. Lastly, both the discussion-type activities, Moon Survival and Team Health, in Week 3 and 9 respectively, had relatively similar responses, with an average of approximately 60% of students finding them helpful in teamwork skill development. In comparison, the Team Health activity, which dealt with conflict, had relatively lower ratings, which could be attributed to first year students' limited experience in dealing with confrontation, causing them to find conflict-related activities uncomfortable and challenging.

A general conclusion that could be drawn from the survey outcomes in Figure 2 was that students largely preferred team-based activities that involved physical engagement and problem-solving. For instance, activities like the Lego and Escape Room activities were heavily favoured over activities that focused on reflection and discussion. Despite the overall positive response to the team building activities, free-form comments suggested that some students felt their time in workshops could be better spent on the assessed subject components which were deemed to be "more important" (for example, hands-on experiments and design tasks). This highlights a potential disconnect between the perceived value of team building activities and the importance of assessed components. It is possible that students at this level are not yet fully able to comprehend the benefits of the team building activities or may not see them as directly relevant to their academic performance. This suggests that more effective strategies might be needed to impart the importance of team building.

Returning to Figure 1, responses to Questions 6 and 7 showed that the Peer Assessment exercises were effective in helping improve teamwork skills for 57.8% of respondents and were deemed by 65.5% to be an effective mechanism for encouraging working within teams. However, these outcomes were lower than expected, suggesting that contribution feedback alone from these exercises may not have been sufficient in supporting the improvement of teamwork skills. Free-form comments indicated that students appreciated the fair moderation of marks via the scale factor based on individual member contribution. However, they felt that there was a lack of scaffolding around the peer evaluation outcomes to help them properly interpret the feedback received from their peers and identify areas for improvement. One recommendation is the need to incorporate opportunities for reflective discussion and feedback interpretation, through activities such as facilitated group discussions or individual feedback sessions, however this requires time and manpower resources that is not viable in the subject at this point. An alternative to consider would be to re-evaluate the resolution of the questions in the Peer Assessment exercise. The current version of assessment is based on 5 general criteria which were perhaps insufficient for meaningful feedback. One example of an improved resolution implementation can be drawn from Strom and Strom (2011)'s Teamwork Skills Inventory, that specifies a breakdown of 5 sub-criteria for each of the 5 main teamwork skills criteria, which would provide more in-depth feedback into each main criterion. However, the drawback of introducing additional sub-criteria increases the amount of time

required for students to complete the assessment, and thus the decision to implement such changes requires careful consideration.

While there are definitely avenues for improvement in the Teamwork Framework, overall there was an encouraging response for Question 8 in Figure 1, where a majority of students (83%) agreed that their experience with working within their project teams had a positive impact on their perception of teamwork and its importance in engineering projects.

Conclusion

The comprehensive Teamwork Framework described in this paper has proven effective in helping the development of teamwork skills in the first-year engineering cohort. The various components that make up the framework allow for the delivery and practice of teamwork skills, and provides effective mechanisms that help students with team formation and performance monitoring. However, an evaluation of student experience with the framework has identified several areas of improvement, which the authors will continue to review and revise to maximise student engagement around the learning and assessment of teamwork skills.

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