An Exploratory Study of Teamwork Processes and Perceived Team Effectiveness in Engineering Capstone Design Teams

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Abstract

In their final year, engineering students in Canada work in teams on a design project. These projects require significant collaboration and, as such, the project's success is largely dependent on the students' teamwork. This work presents an exploratory study of capstone design teams in a large engineering school in Canada. The goal of the study was to draw valuable insights about the teamwork experiences, skills and gaps of students in capstone design teams. These insights will support evidence-based development and improvement of teamwork training for engineering students. The study was conducted in two phases. First, semi-structured interviews with 12 instructors of capstone design courses solicited their perspectives on students' capstone design teams. Findings from the instructor interviews and related literature were used to design a student survey. The survey was administered to more than six hundred fourth-year engineering students to further explore capstone design teams' dynamics. We collected information on students' team formation, distribution of tasks and roles in teams, project management methods used, and the different types of conflicts experienced. In addition, we investigated the potential links between those variables and team effectiveness and enjoyment. In general, our results provide strong evidence that having clear roles, a high degree of a match between students' interests and skills with their assigned tasks, similar expectations about the outcomes, a clear project management plan, and lower levels of conflicts in student teams are significantly correlated with perceived team effectiveness and enjoyment. We discuss the implications of our findings for targeted instructional interventions on required teamwork skills for students.

Keywords: team process; team effectiveness; project management; capstone design

1. Introduction

As mandated by accreditation requirements, engineering students in Canada complete a senior (capstone) design project, typically in teams [1]. Team-based engineering design requires that students develop and demonstrate mastery not only of design process and communication but also teamwork; students should be able to "...*execute and improve team processes, and produce required deliverables with limited resources*" [2, p. 214]. Accordingly, many capstone design programs incorporate intentional instruction in team-related topics [3].

Due to their size and complexity, capstone designs are project-based learning opportunities that require collaborative (rather than co-operative) teamwork: students share in the responsibility of dividing and managing tasks, all activities need to be coordinated, and the project requires significant member interaction throughout [4]. Thus, the success of the design project and the quality of the experience for students in theirs teams is strongly affected by their team dynamics. Understanding the various team factors - how teams form and how they are managed - can help instructors design better curricular training and assessments to help students develop their teamwork skills.

The University of Waterloo is home to Canada's largest engineering school, offering 14 different engineering bachelor degree programs with over 8000 engineering undergraduate students. Those students work on team-based projects throughout their education, culminating in their capstone design project. Given the importance of teamwork to students' professional development as future engineers, in 2015, a series of teamwork training modules began to be developed by the Teamwork Clinic (uwaterloo.ca/teamwork-clinic) - an inter-departmental initiative [5]. The modules wrap around an existing team-based project in a course, tackling key teamwork skills such as team forming and building, communication, conflict, giving and receiving feedback, and team health assessment [6-9].

As the training modules began to be piloted and assessed in lower years, it became apparent that continuous improvement and future module development required an in-depth understanding of students' experiences of teamwork and their effectiveness as members in student teams. Those insights can be drawn from capstone design teams and courses, where the size and complexity of the design problems that are tackled by teams place real(istic) teamwork demands on students. This paper builds on previous literature and presents a large study conducted with two important stakeholders of capstone design projects: course instructors and students. The purpose of the study was to draw valuable insights about student's teamwork experiences, skills and gaps in capstone design teams in order to inform evidence-based development and improvement of teamwork training for engineering programs. Specifically, it sought to identify the main sources of conflicts in capstone teams, students' perceptions of their teamwork and project-management self-efficacy, and the relationship between various teamwork variables and the perceived project success and enjoyment.

The rest of the paper is structured as follows. In Section 2, we conduct a brief literature review of teamwork and teamwork assessment in engineering education, with emphasis on capstone design courses. In Section 3, we provide a detailed description of the methodology used in this study, describing first how we conducted the instructors' interviews and then how we used themes that emerged from those interviews to develop a comprehensive student survey. The results of the student survey are presented in detail in Section 4. In Section 5, we discuss the key findings from our study and their implications for instructional strategies that capstone instructors can take to support student teams in developing effective teamwork processes.

2. Background

2.1 Instructor perspectives

Much of our understanding of what teamwork looks like in engineering capstone design teams is currently based on course instructors' perspectives. A large 2015 survey of capstone programs in the US found that "student teams" was one of the main themes that emerged as a challenge in capstone design courses [10]. In that survey, respondents noted the difficulty that instructors face in maintaining healthy team dynamics in student teams and dealing with uneven member effort within teams. Interviews with instructors, coordinators and advisors of capstone design courses have provided important insights about the types of issues that most capstone teams face, including conflicts due to design decisions, workload imbalance, deficiency in required skills, personality, and ineffective communication [11]. Moreover, because teamwork can be particularly challenging for female students, instructors "*need tools to facilitate gender-inclusive teamwork*" [12].

When significant conflict occurs in teams, the role of the faculty member becomes that of the intervener, in the form of "*instruction and/or walking the team through the resolution process"* [11, p. 5]. However, best practices suggest that instructors' role should be active, limited to not just resolving team dysfunction, but also pre-emptively coaching students to develop effective teamwork skills, through instruction and assessment [13]. For example, instructors can survey teams on their members' task assignments and contributions to the teams to prevent future teamwork failures [14]. While this wealth of experience that faculty members bring is valuable, it has its limits. Students typically only make instructors aware of issues when a team is very dysfunctional [15]; instructors may thus lack a broader understanding of team processes in functioning or semi-functioning teams.

2.2 Student perspectives

In general, students have mixed perceptions about the value of working in teams. While they appreciate teamwork as a means to achieving larger and more complex projects, they are also wary of common teamwork issues such as social loafing, conflict, and difficulties in project planning [16]. Students who have a higher motivation for learning typically have a more positive attitude towards teamwork [17].

Peer evaluations are routinely used in capstone design courses to assess students on the "teamwork" competency [3, 10]. Students assess their peers' behaviour in their teams, capturing information not available to the course instructor who is an outsider to the team. As such, instructors of capstone design courses typically use self- and peer evaluations to adjust students' grades, which are otherwise earned from group effort (e.g., [18]). The timing and frequency of team peer evaluations can be critical factors in determining their usefulness [19]. However, because

instructors use these assessments to adjust course grades, students often do not provide truthful reflections [20]. Thus, it can be difficult for instructors to interpret inconsistent or unreliable peer evaluations [21].

Another option is to use peer team evaluations as formative, rather than summative tools. Ungraded peer evaluations that are formative in intent can better reflect students' attitudes towards and behaviours in their capstone teams. For example, a team health self-assessment tool and workshop developed at the University of Waterloo allows students to assess the effectiveness of their team according to nine categories (e.g., decision making, communication, team processes, etc.), semi-anonymously and without that assessment being tied to grades [9]. The exercise allows teams to determine organically the areas in which their teams are struggling and make a plan for improvement. Preliminary evidence suggests that this form of assessment better reflects the state of teamwork in student teams and can predict team design scores better than traditional team peer evaluations. Data collected from several implementations of this assessment in capstone design courses in three different disciplines has pointed at team processes, decision making, goal-setting, and motivation as being the areas in which teams struggle the most [22].

Capstone instructors looking to grade students' teamwork competency have typically looked to relate teamwork processes to team effectiveness. Generally, team effectiveness has been measure in two ways. One way has been to use "objective" assessments of team output, such as the team's design score in their course (see for example [23]). Another way has been to use students' *perceived* team effectiveness. For example, a study with Mechanical Engineering students in Spain found that the importance students assigned to various teamwork factors (e.g., role assignment, regular meetings, project planning, etc.) correlated positively with their perceived level of functioning of their group [24].

2.3 Motivation and research questions

As reviewed above, instructors' perspectives and peer team evaluations can be a good source of information about what teamwork looks like in capstone design teams. However, these approaches have limitations due to students' hesitation in sharing information with the instructor when they believe this will hurt the team's ability to work effectively in the future. Yet, understanding students' teamwork experiences in project teams and their gaps in teamwork skills is critical to the design of effective and targeted teamwork training.

Previous work highlights the importance of understanding common problems in teams [25, 26]. This paper builds on previous literature and presents a large study that explores both capstone instructors' and students' experiences and perspectives on capstone teams. The purpose of the study was to support the Teamwork Clinic at the University of Waterloo by providing evidence-based recommendations on what teamwork knowledge and skills its training modules should cover. The study had the following three objectives:

1. Understanding the instructors' perspective on the functioning of capstone design project teams
2. Exploring how students experience teamwork in their capstone design project teams and how those experiences affect their perceptions of team effectiveness and their enjoyment of teamwork
3. Determining the students' perceived expertise and need for training in teamwork and team project management skills

3. Method

The study was conducted in two phases. First, interviews were conducted with instructors of capstone design courses to elicit their experiences and perspectives on the common teamwork-related patterns and issues they had observed in their capstone design courses. The results of a thematic analysis on the instructors' responses then formed the basis of a survey that was administered to students across multiple engineering programs working on their capstone design projects in teams.

3.1 Instructor interviews

The first stage of the study was a series of semi-structured interviews with instructors of capstone design courses. The interviews targeted four main areas of inquiry, namely:

1) Determining specific ways in which the various programs' were delivering the capstone design course and evaluating design projects
2) Identifying what teamwork instruction students were receiving in their capstone design course and whether it was adequate
3) Obtain instructors' general evaluation of the student teams' effectiveness and factors impacting teams' performance
4) Identifying common causes of conflicts that arose in capstone design teams

The following questions anchored each interview:

- Questions about the specifics of programs' capstone course design
    - *"Can you outline how the capstone courses are structured in your program?"*
    - *"How is teamwork assessed in your capstone courses (if at all)?"*
    - *"Can you describe how and when students form their capstone design teams?"*
    - *"What is your assessment of the effectiveness of team formation in your program?"*
- Questions about teamwork training
    - *"What kind of teamwork and project management training (if any) do students receive?"*
    - *"Is the current training adequate?"*
    - *"What type of teamwork training would students benefit from?"*
- Questions about teams' effectiveness and common sources of team problems:
    - *"What is your assessment of the effectiveness of teams' performance in your program?"*
    - *"What factors affect teams' performance?"*
- Questions about the main causes of problems/conflicts in teams
    - *"Can you recount some examples of team conflicts that you have dealt with in your capstone courses?*
        - *"What caused the conflict?"*
        - *"How did the team manage the conflict?"*
        - *"Did the team notify you of the conflict? If so, at which stage?"*
        - *"What did you do to handle the conflict?"*
        - *"Are any of the team problems gender-based?"*

Interviews were conducted with 12 engineering instructors who had extensive experience coordinating capstone design courses in 10 different engineering programs. Each interview was 30 to 60 minutes in length and was conducted jointly by the two researchers working on this study. The interviews were not audio-recorded; however, the interviewers took detailed notes (recording the instructors' answers almost verbatim) in each case.

Instructors' answers to the first two groups of questions revealed that the different programs are largely very similar in the processes students employ to form capstone design teams, as well as how teams' performance is evaluated in their respective capstone courses. Further, it was revealed that in most programs, students received formal instruction about teamwork in at most one session. The training was very brief and typically only focused on team formation and explained what to expect in terms of the phases of the design process. Many of the interviewed instructors expressed that while they believed good teamwork and project management were very important to team success, they were unsure as to how best "teach" these skills to students. Instructors also acknowledged difficulties around assessing teamwork. While many were utilizing peer assessment in order to assign a "teamwork" grade to students, they acknowledged that these peer assessments are often not honest. They expressed that many students are not willing to report teamwork problems in peer assessments for fear of further antagonizing team members. When a team conflict is reported to an instructor, it is often the case that the conflict is quite significant and students do not believe they will be able to work as a team going forward.

The instructors' answers of the last two questions underwent a thematic analysis using a grounded theory approach [27]. As we carefully read and analyzed the interview notes, we created broad themes centered on the factors affecting teams' performance and common causes of conflicts. With each new interview that was analyzed, instructor responses were either categorized as part of an existing theme, or in the case when a new idea had

emerged, a new category/theme was created. Emerging themes were saturated after the 10th interview and no new theme emerged from the last two interviews. After the interviews, the coding of the interviews was again cross-validated by the two researchers working on this study. The emerging themes and related instructors' perspectives are summarized below.

When it came to the main types of teamwork related problems in capstone teams, three general themes emerged from the instructors' experiences: 1) team conflicts, 2) lack of effective project management, and 3) lack of team membership skills. The latter are skills that one adopts to effectively interact with other team members, such as communication skills or giving/receiving effective feedback. All interviewed instructors could recount several significant capstone team conflicts they had to manage in the past and could provide a number of reasons why conflict had occurred. Overall, instructors identified eight reasons that typically led to conflict in capstone teams, including differences in expectations about the project outcome, unresponsive or "difficult" team members, social loafing and/or poor quality of work, internal disagreements on methods, approaches, etc. taken in the project, personal conflicts, and individual students having "big egos". The instructors also noted that many teams chose to not have a designated project lead or a concrete and detailed project plan. Overall, the results of the thematic analysis on the instructors' responses were in line with the results of previous studies [10, 11].

Finally, instructors identified several attitudes, skills and tools that they believed would strengthen student teams. Among others, they identified some key areas in which students would benefit from more training: managing conflicts, using team contracts, decision making, role definition and assignment, and project management. However, they also noted their lack of knowledge in this area and resource limitations in developing more comprehensive teamwork training and assessment tools.

3.2 Student survey

In the second stage of this study, building on the themes that emerged from the instructor interviews, we developed a survey targeted at senior students in various engineering programs near the conclusion of their capstone project. The survey was advertised to students in 12 different capstone design courses/disciplines through the capstone instructors of each program. At the time of completion of the survey, none of the participating classes had received any of the teamwork training workshops offered by the Teamwork Clinic. In some programs, students earned a small participation grade for completing the survey. Since the survey was intended to be anonymous, a separate process was in put in places to separate the student names from the data, in order to give participation credit to students (when applicable). The survey was first administered to students in one of the programs. We checked student responses to the questions and found no inconsistency, error, or misunderstanding. Subsequently, the same survey was administered to students in all other participating programs.

A full list of all survey questions is provided in the Appendix. The survey was comprised of several sections including:

- Demographic information including gender, program, team size, and team formation mechanism (questions 1-11).
- Perceptions of team effectiveness and task assignments in the team (questions 12 – 19)
- Project management (questions 20 – 23)
- Conflict in the team (questions 24 – 29)
- Perceived expertise and need for training in teamwork and project management skills (question 30)

Two of the survey questions (12 and 13) sought to measure the students' perceptions of the effectiveness of and enjoyment in their capstone teams. These questions were treated as the main dependent variables in the study. Given the scale of the survey – including both the sample size and the number of disciplines to which the participants belonged, a more objective measure of team effectiveness – such as project grades – was not feasible, nor was it likely to be reliable given the sometimes widely different ways in which capstone deliverables in different programs are structured and graded. Moreover, students' perceived effectiveness of their teams is likely to resemble – at least in part – objective assessments such as grades they receive in the course.

Some of the survey questions (notably those related to team conflict), also included open ended questions that allowed students to describe their experiences in detail. The text in those responses underwent a separate thematic analysis and the results were described in a separate publication [15].

4 Survey results and analysis

The survey was completed by 616 students, 79.6% of which identified as male, 20.4% as female, and 0.2% as "other".

4.1 Team formation

Almost every respondent (98.3%) reported choosing their own team, while the rest were assigned to a team by the instructor. In all the surveyed disciplines students are free to form their own capstone design teams; it is thus likely that those students who reported otherwise were assigned to teams by the course instructor after failing to join a team on their own. A small minority (7.7%) of the respondents were part of a multidisciplinary team; the rest formed teams within their discipline.

Almost half of the students (46%) reported joining their team in the second term of their third year. A small portion (11%) had formed their teams even earlier. The rest (38.2%) did so in the first term of their fourth year. This variation is largely explained by the various capstone course sequences among disciplines. While almost all programs have a two-term capstone project in the fourth year, some also have an additional course in the preceding term during which students choose topics and form teams. Nevertheless, the answers suggest that some students form their teams even prior to this, in earlier years.

4.2 Perceived team effectiveness and experience enjoyment

In terms of the students' overall perceptions of their team's effectiveness in reaching its objectives (question 12), 23% of students perceived themselves to be very effective, 40% effective, 27% moderately effective, and 9% not effective at all. In addition, 31% of students enjoyed their experience in their teams very much, 45% mostly enjoyed it, 19% enjoyed it a little and, 5% did not enjoy it at all (question 13).

4.3 Task and skillset distribution in teams

Table 1 summarizes student responses with regards to role clarity and alignment with their skills and interests (questions 15 and 17).

Table 1 Role clarity (question 15) and alignment with skills and interests (question 17)

	Student response (%)
Role clarity (question 15)	
"I have known exactly what I am supposed to do"	53.8
"I have somewhat known what I am supposed to do"	40.1
"I have been unclear about what I am supposed to do"	6.1
Tasks matched interest (question 17)	
"Did not match at all"	30.4
"Slightly matched"	44.8
"Mostly matched"	20.7
"Completely matched"	4.1
Tasks matched skill (question 17)	
"Did not match at all"	35.3
"Slightly matched"	51.3
"Mostly matched"	11.4
"Completely matched"	2.0

About 94% of the students in teams perceived their roles to be exactly (53.8%) or somewhat (40.1%) clear. However, when it came to the degree to which the assigned tasks matched the students' interests and skillsets, about

75% of the students thought that their tasks only slightly matched (44.8%) or did not match their interest at all (30.4%).

In order to further understand the effect of role and task assignment on students' perceived team effectiveness and enjoyment, we ran a Spearman's Rank-Order Correlation analysis (Table 2). All three variables - r*ole clarity, task alignment with individual members' skills,* and *task alignment with individual members' interest* – were significantly correlated with *perceived team effectiveness* and *enjoyment*.

Table 2 Correlation analysis between task/skillset distribution in teams (rows, questions 15 and 17)) and perceived team effectiveness and enjoyment (columns, questions 12 and 13)

	Team effectiveness	**Team enjoyment**
Role clarity	r(583) = 0.444*	r(583) = 0.430*
Assigned task matched the team members' interest	r(583) = 0.253*	r(583) = 0.374*
Assigned task matched the team members' skills	r(583) = 0.217*	r(583) = 0.237*

* Correlation is significant at the 0.001 level (2-tailed)

Students were also surveyed about the distribution of skills among team members in their teams (question 19) as well as their expectations about the project outcome (question 16), as presented in Figure 1. Most respondents described teams to be quite heterogeneous in this regard: most students (84.8 %) reported that team members had dissimilar skills; 78.1% reported that some team members in the team were (academically) stronger than the rest on some critical skill to the project, and 50.7% reported that one team member had a critical skill (supposedly one not possessed by the rest of the team). Nevertheless, almost every respondent (95.8%) stated that, at least to some degree, team members had similar expectations about the project outcomes.

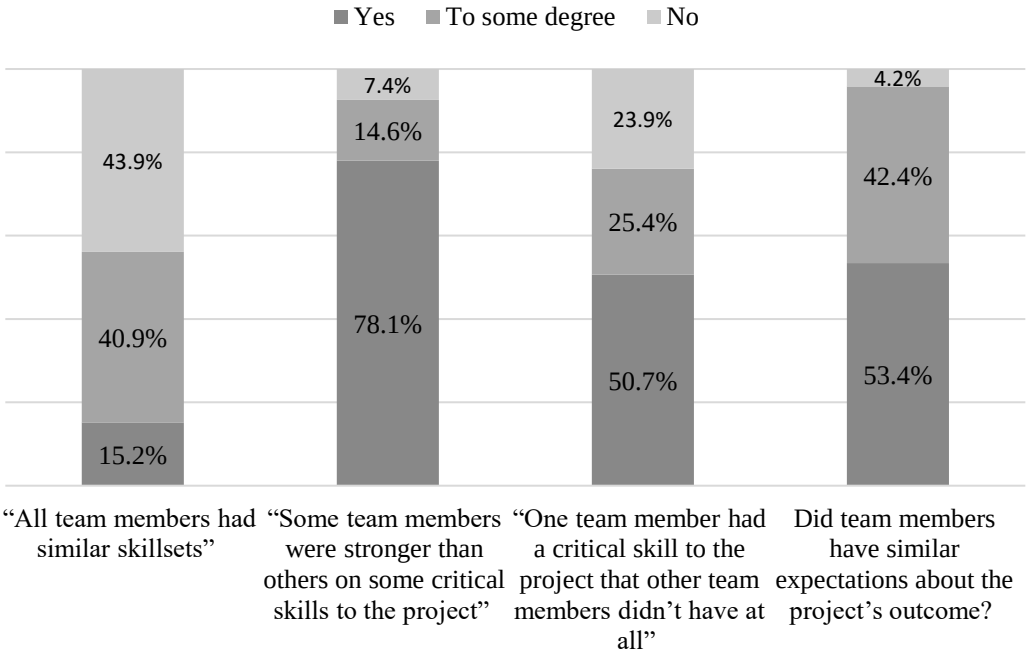

Figure 1 Distribution of skills (question 19) and project outcome expectations (question 16) in the team

A Spearman's Rank-Order Correlation analysis revealed a moderate and significant correlation between having similar expectations in teams (question 16) and both perceived team effectiveness ($r(583) = .406$, $p < .001$) and team enjoyment ($r(583) = .456$, $p < .001$). In other words, *students whose team members had differing expectations about the project's outcome had lower perceived team effectiveness and enjoyment*. There were no significant correlations between any of the variables in distribution of skills and either team enjoyment or team effectiveness.

4.4 Team Conflict

In questions 24-29 of the survey, students were asked about their experiences of conflict in their teams, whether the instructor was notified, and whether the conflict was ultimately resolved.

As also previously reported in [15], 22% of those surveyed reported having experienced significant conflict in their teams. Of those, 76% were ultimately able to solve the conflict. Only 26% reported that they had notified the instructor of the conflict. Of those, 72% reported being satisfied with how the instructor had handled the issue.

Answers to question 18 provided insight into the students' team dynamics and the typical problems they face in their teams. We presented a list of common sources of conflicts in teams, which were sourced from the instructors' interviews and previous work on team conflict [11, 13], and asked the students to indicate how frequently they faced these problems in their teams. The students responded to these questions on a 3-point scale: "Never", "Occasionally", "Frequently". As shown in Figure 2, the most frequently observed sources of conflict in teams were all related to team members' personalities and personal problems including, having *personal problems with each other*, perceiving one or more team members to *have a big ego*, and perceiving one or more team members to be *difficult to work with*.

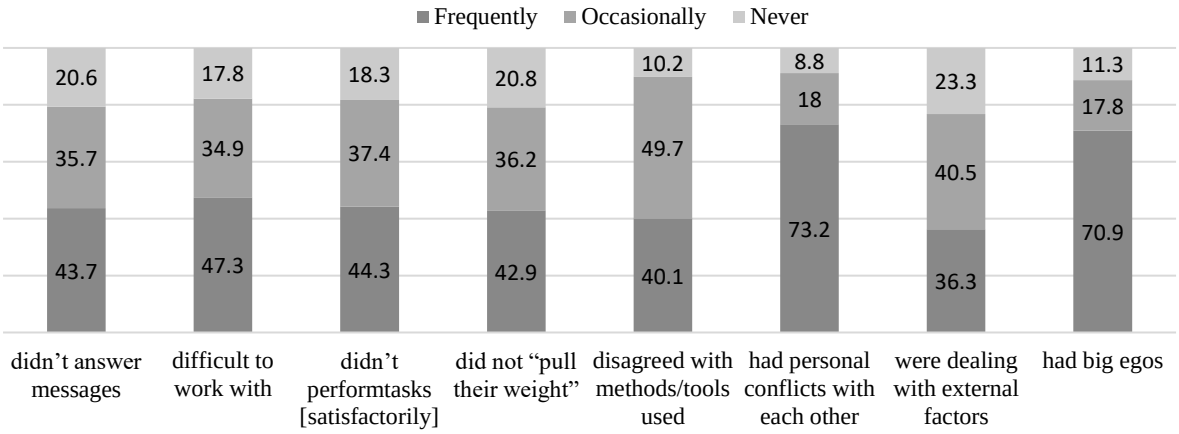

Figure 2 Distribution of common issues in teams, in percentage (question 18)

Given that the eight issues were measured on a 3-point scale (similar to an ordinal scale), we further investigated the relationship between the occurrence of these issues and both perceived team effectiveness and team enjoyment. A Spearman's Rank-Order Correlation analysis found that having the perception that a team member did not perform satisfactory had the largest negative correlation with perceived team effectiveness, ($r(581)= -.420$, $p < 0.01$). In addition, having a team member who was perceived to be difficult to work with had the biggest negative correlation with perceived team enjoyment, ($r(583) = -.491$, $p < 0.05$). The full results of the correlation analysis are presented in Table 3. In general, *students who encountered any one of the team issues in their teams had a lower perceived team effectiveness and enjoyment*.

Table 3 Correlation analysis between different issues experienced in teams (question 18) and perceived team effectiveness (question 12) and enjoyment (question 13)

Types of issues experienced in teams	**Issue occurrence and perceived team effectiveness**	**Issue occurrence and perceived team enjoyment**
Difficult to work with	r(583) = -.345**	r(583) = -.491**
Did not answer messages	r(583) = -.286**	r(583) = -.328**
Did not perform satisfactorily	r(581) = -.420**	r(583) = -.438**
Did not pull their weight	r(581) = -.387**	r(582) = -.391**

Disagree with methods/tools	r(581) = -.172**	r(582) = -.265**
Personal conflict	r(582) = -.141**	r(582) = -.330**
Dealing with external factors	r(583) = -.259**	r(583) = -.259**
Big egos	r(582) = -.173**	r(583) = -.393**

** Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed).

4.5 Project management

In terms of project management, teams took on various project management styles with 44% of teams having one project lead, 29% periodically rotating the project manager role between the team members, and the remainder having no team member in a project manager role. Furthermore, among the teams who had a project manager, in 52% of cases the project manager role was assumed by a team member, while for the rest, team members decided collaboratively who should lead the team. When questioned about their project planning activities, 34% of the teams had a clear and detailed project plan, 54% only had a high-level project plan, while the rest stated that they only had an idea and not a clear plan. Among the teams who had a project plan, 46% regularly updated their plan as they progressed through the project, 49% only updated their plan occasionally, while the rest never updated their plan.

Among the variables that were considered in project management, only *updating project plan* and *having a clear project plan* could be considered ordinal variables. A Spearman's Rank-Order Correlation analysis found that both variables were weakly but significantly correlated with both perceived enjoyment ($r(582) = .256$, $p < .001$) and effectiveness ($r(582) = .322$, $p < .001$) of teams. That is, the team members enjoyed more and perceived the team to be more effective when the project plan was clearer. Similarly, we found that updating project plan was weakly but significantly correlated with team effectiveness ($r(199) = .223$, $p < .001$) and team enjoyment ($r(199) = .230$, $p < .001$). That is, *the students enjoyed their experience in teams more and perceived their teams to be more effective when they updated their project plan more regularly*.

4.6 Teamwork and project management skills self-assessment

The last section of the survey evaluated students' perception of their skills and their perceived need for training, as presented in Figures 3 and 4 respectively. In terms of team membership skills, students perceived themselves to be most skilled in *communication*, *giving and receiving feedback*, and r*ecognizing the sources of conflict*. The three areas in which they self-identified as least skilled were *dealing with difficult people*, *project management*, and *conflict resolution*. These were also the three areas in which students identified as needing the most training.

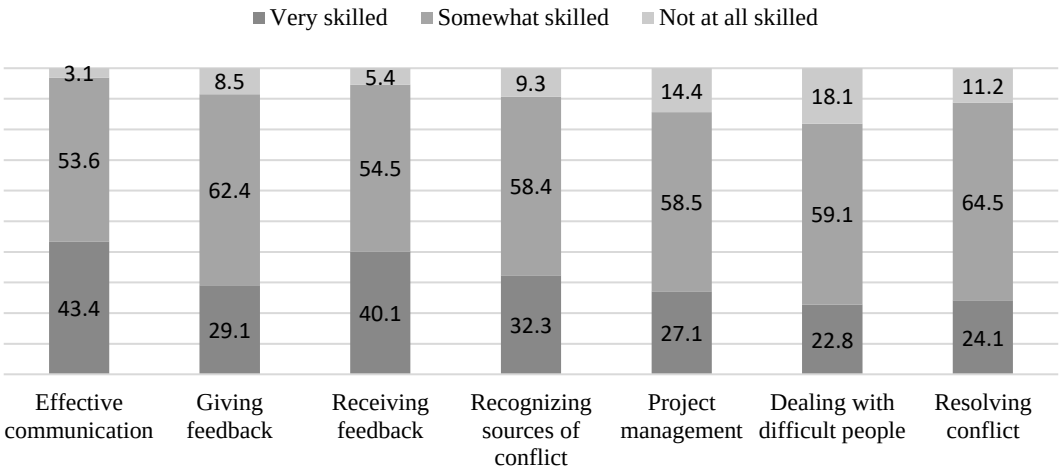

Figure 3 Distribution of perceived expertise in teamwork skills (question 18), in percentage

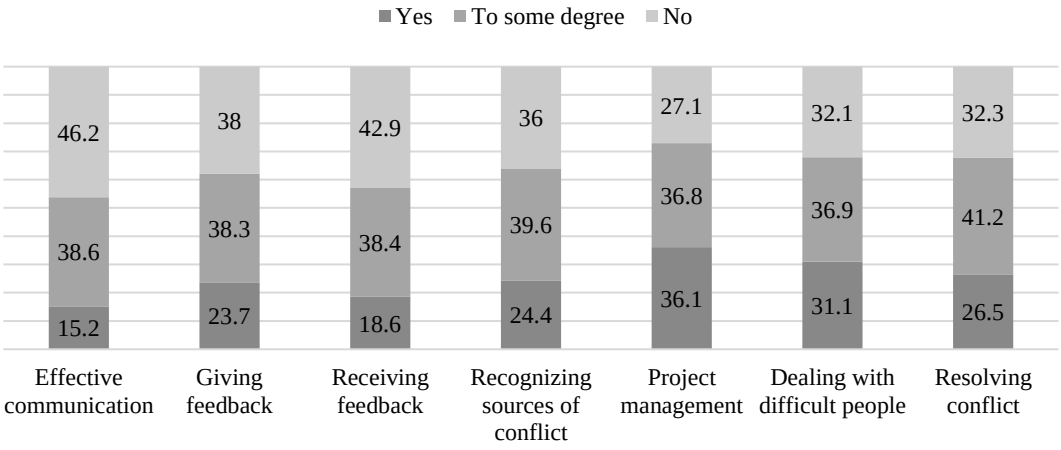

Figure 4 Distribution of perceived need for training in teamwork skills (question 18), in percentage

5. Discussion

The purpose of this study was to capture students' teamwork experiences and skills in their capstone design project teams in order to improve the content and design of teamwork training modules offered by the Teamwork Clinic.

The study was built in two phases. In the first phase, we interviewed 12 instructors of capstone design courses, who spanned 10 engineering disciplines and combined decades of experience in managing hundreds of capstone design teams. In semi-structured interviews, those instructors described what they perceived to be the main sources of conflict in capstone teams and their assessment of the adequacy of and gaps in existing teamwork training. The magnitude of experience they brought gave us confidence that the issues they brought up cover the real issues students encounter in capstone design courses.

In the second phase of the study, we surveyed over 600 fourth-year engineering students in 12 engineering programs. The large sample size (an order of magnitude larger than most similar studies) and the large number of disciplines it covers lend the study considerable significance. Survey questions were built around the themes that emerged from the instructor surveys and sought to understand students' teamwork practices in capstone teams, gauge their impact on perceived team effectiveness and enjoyment, and identify key gaps in existing teamwork training.

The results bring new insight on what drives students' perceptions of team effectiveness and enjoyment and can support evidence-based design of teamwork and project management instruction in engineering programs. Below we summarize the main study findings and discuss their implications.

5.1 Main findings and recommendations

At the outset, the study sought to address a number of research objectives. Below we discuss the insight that the study results bring in answering each question.

1. Understanding the instructors' perspective on the functioning of capstone design project teams

A thematic analysis of the instructors' interviews showed that they identified three main factors affecting student teams' performance: 1) team conflicts, 2) lack of effective project management, and 3) lack of team membership. Furthermore, instructors identified eight commonly observed causes of conflict in capstone teams, including differences in expectations about the project outcome, unresponsive or "difficult" team members, social loafing and/or poor quality of work, internal disagreements on methods, approaches, etc. taken in the project, personal conflicts, individual students having "big egos", and lack of a detailed plan. Overall, the results of the thematic analysis on the instructors' responses confirm results of previous studies [10, 11], which suggests that, at least in this regard, capstone instructors' experiences are universal and transcend disciplines and institutions.

2. Exploring how students experience teamwork in their capstone design project teams and how those experiences affect their perceptions of team effectiveness and their enjoyment of teamwork

Most students in our survey perceived their teams to be effective and stated that they enjoyed their teamwork experience. However, we found that lower levels of perceived team effectiveness and enjoyment were linked to a number of factors.

First, the study results suggest that team members do not have good role clarity and alignment with their interest and skills. In fact, almost half of the student respondents said that they were either unclear or only somewhat clear on what they were supposed to do in their teams. It was thus not surprising that role clarity was found to be moderately correlated with both team enjoyment and team effectiveness. Further, for most students, their assigned tasks in the team, at best, only slightly matched their interest and skill. Our analysis showed that higher degrees of a match between the assigned tasks and team members' interests and skills result in significantly higher perceived team effectiveness and enjoyment. Role clarity and alignment with skills and interests is particularly important in the case of capstone design teams. By 4th year, engineering students – even within the same program – have begun to specialize considerably through different elective courses (and in the case of students at the University of Waterloo, through different co-op experiences in industry). This was confirmed in our survey, with a majority of respondents stating that their teams where highly diverse in skillset and expertise.

Design problem are large, complex, and ill-structured [28]. Working on design projects requires students to re-structure the presented problem into well-structured sub-problems that they can solve. Requirements for those identified sub-problems can often be in conflict (creating what Dorst [29] describes as "design paradoxes"). Identifying and working through those paradoxes, especially in a team context, requires students to actively build shared expectations. It is then not surprising that in our survey the degree to which team members shared those expectations about the project outcome significantly correlated with perceived team effectiveness and enjoyment.

Another focus of the survey was to understand how students were experiencing conflict in their capstone teams. Almost 1 in 4 respondents had experienced significant conflict, with the most frequent sources of conflict being (inter)personal in nature. Correlation analysis revealed that team conflict is highly negatively correlated with team performance and team enjoyment. This result was not surprising. Although some types of conflict such as task conflict can be constructive for teams under certain conditions [30], the types of conflicts that were identified by capstone instructors – which then formed the basis for our survey - were all shown to have a negative effect on team performance. Having the perception that a team member does not perform satisfactorily in their assigned tasks had the largest negative correlation with perceived team effectiveness, while having a team member who is perceived to be difficult to work with has the biggest negative correlation with perceived team enjoyment.

Finally, the survey sought to explore the degree to which student teams employ project management methods to manage their capstone design project, looking a primarily two indicators: the emergence of the project manager and the development/maintenance of a project plan. We found student project management to be limited; less than half the teams had a singular project manager, with the remainder of teams opting instead to have a "rotating" project manager role or none at all. Further, 1 in 3 teams did not create/maintain a project plan, and even when looking at teams that did produce a project plan, less than half updated it regularly. Not surprisingly, having a clear project plan and regularly updating the plan was found to be weakly but significantly correlated with higher levels of perceived team effectiveness and enjoyment.

3. Determining the students' perceived expertise and need for training in teamwork and team project management skills

Our results also identified the teamwork skills in which students perceived themselves to be more skilled and the areas in which they perceived to need more training. We found that students perceived themselves to be the most skilled in communicating effectively, while they were the least skilled in dealing with difficult people, project management, and resolving conflict. Those three areas were the ones in which students also perceived to need the most training. These results are in alignment with what emerged from student answers to previous questions, as discussed above in response to the second research objective. Taken together, these findings point to the importance

of instruction on two main topics: 1) project management, including assigning a project manager, developing and maintaining a project plan, dividing work and assigning roles, building shared project goals and objectives, and agreement on how those will be measured, and 2) identifying and managing/resolving team conflict.

The importance of the factors listed above is evident; they confirm results from prior studies, which have identified several teamwork areas in which engineering students should gain more training, including project management, work distribution, and conflict resolution [11]. For example, in a previous study, at the end of a significant team problem-based learning activity, "assignment of roles", "task assignment considering members' strength", and "project planning" emerge as important factors that students identify as leading to team effectiveness [24]. Therefore, communicating the importance of these factors to students prior to the beginning a team project; and perhaps, introducing tools/means through which students can address these problems in practice may be highly beneficial for the students. For instance, by writing a team contract in which students identify the tasks, the roles, and project outcomes in detail, students have a chance to discuss their concerns and agree upon their roles and assigned tasks, as well as project outcomes prior to starting their work. Furthermore, considering the role of project management and conflict resolution skills on team effectiveness, providing students with skills and tools to manage related problems is critical to their successful experience in teams. Importantly, this training should extend not just to students, but also to the faculty members teaching or coordinating capstone design courses [11].

5.2 Limitations and future work

Although instructor interviews provided valuable insight for the development of the student survey, incorporating students' perspectives through interviews/focus groups could have further enriched the development of our survey. Subsequently, considering the exploratory nature of this study, a limitation of our work was a lack of a systematic approach in the survey development to explore all the components affecting student team's performance.

Students' skills and need for training in teamwork and project management – as explored by the student survey – are also limited; it may as well be that students "don't know what they don't know". For instance, most of the areas identified as frequently observed and important sources of conflict (e.g., not doing the assigned tasks properly or having personal conflicts) could be reduced and better managed by utilizing effective communication methods; however, students may not understand the broad applications that effective communication can help with. Therefore, in order to conclude where students lack teamwork skills and need more training, it is better to also look at the team dynamics and performance, as opposed to solely relying on students' perceived expertise.

Another limitation lies with the statistical analyses, especially with regards to the correlation analysis. In order to perform these analysis, survey answers had to be mapped unto ordinal scales. We are thus cautious with our interpretation of the results – further investigation is needed to better understand how and to what extent these variables are correlated. However, the correlation analysis gives us an overall insight to determine the more important factors to be investigated in future studies.

Finally, there may be cofounding variables affecting some of our correlation analysis. However, given the scale in which we interpreted our results, our results are still reasonable to be used and applied in practice.

Overall, this work acts as an exploratory study of the engineering capstone design teams' dynamics, providing an insight into team dynamics and common sources of problems affecting student teams' performance. Future work can build upon our findings to develop more precise measures that explore various teamwork components and their relationships.

6. Conclusion

This study identified factors contributing to team effectiveness and enjoyment in students' capstone design teams using both the instructors' and students' point of views. It also provided strong evidence that across programs, students need better and earlier training in key teamwork and project management skills. Our findings can thus inform the design of targeted instructional interventions on required teamwork skills in order to promote more effective capstone design teams.

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Appendix – Student survey questions

Demographic

1. What program are you in? [list of 12 programs participating in the survey]

2. What stream are you in? [list of options that dictate course/co-op sequence for engineering programs at this university]

3. Are you enrolled in the multi-disciplinary capstone design series of courses? [options: yes, no]

4. What is your gender? [options: male, female, other]

Team survey questions

The following is a series of questions about your fourth-year design project team, from here on referred to as "team".

5. How many members did your fourth-year design project team have? [options: 1, 2, 3, 4, 5, 6 or more]

6. How many team members are female (including you, if applicable) [options: 0, 1, 2, 3, 4, 5, 6 or more]

7. When did you join your team? [list of options in third and fourth year coinciding with typical team formation timelines in capstone courses of the different programs, other]

8. Before the team was formed, with how many of your team members had you worked with on prior course projects? [options: none, some, all]

9. Before the team was formed, how well did you know the other team member? (If you have more than 6 teammates, only rate the 6 you know the best) [matrix where each team member (1, 2, 3...6) is rated on a 4-point scale: “not all, slightly, somewhat, very well”]

10. How did you join your team? [options: “I chose my team”, “I was assigned to the team by the course instructor”]

11. How did you feel about your team’s project topic at the beginning of the fourth-year design project? [options: “I did not like it”, “I somewhat liked it”, “I really liked it”]

12. How would you describe your team’s overall effectiveness in meeting its design project objectives? [options: “Not at all effective”, “Slightly effective”, “Moderately effective”, “Effective”, “Very effective”]

13. How much did you enjoy your experience in your team? [options: “I did not enjoy at all”, “I enjoyed a little”, “I mostly enjoyed”, “I enjoyed very much”]

14. In general, are the roles (I.e., the tasks assigned to team members) clear in your team? [options: “The team members know exactly what they are supposed to do”, “The team members somewhat know what they are supposed to do”, “The roles in our team are unclear”]

15. Has your role in the team (in other words, the tasks assigned to you) been clear? [options: I have known exactly what I am supposed to do”, “I have somewhat known what I am supposed to do”, “I have been unclear about what I am supposed to do”]

16. Did team members have similar expectations about the project’s outcome? [options: “Yes”, “To some degree”, “No”]

17. Did the tasks assigned to you match your skills and interests? [matrix where “Matched my skills” and “Matched my interests” are rated on a 4-point scale: “Did not match at all”, “Slightly matched”, “Mostly matched”, “Completely matched”]

18. Reflect on your team experience and state the degree to which you have observed the following: [matrix where the following statements: “One or more team members didn’t answer messages/emails in a timely manner”, “One or more team members were difficult to work with", “One or more team members didn’t perform theirs tasks to a satisfactory degree”, “One or more team members did not “pull their weight”, “One or more team members disagreed with methods/tools/approaches used to solve the design need”, “One or more team members had personal conflicts with each other”, “One or more team members were dealing with external factors (e.g., job hunting, heavy course-load, family issues, etc.) that affected their performance on the team”, and “One or more team members were full of themselves (had big egos)” were rated on a 3-point scale: “Never”, “Occasionally”, “Frequently”]

19. Please reflect on the following statements regarding your team members’ skillsets: [matrix where the following statements: “All team members had similar skillsets”, “Some team members were stronger than others on some critical skills to the project", and “One team member had a critical skill to the project that other team members didn’t have at all” were rated on a 3-point scale: “Yes”, “No”, “To some degree”]

20. How was the project managed? [options: “The team had one project manager throughout the project”, “The project manager role rotated periodically between team members”, “No team members assumed a project management role in the team”]

21. How did you choose your project manager? [options: “One of the team members just assumed the project manager role”, “We decided as a team about who should be the project manager”]

22. Did you have a clear project plan (including the project outcomes/deliverables with specific deadlines)? [options: “Yes, we had a detailed plan”, “We had a high-level plan but the details were not clearly mapped out”, “We did not have a specific plan, we only had an overall idea”]

23. Did you update your project plan often, based on new conditions and changes to the project? [options: “Yes”, “To some degree”, “No”]

Conflict

24. Did your team experience any significant conflicts? [options: “Yes”, “No”]

If “Yes”

25. In your opinion, what was the source of the conflict? Please provide a short description: [textbox]

26. Was the instructor notified of the conflict?[options: “Yes”, “No”]

27. Where you satisfied with the instructor’s handling of the problem? [options: “Yes”, “No”]

28. Was the team able to resolve the conflict? [options: “Yes”, “No”]

If “No”

29. Why was the conflict not resolved? [textbox]

Required skills

30. Please indicate your level of expertise in the following skills. Would having received more training in those skills have improved your performance in the team? [matrix where several "skills" are rated on two 4-point scales. The first scale - “Rate your current expertise in the following skills”- has these options: “Very skilled”, “Somewhat skilled”, “Not at all skilled”, “Don’t know”. The second scale - “Would more training have been helpful?” - has these options: “Yes”, “To some degree”, “No”, “Don’t know”. The skills to be assessed are: “Communicating effectively with team members”, “Giving effective feedback to team members”, “Taking feedback from other team members”, “Understanding the potential courses of conflict in a team”, “Project management”, “Dealing with difficult people”, “Resolving conflict in a team”]

Team number

31. What is your team number? [used to aggregate responses by teams]

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