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Working in Large Teams: Measuring the Impact of a Teamwork Model to Facilitate Teamwork Development in Engineering Students Working in a Real Project*

HOMERO G. MURZI[1], TAHSIN M. CHOWDHURY[1], JURIJ KARLOVŠEK[2] and BIANEY C. RUIZ ULLOA[3]

[1] Department of Engineering Education, Virginia Tech, 635 Prices Fork Road, 345 Goodwin Hall, Blacksburg, VA, 24061, USA. E-mail: hmurzi@vt.edu, tahsin@vt.edu

[2] School of Civil Engineering, The University of Queensland, Advanced Engineering Building 49 - Room 443, Brisbane, QLD 4072, Australia. E-mail: j.karlovsek@uq.edu.au

[3] Department of Industrial Engineering, National Experimental University of Táchira, , Av. Rotaria Prolongación Unidad Vecinal. Vda. 15, No. 127 San Cristóbal, Venezuela. 5001. E-mail: bruiz@unet.edu.ve

Teamwork is an essential competency for engineering graduates. Companies use high performing teams to efficiently adapt and meet complex societal demands. In several engineering programs students are expected to work in teams; however, teamwork is seen by most students as a course requirement to get a grade, rather than as a skill they need to master to become effective engineers. The purpose of this study is to understand the experiences of students and measure the effectiveness of a teamwork training model used to manage large teams and promote teamwork competencies in engineering students when working on a real senior capstone design project. We used a mixed methods approach. For quantitative data, descriptive and inferential statistics are reported to understand how the students' perceptions about different teamwork constructs changed after the semester concluded. In addition, qualitative data were collected by semi-structured interviews. Results suggest that the teamwork model used to train the students was effective in helping them achieve their desired teamwork competencies and overcome the challenges of working in large teams. Students reported that they felt more ready to face the professional engineering working environment as they now recognize teamwork is a key required competency.

Keywords: teamwork; large teams; problem-based learning; design; mixed methods

1. Introduction

Industry requirements regarding graduate engineers are increasing as we face the complexities of a fast-paced environment in the contemporary world. One of the competencies required by industry in every engineering discipline is teamwork. Companies use high performing teams to adapt to societal demands and become more productive [1]. Organizations recognize the importance of employees that work effectively with others, but also express that new employees do not bring adequate teaming skills to the workplace [2–5]. Additionally, engineering programs recognize the importance of teamwork. For example, teamwork is one of the requirements demanded by the Accreditation Board of Engineering and Technology (ABET). The ABET accreditation criteria is "an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives" [6]. Development of teamwork skills are thus essential in the preparation of future engineers to adapt to the workplace, team projects have been demonstrated to improve desired learning outcomes [7, 8]. Research on the benefits that teamwork has on students has been extensively reported in the literature [9–14]. Yet, despite teamwork being recognized as indispensable for engineering, engineering schools have been generally slow in developing pedagogies that successfully promote effective collaborative behaviors and positive attitudes in students toward teamwork.

Several engineering education initiatives, such as project-based learning and team-based learning, have been used to promote teamwork skills [10, 15–18]. However, in engineering classrooms, teamwork is seen by most of the engineering students as a course requirement in order to get a grade, rather than as a skill they need to master to become effective engineers. Part of the problem is that students are selected and assigned to teams with the expectation that they will know how to effectively work with others without receiving any teamwork training. As Gallegos [19] argue, just placing participants into groups does not automatically develop teamwork skills; thus, an adequate model is required to develop those skills. In a previous study, the authors identified the impact of teamwork training to not only improve teamwork per-

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ceptions in students but also to improve several other learning outcomes [14]. Furthermore, teamwork training is not only required for students but also for faculty members because faculty are expected to know how to promote teamwork competencies without receiving any training on how to prepare students to work in teams.

Engineering programs need to find ways to effectively train engineering students so they understand what is required to become a successful team member and what constructs associated with effective teamwork they need to master. However, training engineering students in teamwork is not a trivial task. In order to understand how to do it effectively, it is important to understand the impact that different teamwork frameworks can have and the perceptions of participants going through teamwork training and experiences in terms of the different constructs that a teamwork model has and its impact on the students.

1.1 Research Aims

The purpose of this study is to better understand the experiences of students working on a design project in large teams and to measure the effectiveness of using a teamwork model to promote teamwork competencies in engineering students. We worked with a large senior design engineering course at a large research University in Australia. Students were working in large teams on a real project and had a real company supervising their work. A teamwork model was used to make sure they received the proper training before facing such a challenging task. Our focus was to provide structured team training that addressed required individual and team competencies. The training was designed as part of instructional strategies that allowed individuals the opportunity to experience real team situations (i.e., a problem-based design project). In addition, the different constructs of the teamwork model were measured by the researchers over the course of the semester. This study answered the following research questions:

RQ1: Do students' perceptions of teamwork competencies change after working on a real problem in large teams in a large course?
RQ2: How effective was the teamwork model used to train the students to help them succeed in the project?
RQ3: How do the students describe the experience of working in a large team to solve a real problem?

In this study we implemented a problem-based learning approach in large design teams that had the unique opportunity of working with a real problem. In the following sections we describe the theoretical frameworks used to design the course and to guide our data collection and analysis.

2. Theoretical Framework

2.1 Problem-Based Learning (PBL)

Problem-based learning (PBL) is an active learning pedagogical approach used in higher education where students' learning is generated under the context of a challenging open-ended problem [20]. According to Bonwell, active learning is "any instructional method that engages students in the learning process" (as cited by Prince, 2004, p.1). Active learning is presented in the literature as the opposite to traditional lecture, because students reflect about what they are doing after engaging in several learning activities introduced in the classroom. According to Bonwell [21] the amount of information retained by students declines considerably after 10 minutes of listening. The reflection promoted in active learning has been proven to be more effective in engineering students. By actively participating students are able to develop the desired learning outcomes and also promote the competencies that industry requires -such as teamwork [9, 10, 22, 23]. In PBL, students' learning is self-directed as they investigate and try to solve typical, complex, real-world problem. In this context, students also gain the ability to collaboratively apply knowledge to new situations [20, 24, 25].

According to Prince and Felder [11], students working on PBL are confronted with open-ended, ill-structured, authentic problems that are similar to a real-world situation, and work in teams to identify learning needs to solve the problem and develop a viable solution. The students receive few instructions to solve the problem, and the instructor works as a facilitator rather than as the key source of information.

In the context of this paper, the Civil Engineering Design III course was structured using a PBL approach. Students were introduced to a complex, real problem and had to develop their design according to the parameters that a large civil engineering company used. Because we wanted to provide an experience that was as realistic as possible, company representatives were involved in the course. One of the requirements was to minimize the number of teams in the class so every team could have access to some industry experts and some faculty members, which resulted in large teams. To improve the experience for the students, we decided to implement a teamwork model and train the students on how to effectively work in teams.

2.2 Previous work on Teamwork

The engineering education literature has presented several strategies regarding how to ensure effective teamwork in engineering. Research has focused on enhancing student teamwork capabilities by the development of conceptual teamwork frameworks [1, 2, 26, 27], and the development of techniques to assess team effectiveness among students [26, 28–30]. Several authors have conducted survey research and team assessments to identify key attributes for effectively working in teams. [31–34] conducted surveys to assess team effectiveness among student teams. Riebe et al. [31] discussed about the importance of shared goals and effective communication attributes by conducting online surveys to track the development of student team skills using feedback loops for facilitators and students. Zeigler [32] used assessment techniques from industry models to assess teamwork skills among student team members. The survey was conducted by peer-to-peer evaluation and the findings highlighted the important teamwork attributes including shared goals and values, motivation, open and effective communication, constructive feedback, leadership and accountability. Kotey [33] identified attributes including motivation and ideal team composition by analyzing students' grades in different group assessment tasks and peer evaluation survey. Brackin and Williams [34] discussed about conducting team interviews and peer evaluation surveys among students in a PBL course. The peer evaluation was guided using rubrics for team performance criteria. The study helped in identify accountability and commitment to team process and performance as the key attributes. Other authors discussed about the teamwork attributes by conducting review on successful teamwork efforts in academia and industries. Davis [26] identified open and effective communication as the key attribute for students by conducting research on teamwork development by incorporating workshop and mentoring sessions into courses. Scartani [35] identified the importance of commitment to team success and interdependence by reviewing historical and contemporary examples of successes in business, industry and organizations through team efforts. Johnson [36] conducted reviews on high performing teams in several industries and found out that effective communication and interdependence are key attributes for successful teams in the 21st century.

In order to identify key attributes that make teamwork effective, we conducted a systematic literature review (see [37] for more information). The main teamwork attributes identified are presented in Table 1.

Table 1. Teamwork attributes

Attribute	Authors
Shared Goals and Values	[31, 32, 35, 38–40]
Commitment to team success	[35, 41]
Motivation	[32, 33, 42–44]
Interpersonal Skills	[38, 40, 41]
Open and Effective Communication	[26, 31, 32, 38, 40–42]
Constructive Feedback	[32, 40, 45]
Ideal Team Composition	[33, 40–42, 44]
Leadership	[32, 46–48]
Accountability	[30, 32, 34]
Interdependence	[30, 35, 36, 39, 40, 42, 49]
Commitment to Team Process and Performance	[34, 44, 50]

2.3 Teamwork Model

We decided to use the "Model for the development and assessment of effective teamwork" proposed by Adams [51] because it was the model that had the closest match to these attributes. According to the authors, highly effective teams exhibit certain characteristics described as constructs (i.e., common purpose, clearly defined goals, psychological safety, role clarity, mature communication, productive conflict resolution, and accountable interdependence). In order to implement the model, the first step was to understand the difference between effective teamwork and team effectiveness. According to Adams [51] effective teamwork refers to the process teams go through while displaying specific characteristics that make them effective. Team effectiveness on the other hand refers to the degree to which a group's output meets requirements in terms of quantity, quality, and performance [52].

According to Adams [51], effective teamwork refers to the process teams go through while displaying specific characteristics that make them effective. These seven effective teamwork characteristics can be considered constructs that are measurable [51]:

- Common purpose defined as the main objective of the team, which should be understood and shared by all team members. This element should lead to the development of the team's goals.
- Clearly defined goals refer to quantifiable and commonly agreed upon statements that define the actions to be taken by the team. Clear and common goals help team members maintain their focus.
- Psychological safety is the shared belief that the team is safe for interpersonal risk taking [53]. The team climate is characterized by interpersonal trust and mutual respect in which people are comfortable being themselves. Team members are confident that the team will not embarrass, reject, or punish someone for speaking up.

- Role clarity is the team members' common understanding of each individual's expected role that helps to minimize misunderstandings regarding task assignments and avoid role ambiguity.
- Mature communication refers to team members' ability to articulate ideas clearly and concisely, give compelling reasons for their ideas, listen without interrupting, clarify what others have said, and provide constructive feedback.
- Productive conflict resolution refers to the procedures and actions taken when conflict occurs that leads to results such as facilitating the solution of the problem, increasing the cohesiveness among team members, exploring alternative positions, increasing the involvement of everyone affected by the conflict, and enhancing the decision-making process [54].
- Accountable interdependence refers to the mutual dependence that all team members have regarding the quality and quantity of each individual's work within the team.

According to Adams [55] there is a relationship between team effectiveness and effective teamwork. Team effectiveness is the result of an effective teamwork process. Hence, we developed a training module based on the effective teamwork model that was introduced to the students during the first week of class. In the next section we provide detailed information regarding the course settings for this study.

2.4 Context and Implementation

2.4.1 Course Description

The course where this study was developed was the senior civil engineering design course III at the University of Queensland in Australia. This course is taken by every senior student in their last semester. The class had 238 students enrolled. The purpose of the course is to provide students with the opportunity to work in teams to apply previously acquired engineering skills in environmental, structural, transport, and geotechnical courses to a practical engineering design project in a supportive environment. The expected learning outcomes of the course are:

1. To synthesize, consolidate, and extend students' knowledge of engineering science, analysis, and design by the application of this knowledge to real civil engineering projects involving geotechnical, structural, transport, and environmental engineering issues.
2. To give experience in integrated and collaborative design.
3. To develop an understanding of how ethics and sustainability impact in infrastructure development.
4. To appreciate the positive influence of a diversely skilled team on design outcomes.
5. To give experience in the effective use of report writing and other means of communicating and understanding designs.
6. To develop students' informal and formal spoken presentation skills.
7. To develop independent research skills as they apply to multi-disciplinary design.

The course was taught by a teaching team composed of an expert in Geotechnical-Structural Engineering (course coordinator), an expert in Costal Engineering, an expert in Chemical and Environmental Engineering, an expert in Traffic Engineering, and an expert in Engineering Education. In order to implement the PBL experience, we changed from a traditional model to a studio-based setting. In the past, students typically received a lecture at the beginning of the week and then had a second session to work on their projects. We decided to not include the lecture and use all the in-class time as a design studio where students had time to meet in teams in every session and work on their design projects. Nevertheless, students received technical sessions on different topics relevant to their project. For example, in the first session students received training on the teamwork model. There were other sessions where people from the Brisbane city council came to talk about expectations the City had regarding the project and some sessions where experts from technical engineering topics provided technical information.

Because one of the goals of the course is for students to be independent in developing solutions to engineering design problems, they were expected to (i) independently (individually and as part of a team) draw on and use knowledge and skills gained during the first 3 years of the civil engineering program; (ii) independently address ambiguous and open-ended design problems typically encountered by professional engineers and justify design choices using supporting evidence; (iii) independently locate, interpret, and assimilate information (including guidelines, standards, etc.) that students had not previously encountered; (iv) develop the competencies, knowledge, skills, and attitudes toward effective teamwork that allow effective team processes when faced with the demands of the job market; (iv) develop a design project with a focus on a real company vision, mission, corporate values, objectives, and strategic planning. Therefore, we considered this to be a great opportunity to bring in a real-world project and implement a PBL pedagogical approach to the course. We decided to use a real infrastructure project in the city of Brisbane and were able to obtain support from the ARUP company. The project, called cross-river rail was a real project that is currently being developed in the city of Brisbane. As a result, there were two ARUP industry representatives involved in the brief writing of the project and four ARUP representatives involved in the course both in the evaluation of the projects and in continuously assisting students during class. In a class session, students had available all the teaching team, a group of graduate teaching assistants, and the industry representatives to ask questions, present ideas, and obtain support. All sessions were completely interactive and the students had a space where they could work as a large team or the sub-teams could do work on different aspects of their design. In the middle of the semester we provided two sessions for students to pitch their design draft idea to industry representatives, faculty members, and representatives from the Brisbane city council. The sessions were managed the same as the real sessions the companies use to present their projects to their real clients.

2.4.2 Teamwork Model

Because of the limitations imposed by industry representatives, we decided to limit the number of teams in the course to 15. Despite research suggesting that in students' teams an optimal size is from three to five members [56, 57], the opportunity to have industry involved was more important for us. Moreover, because we had an engineering education researcher with experience in large teams, he was in charge of supervising and helping students manage large teams. Hence, our teams consisted of 15 students on average, replicating a typical team in a large, real, civil engineering project.

Team assignments were purposefully designed so we could have diverse teams in terms of different levels of academic performance (as indicated by GPA). Each team had to develop a design project with a focus on a real company vision, mission, corporate values, objectives, and strategic planning. Hence, teams were provided with real company names and they had to do research to understand the company organizational culture and approach to similar projects. Teams were encouraged to divide in sub-teams according to the three or more tracks that each project had (i.e., geotechnical, environmental, transport, and, if required, other disciplines of civil engineering). For every team, we suggested they have a team leader and each track have a student leader. In addition, each track had an academic who could be consulted on technical issues associated with that aspect of the project. A researcher, in consultation with the course coordinator, advised on the development and the implementation of the model, supervised the development of teamwork skills, and provided support with conflict resolution.

In order to ensure that students understood how to effectively work in teams, the first lecture of the semester was teamwork training. Students understood their roles and the purpose of the teamwork model. During the training students took the Team Effectiveness Questionnaire (TEQ) to understand their attitudes toward teamwork. The same test was administered at the end of the course to compare how students' perceptions of teamwork changed (or not) during the experience. As mentioned before, [51] model guided the teamwork settings for the course, which offered the students different experiences to develop each construct of the proposed model:

- Common purpose: The primary grade was based on team submissions of their design project (all the teams developed a project based on the course objectives). Every team had a common purpose (i.e., to propose a design for the cross-river rail project). In order to provide each team with a common purpose and commitment from all members, teams developed a "Team code of conduct and expectations" during initial team training.
- Clearly defined goals: teams were required to develop quantifiable and commonly agreed upon goals based on the needs of all the tracks. The faculty member overseeing the teamwork aspect of the course reviewed the goals development and provided suggestions continuously.
- Psychological safety: students were trained on safety for interpersonal risk taking in the team. In addition, students had access to an academic who was in charge of dealing with conflict. Whenever a student felt there was an issue in the team where they did not feel safe, they could express this to the academic who acted as an impartial supporter.
- Role clarity: each team member was encouraged to assume a different role, and they received clear instructions on the expectations of their roles. The presence of role clarity minimized misunderstandings regarding task assignments.
- Mature communication: students had several channels to communicate effectively: they had a blackboard site, social networks interactions, and traditional email. During their training, teams were asked to maintain a log of every communication that the team had so they could understand how they evolved in the process. Mature communication among team members ensures a higher level of understanding.
- Productive conflict resolution: a researcher spe-

cializing in large team interactions was available to advise on communication methods and dispute resolutions within teams. The researcher provided support to solve all the conflicts the teams had.

- Accountable interdependence: students continuously evaluated their peers regarding the quality and quantity of each individual's work within the team.

2.4.3 Assessments

In conjunction with the model implementation, to manage the teams and maintain control of the large lecture several assessments were implemented. The assessments allowed us to not only evaluate the students' development on the expected learning outcomes, but also to supervise the effectiveness of the students' participation in the large team, avoid social loafing, monitor student performance (to be able to provide support to the students who were struggling), and manage conflict resolution with all the teams. Fig. 1 shows the different assessments implemented during the class. Some of these assessments complemented the traditional assessment plan designed for the course and were therefore mandatory. Other assessments (marked with *) were only for research purposes and were voluntary. The research aspects of the project will be discussed in more detail in the methods section.

3. Methods

In this study, we used a mixed methods research design. The purpose of the study was to understand the experiences of students working in large teams in a PBL environment. According to Creswell [58], mixed methods designs sequentially combine and integrate two forms of data (quantitative and qualitative) in a single study, and give priority to one form of data depending on the research problem. In this study, the first step was to use a quantitative approach to collect data using a survey to measure students' perceptions of teamwork at the beginning and the end of the semester. After the course was over, qualitative data was collected using interviews with students to further explore some of the quantitative findings. The overall study was an explanatory sequential design (Fig. 2) that began with the collection and analysis of quantitative data, followed by subsequent collection and analysis of

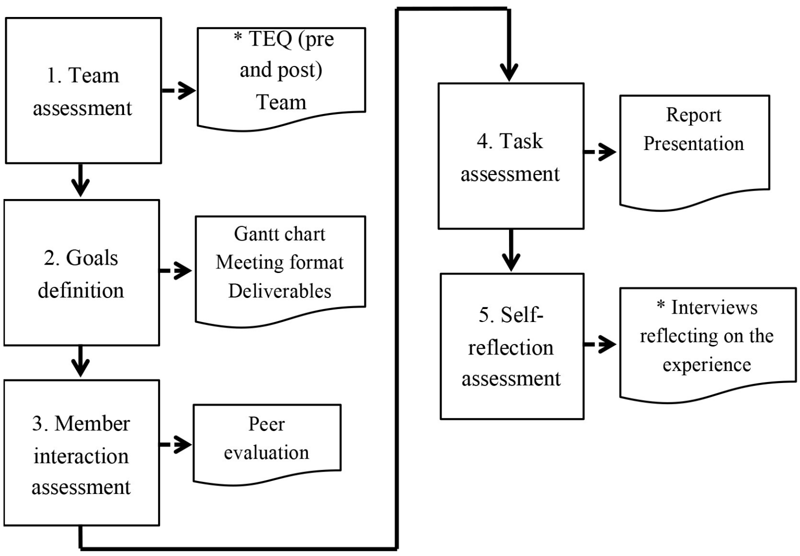

Fig. 1. Teamwork assessment frame. * Represents a deliverable used for research purposes only.

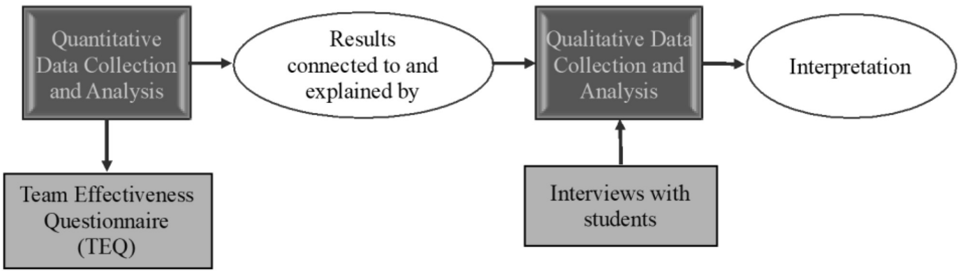

Fig. 2. Explanatory Sequential Mixed Method Design (adapted from Creswell and Plano Clark, 2017).

qualitative data, with the qualitative analysis being informed by preliminary results from the initial quantitative phase [58].

3.1 Data Collection and Analysis

3.1.1 Quantitative Data

Quantitative data was collected using the TEQ [1]. Students took the TEQ as a pre-test at the beginning of the semester before the teamwork training started to determine their attitudes toward teamwork. The same test was administered at the end of the course to be able to compare how students' perceptions of teamwork changed (or not) over the experience. The survey was administered during class time in the first and last weeks of the semester. Students had 20 minutes during class to take the survey. All the students had access to computers/electronic devices during class; however, we had several iPads available for students in case they didn't want to access their own devices.

Data were collected electronically using Checkbox, a survey management online service available at the University that aligns with the Australian Code for the Responsible Conduct of Research. The study secured ethical approval, and participation was voluntary. Students were asked to provide consent for participation in the study before starting the survey. Results from the survey were analysed using the Statistical Package for the Social Sciences (SPSS). SPSS provides researchers with a secure platform to analyse quantitative data and conduct different statistical procedures.

Participants included 164 undergraduate engineering students enrolled in a compulsory engineering design course at the same research institution. One hundred sixty-one students took the pre-test on the first week of the course, representing 67.6% of the number of students enrolled. On the last week of the semester 164 students took the post-test, representing 68.9% of the students enrolled in the course. From the sample, 36.5% were female and 63.5% were male, 14.8% were international students and the rest domestic students. These demographics are representative of the civil engineering population at the University.

In order to determine if students' perceptions of teamwork changed after the experience of working in large teams and receiving teamwork training, we used the TEQ instrument to measure the seven teamwork effectiveness constructs as well as the students' perceptions on the importance of teamwork as future engineers. Descriptive and inferential statistical tests were reported to present the differences in the responses of the students before and after the semester, and an independent sample t-test was conducted. It wasn't possible to conduct a paired-sample t-test because students were not identified in the pre-test based on human subjects' ethical regulations.

3.1.2 Qualitative Data

Qualitative data was collected to address research question 3. There were seven participants who agreed to participate in the interviews. Participants were from different teams so we were able to have a broad representation. In terms of the demographics of the participants in the study, the sample consisted of three females and four males in the senior design class. In terms of participants' roles in their respective teams, there were four team members, two student leaders of a sub-group (track), and one team leader.

Data were collected using semi-structured interviews with the participants who signed consent forms. The purpose of the interviews was to accumulate qualitative responses, and interpret and analyze the data in order to identify the different teamwork experiences that participants had during their engineering design course in a large team setup. The study secured ethical clearance from the Human Research Ethics Committee of Australia and participation was voluntary. The interviews were held in an enclosed area to ensure confidentiality among participants. Interviews lasted no more than 1 hour and were audio recorded. To ensure process reliability of the study, pseudonyms were used in the transcription of the recordings and identifiable data was removed to secure participant confidentiality [59].

Data were analyzed using thematic analysis methods [60, 61]. Thematic analysis is defined by Clarke and Braun [60] as a method of identifying, analyzing, and reporting patterns within qualitative data. According to Robson and McCartan [61], thematic analysis is a generic qualitative method that allows data to emerge from patterns after doing open coding of the data. Our coding process was guided by Saldaña [62] coding techniques procedures. Initially, open coding was carried out from the interview data. Several themes emerged from the first step of open coding during data analysis. A codebook, was established by creating a category of codes corresponding to each of the themes. These themes represented ways of understanding different teamwork experiences that participants had during the course. Table 2 explains the codebook developed and the definition we assigned to each code, including a sample quote from the interview data.

3.2 Measures of Research Quality

In mixed methods research, establishing validity, reliability, and trustworthiness of the findings goes

Table 2. Coding categories and description

Activity Type	Description of the Teamwork Activity	Sample Quote
Workplace Experience/Event	The participant is describing a teamwork experience or event that happened in the senior design project	"I found the group project was really interesting because people were very interested in coming up with ideas and working together as a group because it was our own project that we had to start."
Accomplishment	The participant is describing the activity as a significant teamwork accomplishment.	"Even a big project, we were able to do it in a very cooperative way that took a lot less time and a lot less effort."
Challenge	The participant is describing the activity as something they found challenging as a team during the project	"These challenges, just that different expectation of work, that not everyone's on the same page as what needs to be done, and how often you need to meet in person."
Strategy	The participant is describing the activity as a strategy they used to meet a challenge or succeed at a teamwork task within their project	"For the group project we looked at the task we were assigned and tried to break up into equal bits and then if someone has an interest in a particular task, then that person would take that one and divide it."
Difference	The participant describes the activity in terms of a difference between small and large team size	". . . because there so many people there were a lot more strengths to work on with, and I think you also gave an opportunity to help, when you have five or six people, you don't really have as much of a learning opportunity."
Teamwork Advice	The participant is providing advice for any kind of teamwork related advice	"In the future, I would try and get someone to be the leader, because it got to the end and then we had three weeks left and the three of us that were working together on the last day realized that one of us three would have to start being the person who took charge."

beyond addressing separately the validity of the quantitative and qualitative portions of the study [63, 64]. Thus, it is very important to address the validity of the mixed methods as a whole in the study, in addition to using quantitative strategies of validation in the quantitative section, and qualitative strategies of validation in the qualitative section. In this study, several authors [64–66] guided data collection and analysis to ensure the validity of our mixed methods design. For example, sample integration was obtained by having the specific participants being recruited to the qualitative portion of the study [65, 67]. We were especially interested in a diversity of roles within the team to be able to understand how the students experienced some of the teamwork constructs that did not improve in the quantitative phase. Weakness minimization was also implemented by actively looking for the weaknesses of each research approach and compensating for those weaknesses with strengths from the other research approach [65, 67]. The researchers in the paper kept reflecting about the limitations of the study and finding ways to minimize them based on the strengths of each of the research approaches. Multiple validities [64, 67] were considered by using an instrument that had internal consistency and had been validated, and by piloting the interview protocols with several graduate students. Finally, inferential consistency [64] was achieved by connecting the theory in the study with our final results and considering this connection when explaining our findings and providing recommendations.

3.3 Limitations

There are several limitations to consider in the development of this study. One limitation is regarding the sample size. Although our sample represented almost 50% of the population, our findings need to be treated with caution when trying to make generalizations. Our sample is relatively small in order to provide results that are statistically significant; thus, making inferences regarding the significance of the differences in the pre- and post-test is limited. In addition, we didn't have a comparison group (i.e., engineering student teams without the training) in order to determine if the training experience in the course was the factor causing the changes of perceptions regarding the constructs. Another limitation of this study is participant bias. Participants were actively trained in teamwork and its constructs; therefore, it is possible that students who chose to participate in the post-test were very aware of the importance of our experiment, and their responses could be influenced by the training and the expectation of receiving some reward from the teaching team.

Regarding the qualitative data, it was difficult to recruit many participants for the interview as it was the first time in the senior design class where participants had to be involved with engineering education researchers and were not comfortable with openly talking about their experiences. Also, The Human Research Ethics Committee of Australia has a restriction in terms of accumulating participants' demographics other than 'gender' of the participants. The team also faced limitations while conducting interviews with the participants. Most of the participants worked part-time in parallel to their undergraduate engineering degree, and thus they sometimes brought in their personal experiences from their professional work so the researchers had to continually bring them back to the senior design experience. In addition, the researchers had to ensure that only experiences from participants' senior-design class were coded and analyzed for this study.

4. Results

4.1 Quantitative Study

As mentioned before, we used the TEQ instrument as a pre- and post-test. Descriptive statistics representing the mean scores for each construct are presented in Table 3 and visually represented in Fig. 3. In order to determine if there were significant differences in the responses of the students before and after the semester, an independent sample t-test was conducted. We assumed that our data are approximately normally distributed by using a Shapiro-Wilk's test ($p > 0.05$), you can see the detailed results of the test in Appendix C. The independent sample t-test was conducted assuming equal variance; the assumption was tested using Levene's Test for Equality of Variances. Table 3 present the results for the independent sample t-Test. These results were previously presented as a work in progress by the authors [68].

Based on the data analyzed, it is possible to affirm that there are statistically significant differences in the responses of the TEQ before and after the semester in most constructs except *clearly defined goals* (CDG). Based on the t-test results (Table 4), after the semester, students' perception of the importance of teamwork increased ($t = –2.145$, $p = 0.033$). Students also showed a slight increase on *productive conflict resolution* (PCR) ($M = 3.84$ in pre-test to $M = 3.94$ in the post-test), with a significant variation ($t = –1.996$, $p = 0.047$). Similarly, *mature communication* (MC) had a significant ($t = 5.291$, $p = 0.000$) increase on students' perceptions ($M = 3.89$ pre-test to $M = 4.21$post-test). Regarding CDG and common purpose (CP) the differences in these two constructs were negative, meaning that students' perceptions about them decreased after the experience. In the discussion section we explain our rationale for why we believe this was the case.

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Table 3. Descriptive statistics of the constructs

		N	Mean	Std. Dev.
Importance of teamwork (IMP)	Pre	161	3.0113	0.80051
	Post	164	3.9108	0.62756
Productive conflict resolution (PCR)	Pre	161	3.8491	0.47016
	Post	164	3.9827	0.54291
Mature communication (MC)	Pre	161	3.8923	0.40363
	Post	164	4.2113	0.50249
Clearly defined goals (CDG)	Pre	161	4.1156	0.46952
	Post	164	4.0750	0.55392
Common purpose (CP)	Pre	161	4.1085	0.54228
	Post	164	3.9442	0.53034
Accountable interdependence (AI)	Pre	161	3.2154	0.50253
	Post	164	4.6057	0.54991
Role clarity (RC)	Pre	161	3.0135	0.46430
	Post	164	4.7392	0.56746
Psychological safety (PS)	Pre	161	3.4175	0.60427
	Post	164	4.0692	0.53285

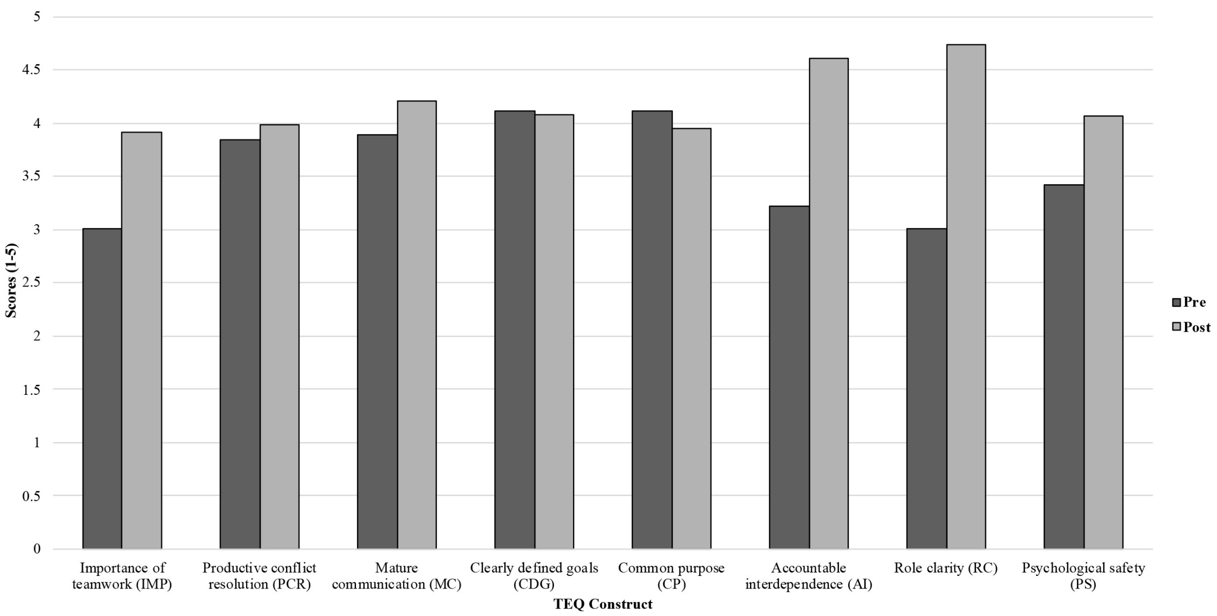

Fig. 3. Teamwork constructs differences between pre-test and post-test.

differences in these two constructs were negative, meaning that students' perceptions about them decreased after the experience. In the discussion section we explain our rationale for why we believe this was the case.

The constructs that demonstrated a higher increase on the students' perceptions were *accountable interdependence* (AI) with a significant difference ($t = 2.748$, $p = 0.006$) of 1.4 in the mean responses ($M = 3.2$ pre-test to $M = 4.6$ post-test), *role clarity* (RC) ($M = 3.01$ pre-test to $M = 4.73$ post-test), and *psychological safety* (PS) ($M = 3.41$ pre-test to $M = 4.06$ post-test). In the discussion section we elaborate more about each construct.

4.2 Qualitative Study

Several key patterns emerged across the participants' qualitative responses on their teamwork experience in the senior design project. A total of 182 teamwork activity instances were coded from the interview data. From interview data coding analysis, "Challenges" was the most represented activity, followed by "Strategies" and "Accomplishment". From the coding pattern it was found that the participants had primarily discussed challenges regarding their teamwork in the senior design project. In the following subsections, a more detailed look at the three most prominent teamwork activity types from the qualitative responses are provided: challenges experienced, strategies used to succeed, and accomplishments.

4.2.1 Challenges

As discussed above, challenges were experiences where participants described the activity as something they found challenging as a team during the project. Challenges were mentioned frequently during the interviews. From the responses, participants discussed their challenging experiences mostly in terms of *team composition* and *open and effective*

Table 4. Independent sample t-test results

	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Importance of teamwork (IMP)	–2.145	234	0.033	–0.19945	0.09297
Productive conflict resolution (PCR)	–1.996	234	0.047	–0.13364	0.06694
Mature communication (MC)	5.291	234	0.000	0.31901	0.06030
Clearly defined goals (CDG)	0.599	234	0.550	0.04057	0.06776
Common purpose (CP)	2.343	234	0.020	0.16426	0.07011
Accountable interdependence (AI)	2.748	234	0.006	0.19028	0.06925
Role clarity (RC)	4.752	234	0.000	0.32569	0.06853
Psychological safety (PS)	–8.799	234	0.000	–0.65178	0.07407

communication attributes. With respect to team composition, participants frequently described challenges they faced while working in a large group. Participants felt a lack of coordination among the team members when working in their team and also expressed concerns over working together with a common project goal. These challenges are exemplified by the two quotes below:

> "I think it was really challenging when I was working group work, there was never a sense of cooperatively working together, which I found really different to a lot of the volunteering work where I've done, where you're working in groups, everyone's there together, working together. You're working towards a goal and everyone's willing to help each other and work cooperatively. I never really saw that when I was working in this group . . ." (participant #3)

> ". . . these challenges, just that different expectation of work, that not everyone's on the same page as what needs to be done, and how often you need to meet in person. And how is that different in other classes? Because of the size? Yeah, because I think with four people were better." (participant #1)

Participants in the interview also described the challenges they faced in terms of open and effective communication. Some team members were not open to each other in terms of communication during project meetings and also when decision making was required within the team. This created some problems in the project and several submissions had errors that were not addressed by any team member. Participant #7 described the communication within their team to be very 'informal', which created a lack of accountability among the team members and also emphasized the use of messages for communication purposes instead of communicating openly in the group when all team members were present: ". . . so, everyone's like if they don't know something, they will never ask you. I've seen it in many [ways]. If they don't know something, they will never ask the group. And they are happy to submit it wrong." (participant #7)

> ". . . I think communication is always an issue. When for example, if I volunteer in meetings or if I have meetings at work, everyone shares what they've done throughout the week, and it's very formal. You know you are responsible for that, so you do your part, whereas in group, I feel like when you do group work at the university it's more informal. Even if you try to make that happen, it doesn't really happen. You see each other as friends, and you don't say, "This was my responsibility," so communicating openly about that. . . . Communication mostly was through messages I would find." (participant#2)

4.2.2 Strategy

Strategies were experiences where participants described their teamwork activity as a strategy they used to meet a challenge or succeed at a teamwork task in the project. Because participants faced a number of challenges as described in the previous section, they developed strategies to overcome the challenges they faced and work toward the goal of the design project. From the interview responses, participants described their use of strategies mostly regarding their team composition in order to be more effective in terms of communication. It is important to note that most of the strategies described were suggestions given to them during their teamwork training that they then realized had to be implemented in order to succeed in the final task.

Because the project involved a large team, participants discussed dividing into smaller sub-teams. The groups were divided among the team members based on expertise and interests of the members for a particular task responsibility in the project. This enhanced effective communication among the members in the sub-teams and they were more accountable for their tasks within that team. The team composition strategies are exemplified by the two quotes below:

> "I think at the beginning, for any group project we look at the task we were assigned and try to break up into equal bits and then if someone has an interest in a particular task, then that person would take that one and divide it." (participant #5)

> ". . . people who did need work to be done, they would talk in their small groups so it wouldn't bother everyone else, and they wouldn't have to explain the background of exactly what they were doing, they could just get into the technical stuff within their own small group, which was really good, which meant that everyone was very task-focused." (participant #2)

4.2.3 Accomplishment

Participants' accomplishments were described as a significant success in terms of teamwork. In spite of all the challenges they faced while working in a large team, participants discussed experiences that made their senior design project successful. In particular, participants discussed accepting the fact that every member within their team had different personalities, but the team project was successful when members understood each other's strengths and weaknesses and tried to contribute to the project using the strength of each member. One student commented:

> "Another good thing was learning to work with different personalities and learning to use your strength. Some people in our group were really good with the drawing part, so they wanted to take that strength, and some people who were really good at editing and formatting, so they wanted to take that strength." (participant #8).

Participants also highlighted the importance of working with a group of diverse students who had expertise in different disciplines in civil engineering.

Each team member was able to contribute toward the project goal through their strengths in their respective discipline. As described by participant #4:

> "I feel like this was a good project to have as the last one just before we go out, because it was one that had the different disciplines, with different people working on different things. And it's good to learn with people who have the same current experience as you, and then you can build on and work on it together. You can figure out what needs working." (participant #4)

Participants described a greater sense of accomplishment after finishing the project and being able to deliver a real design for a real project working in a large team, as compared to working in smaller teams from previous experiences. One participant emphasized that using the teamwork model effectively and understanding the constructs to create a real cooperative environment was really effective to overcome challenges, he described open and effective communication among themselves as one of the most important aspects: "Even [in] a big project, we were able to do it in a very cooperative way that took a lot less time and a lot less effort, whereas if it was a five- or six-people group, that would take a lot more time to do because you usually are not efficient." (participant #6)

5. Discussion

We provided students with a PBL course design where they had to experience a real infrastructure design project. This setting helped us implement an effective teamwork model to train the students on how to develop the competencies they require without losing the main focus of the class – to develop problem-solving and design skills. Results suggest that providing teamwork training had a positive impact on some of the teamwork constructs as perceived by the students and helped them overcome the challenges of working in large teams. Students benefited from working on a large project because they had exposure to a real project supported by a real company. To succeed, students had to assume different roles throughout the semester; therefore, they learned how to solve a real problem, achieve results by working with others, assume leadership positions, and manage a large project.

Regarding some of the effective teamwork constructs, we identified that, overall, students' perceptions about the importance of teamwork increased after the experience. They also recognized how crucial it was to work effectively on teams to be able to finish the project and deliver the expected results. We believe that training on teamwork was crucial in this. Also, using a PBL approach with a real project provided demands that helped overcome some of the issues, this is consistent with the literature regarding teamwork. For example, one of the main issues in teams is social loafing [69, 70]; however, research suggests that task complexity can minimize this problem [71–73]. The project was so demanding and complex that every student in the team realized quickly that they had to get involved and provide substantial contributions otherwise the entire team was not going to succeed.

There were two constructs that didn't show any improvement in our results (i.e., clearly defined goals and common purpose), and this is aligned with the challenges the students discussed in their interviews. We believe that part of the problem was the nature of the design problem they needed to solve and the messiness of working in large teams for the first time. We used a PBL approach and information given to the students regarding what they were supposed to do with the project was limited. We believed this created a sense of misdirection regarding what was expected and created confusion on the clarity of the goals of the team. One thing we found interesting was that students were encouraged during teamwork training to establish clear roles and to divide the large team into smaller sub-teams, having leaders for the whole team and for each sub-team. However, students at the beginning did not take this recommendation seriously, and it was later in the semester when challenges started to arise when they implemented this strategy. In the interviews students reported this as one of the strategies they used to succeed. Furthermore, in the survey, the role clarity construct was one where students improved their perception the most.

Regarding mature communication, students demonstrated a considerable increase on this construct, meaning that they used different communication strategies based on the training provided to communicate better as a team. This also relates to the qualitative data where students explained that communication was a big challenge. The main issue was to be able to communicate in the large team as too many people were involved in the communication channel. The fact that students had to reflect on their process and were required to archive all their communication logs also helped them to realize the importance of this construct. Students also demonstrated high levels of improvement after the experience regarding role clarity, accountable interdependence, and psychological safety. Providing training on how to deal with conflicts and how to include diversity in their design process was a factor in the improvement of their perceptions of conflict resolution and psychological safety. Also, having a faculty member helping with teamwork issues and conflict management was helpful for the students.

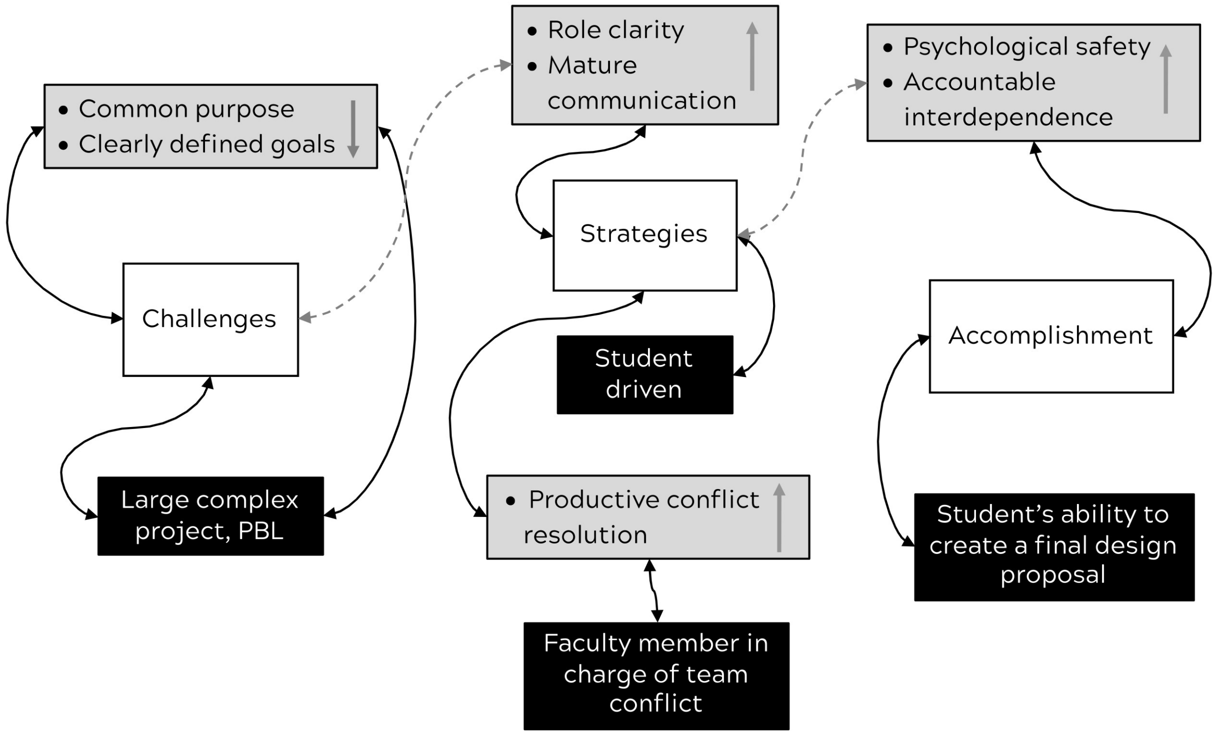

Fig. 4. Concept map of quantitative and qualitative results.

After analyzing both the quantitative and qualitative data, it was possible to conclude that the teamwork model used to train the students was effective in helping them achieve their desired teamwork competencies and overcome the challenges of working in large teams in a real project in a large civil engineering design course. Fig. 4 is a visual representation of how the constructs from the survey, the themes from the interviews, and some aspects inherent in the course interact. It is important to highlight that the interaction among teamwork constructs is not linear or clear, instead, the constructs interact dynamically in different ways depending on the context [51]. The main challenge expressed by students was working and communicating in a large team, this might be the reason why clearly defined goals and common purpose did not represent an increase in the post-test. We argue that having the PBL setting and such a complex real project influenced this. One recommendation is when implementing PBL to make sure to do continuous check points with the students to promote the development of a common purpose and make sure the entire team is on the same page, in addition, it is important to have them define roles early in the semester as suggested by Humphrey, et al. [74].

Nevertheless, when students were faced with these challenges they quickly realized the need to develop strategies to succeed, we argue that is the reason why their perceptions of role clarity and mature communication had an increase in the post-test. Paretti [75] suggests that under a PBL approach students can develop effective and transferable communication skills, this is consistent with our findings as we think the PBL environment forced the students to develop effective communication strategies and recognize their importance when working in teams. In addition to those student driven strategies, the productive conflict resolution construct also had an increase in the post-test, however, we do not think this is motivated by the students, instead, we argue that having a faculty member dedicated to oversee team's conflicts had a big influence in that construct, therefore, students did not comment on the some of the conflicts that some team experienced as those where handled by an external "expert". Finally, students being able to finish their design and do a final presentation and pitch to the client had an impact on the sense of accomplishment that is also related to the recognized increase in psychological safety and accountable interdependence in the post-test.

6. Conclusion

Out results suggest that after their experience in the course, students' perceptions of their teamwork competencies in some of the constructs measured increased with statistical significance. In addition, qualitative data suggest that the training using a teamwork model helped the students understand how to approach a complex teamwork situation. They understood communication as a key factor, and recognized that having a faculty member with expertise in teamwork, and focused on managing team issues and providing teamwork training made a huge difference. Students also reported that having a real project that was demanding and industry-driven was helpful in engaging all team-members and working on their part of the project. The majority of the students praised the experience, despite having a lot of resistance at the beginning of the semester. They reported that they feel more ready to face the professional engineering working environment as they now recognize teamwork is a key required competency.

To develop effective teamwork skills in engineering students it is important to understand the factors affecting team performance and effectiveness. It is understood that team members will not be able to control all variables, therefore the foundation of the model requires training team members to consciously understand the barriers and characteristics of the teaming process and factors that make and affect team effectiveness. Under our approach, even though, team members could not control all variables, they were able to choose strategies based on their training to make the team successful. The model we used shows that context and individual, task, and group characteristics affect effective teaming, which is characterized by mature communication, role clarity, clear goals, common purpose, accountable interdependence, psychological safety, and productive conflict resolution. The degree to which these elements are present in the team will shape team effectiveness as displayed by team performance, team behavior, and individual attitude toward teamwork. The model implies that team members need to be prepared for managing their own team process and be able to define and apply strategies that allow them to deal with those factors affecting team effectiveness. The conscious understanding of the process of teaming and team effectiveness is key for preparing individuals to become effective team players.

Anecdotally, students informally reported how the experience changed their perceptions of engineering and how this course made them more comfortable and prepared to go into industry. They felt that they were exposed to real-world scenarios where things were messy and complex, but they were able to create a design project nevertheless. Some of them also expressed how this experience changed their perceptions of teamwork from a small project that was divided in parts with each of the members of the small team completing a part and then putting everything together at the end, to a complex project that required several interactions, managing people with different skills, being strategic when communicating, and managing time, deadlines, and resources. They realized that teamwork is powerful and involves many different variables that are not static but dynamic and in constant movement. We agree with them and we believe in practice this means that even when there is no clear strategy and some variables cannot be predicted, having a model and understanding what constructs are important can make it possible to develop effective teamwork competencies that can be implemented in any scenario. Despite having some resistance at the beginning (including a letter that 12 of the students sent to the Department Head complaining about the experience), in the end the students benefitted from the experience. Three years later we still have students emailing us to let us know how the design course experience impacted their transition into the workforce, and how large teams and real projects were not intimidating for them in their first year as practicing engineers. Furthermore, the project assigned to the students is being developed currently, and more than 20 students that took the course have been hired as engineers in the actual project because of their design proposals during the course.

We believe engineering students need to develop the competencies, knowledge, skills, and attitudes toward effective teamwork that allow them to become effective team contributors when they face the demands of the job market. Thus, teamwork's purpose goes beyond assigning a task to a group of people to achieve a goal. Teamwork has a bigger purpose, to create synergy that allows the team to develop in the most effective way to solve a complex problem. Team members must understand the different variables that have an influence in the teamwork process. The success of the team is determined by the correct use of the mentioned competencies and management of the variables.

7. Implications and Future Work

Our study has several implications for research and practice. In terms of research, the model used in this research can be a good starting point for training engineering students in teamwork and we were able to explore several constructs of the model in this study. We believe we need to include more attributes from our literature review and improve the constructs in the model. More specifically, we aspire to take a systems thinking approach to be able to model how the different constructs interact with each other and how those interactions impact the overall teamwork effectiveness. This research also suggests that teamwork is a process that not only should lead to effectively achieving the team purpose but also that it should be a process that generates positive experiences in people involved, thus promoting positive future attitudes toward teamwork.

In regard to practice, we believe that using a teamwork model and proper training is important when trying to develop teamwork competencies in engineering students. Just assigning students to a team doesn't mean that students will learn to work effectively in teams. In addition, we were able to see the benefits of using PBL in this experience to provide the required context for student understanding of the importance of different teamwork constructs for a successful team project. However, this required considerable resources and preparation. The entire research team spent at least one semester before the course was offered working on the details of the project that included coordinating with industry professionals; developing a rich database so students could have access to good resources, both in terms of the context of the project and in terms of technical content; and developing meaningful assessments. Having the students in the large teams was probably the most challenging aspect of the course; however, at the end it gave us positive, unexpected outcomes that also required a large investment of time in terms of preparation. Having an engineering education researcher on the team dedicated to managing team dynamics the entire semester was also very helpful. In terms of implementation we think that providing the students with the roles, the goals, and the purpose of the project, and making those constructs explicit, could have helped with the challenges students faced and could have helped us track the team's progress earlier in the process. We advise faculty members who must use large teams in their courses for any reason to (i) make sure that both faculty members and students receive teamwork training using an existing teamwork model, (ii) provide a project that is challenging enough that students value the importance of good collaborative practices, (iii) find support systems in terms of engineering education research to make sure teaching practices are in line with what research suggests, and (iv) obtain support from administration. Support from our department head was crucial when implementing this intervention as we knew that students were going to resist the non-traditional structure of the course. We received full support not only to implement the course but to conduct the education research on the experience.

We also believe that training faculty members on how to implement effective teamwork experiences in the classroom is important. Students are expected to know how to work in teams when they arrive into senior capstone design courses, and in most cases, they have had teamwork experiences only in their first year. According to our experience with this design course, we think it is important to implement effective teamwork experiences in engineering programs throughout the curriculum and gradually develop this competency in the students.

In terms of future work, we are working to improve the survey to validate new constructs for inclusion. Also, the effective teamwork model (ETM) is being updated to include more constructs. Our goal is to conduct a longitudinal study to evaluate the developmental process of teamwork in engineering students during their academic program and to be able to measure how the constructs in the ETM interact. Our long-term goal is to be able to use the ETM as a theoretical framework that can be implemented in educational settings not only to train students and professionals on how to develop effective teamwork competencies but also to train educators on how to train their students on effective teamwork.

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References

1. T. Varvel, S. G. Adams, S. J. Pridie and B. C. Ruiz Ulloa, Team effectiveness and individual Myers-Briggs personality dimensions, *Journal of management in Engineering*, **20**(4), pp. 141–146, 2004.
2. B. C. Ruiz Ulloa and S. G. Adams, Attitude toward teamwork and effective teaming, *Team Performance Management: An International Journal*, **10**(7/8), pp. 145–151, 2004.
3. E. T. Pascarella and P. T. Terenzini, *How College Affects Students: A Third Decade of Research, Volume 2*, ERIC, 2005.
4. J. Talman, Enhancing Teamwork in Group Projects by Applying Principles of Project Management, in *Innovations in Teaching & Learning Conference Proceedings*, Fairfax, VA, 2018.
5. J. Long, A. R. Rajabzadeh, and A. MacKenzie, Teaching Teamwork to Engineering Technology Students: the Importance of Self-Reflection and Acknowledging Diversity in Teams, in *Proceedings of the Canadian Engineering Education Association (CEEA)*, Toronto, Canada, 2017.
6. ABET. Criteria for Accrediting Engineering Programs, 2019–2020. ABET. https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2019-2020/ (accessed April 12, 2019).

7. J. Wolfe, B. A. Powell, S. Schlisserman and A. Kirshon, Teamwork in engineering undergraduate classes: What problems do students experience?, in *Proceedings of the American Society for Engineering Education (ASEE) Annual Conference & Exposition*, New Orleans, LA, 2016.
8. R. Žavbi and N. Vukašinović, A Concept of Academia–Industry Collaboration to Facilitate the Building of Technical and Professional Competencies in New Product Development, *International Journal of Engineering Education*, **30**(6), pp. 1562–1578, 2014.
9. P. T. Terenzini, A. F. Cabrera, C. L. Colbeck, J. M. Parente and S. A. Bjorklund, Collaborative learning vs. lecture/discussion: Students' reported learning gains, *Journal of Engineering Education*, **90**(1), pp. 123–130, 2001.
10. M. Prince, Does active learning work? A review of the research, *Journal of Engineering Education*, **93**(3), pp. 223–231, 2004.
11. M. Prince and R. Felder, Inductive teaching and learning methods: Definitions, comparisons, and research bases, *Journal of Engineering Education*, **95**(2), pp. 123–138, 2006.
12. M. Freeman, To adopt or not to adopt innovation: A case study of team-based learning, *The International Journal of Management Education*, **10**(3), pp. 155–168, 2012.
13. L. K. Michaelsen, A. B. Knight and L. D. Fink, *Team-based learning: A transformative use of small groups*, Greenwood Publishing Group, 2002.
14. H. Murzi, Team-based learning theory applied to engineering education: A systematic review of literature, in *Proceedings of the American Society for Engineering Education (ASEE) Annual Conference & Exposition*, Indianapolis, IN, 2014, pp. 15–18.
15. R. M. Felder and R. Brent, Active learning: An introduction, *ASQ Higher Education Brief*, **2**(4), pp. 1–5, 2009.
16. J. García-Martín and J. E. Pérez-Martínez, Method to guide the design of project based learning activities based on educational theories, *International Journal of Engineering Education*, **33**(3), pp. 984–999, 2017.
17. B. Johnson and R. Ulseth, Student experience for the development of professional competencies in a project-based learning curriculum, *The International Journal of Engineering Education*, **33**(3), pp. 1031–1047, 2017.
18. D. Bairaktarova, M. F. Cox and M. Srivastava, A project-based approach professional skills training in an undergraduate engineering curriculum, *The International Journal of Engineering Education*, **31**(1), pp. 425–433, 2015.
19. P. J. Gallegos and M. Peeters, A measure of teamwork perceptions for team-based learning, *Currents in Pharmacy Teaching and Learning*, **3**(1), pp. 30–35, 2011.
20. H. S. Barrows, Problem-based learning in medicine and beyond: A brief overview, *New directions for teaching and learning*, **1996**(68), pp. 3–12, 1996.
21. C. C. Bonwell and J. A. Eison, *Active Learning: Creating Excitement in the Classroom. 1991 ASHE-ERIC Higher Education Reports*, ERIC, 1991.
22. C. M. Hsiung, The effectiveness of cooperative learning, *Journal of Engineering Education*, **101**(1), pp. 119–137, 2012.
23. W.-T. Chung, G. Stump, J. Hilpert, J. Husman, W. Kim and J. E. Lee, Addressing engineering educators' concerns: Collaborative learning and achievement, in *Proceedings of the Frontiers in Education Annual Conference*, Saratoga Springs, NY, 2008: IEEE, pp. T3A-3-T3A-7.
24. J. R. Savery and T. M. Duffy, Problem based learning: An instructional model and its constructivist framework, *Educational Technology,* **35**(5), pp. 31–38, 1995.
25. R. Ulseth and B. Johnson, Self-directed learning development in PBL engineering students, *The International Journal of Engineering Education,* **33**(3), pp. 1018–1030, 2017.
26. D. C. Davis and R. R. Ulseth, Building student capacity for high performance teamwork, in *Proceedings of the American Society for Engineering Education (ASEE) Annual Conference & Exposition*, Atlanta, GA, 2013.
27. Ş. Purzer, The relationship between team discourse, self-efficacy, and individual achievement: A sequential mixed-methods study, *Journal of Engineering Education*, **100**(4), pp. 655–679, 2011.
28. M. Ahmadian, Effective Practices in Multidisciplinary Teamwork, in *Proceedings of the American Society for Engineering Education (ASEE) Annual Conference & Exposition*, Vancouver, Canada, 2011.
29. P. K. Sheridan, G. Evans and D. Reeve, A Proposed Framework for teaching teameffectiveness in team-based projects, in *Proceedings of the American Society for Engineering Education (ASEE) Annual Conference and Exposition*, San Antonio, TX, 2012: American Society for Engineering Education.
30. J. Smith, G. Hoffart and T. O'Neill, Peer Feedback on Teamwork Behaviors: Reactions and Intentions to Change, in *Proceedings of the American Society for Engineering Education (ASEE) Annual Conference and Exposition*, New Orleans, LA, p. 15, 2016.
31. L. Riebe, D. Roepen, B. Santarelli and G. Marchioro, Teamwork: effectively teaching an employability skill, *Education+ Training,* **52**(6/7), pp. 528–539, 2010.
32. W. L. Ziegler, Teaching and assessing teamwork: Including a method (that works) to determine individual contributions to a team, in *Proceedings of the American Society for Engineering Education (ASEE) Annual Conference and Exposition*, Nashville, TN, p. 1, 2003.
33. B. Kotey, Teaching the attributes of venture teamwork in tertiary entrepreneurship programmes, *Education+ Training,* **49**(8/9), pp. 634–655, 2007.
34. P. Brackin and J. Williams, Teaching and assessing team skills in a senior level design course, in *Proceedings for the American Society for Engineering Educaiton (ASEE) Annual Conference and Exposition*, Albuquerque, NM, **6**, p. 1, 2001.
35. J. T. Scarnati, On becoming a team player, *Team performance management: An International Journal*, **7**(1/2), pp. 5–10, 2001.
36. P. R. Johnson, V. L. Heimann and K. O'Neill, The wolf pack: team dynamics for the 21st century, *Journal of Workplace Learning*, **12**(4), pp. 159–164, 2000.
37. T. Chowdhury and H. Murzi, Literature review: Exploring teamwork in engineering education, in *Proceedings of the 8th Research in Engineering Education Symposium, REES 2019-Making Connections*, 2019: Research in Engineering Education Network, pp. 244–252.
38. M. F. K. De Vries, High-performance teams: Lessons from the pygmies, *Organizational Dynamics*, **27**(3), pp. 66–77, 1999.
39. D. Francis and D. Young, *Improving work groups, a practical manual for team building*, University Associates, 1979.
40. P. R. Harris and K. G. Harris, Managing effectively through teams, *Team Performance Management: An International Journal*, **2**(3), pp. 23–36, 1996.
41. B. Critchley and D. Casey, Second thoughts on team building, *Management Education and Development*, **15**(2), pp. 163–175, 1984.

42. J. H. Bradley and F. J. Hebert, The effect of personality type on team performance, *Journal of Management Development*, **16**(5), pp. 337–353, 1997.
43. B. S. Gardner and S. J. Korth, A framework for learning to work in teams, *Journal of Education for Business*, **74**(1), pp. 28–33, 1998.
44. R. Wageman, Case study: Critical success factors for creating superb self-managing teams at Xerox, *Compensation & Benefits Review*, **29**(5), pp. 31–41, 1997.
45. V. U. Druskat and D. C. Kayes, Learning versus performance in short-term project teams, *Small Group Research*, **31**(3), pp. 328–353, 2000.
46. V. U. Druskat and J. V. Wheeler, Managing from the boundary: The effective leadership of self-managing work teams, *Academy of Management Journal*, **46**(4), pp. 435–457, 2003.
47. W. O. Einstein and J. H. Humphreys, Transforming leadership: Matching diagnostics to leader behaviors, *Journal of Leadership Studies*, **8**(1), pp. 48–60, 2001.
48. F. P. Morgeson, D. S. DeRue and E. P. Karam, Leadership in teams: A functional approach to understanding leadership structures and processes, *Journal of Management*, **36**(1), pp. 5–39, 2010.
49. M. A. Campion, G. J. Medsker and A. C. Higgs, Relations between work group characteristics and effectiveness: Implications for designing effective work groups, *Personnel Psychology*, **46**(4), pp. 823–847, 1993.
50. R. Valdez and B. H. Kleiner, How to build teamwork in the defence industry, *Team Performance Management: An International Journal*, **2**(2), pp. 41–48, 1996.
51. S. G. Adams, L. C. S. Vena, B. C. Ruiz-Ulloa and F. Pereira, A conceptual model for the development and assessment of teamwork, presented at the American Society for Engineering Education (ASEE), Montreal, Canada, 2002.
52. J. R. Hackman, *1990, Groups that work*, ed: Jossey-Bass, San Francisco, CA, 1993.
53. A. Edmondson, Psychological safety and learning behavior in work teams, *Administrative Science Quarterly*, **44**(2), pp. 350–383, 1999.
54. T. K. Capozzoli, Resolving conflict within teams, *The Journal for Quality and Participation*, **18**(7), p. 28, 1995.
55. S. Adams and B. Ruiz, A Framework for Team Training in the Classroom, *American Society for Engineering Education (ASEE)*, pp. 181–195, 2004.
56. C. J. Finelli, I. Bergom and V. Mesa, Student Teams in the Engineering Classroom and Beyond: Setting up Students for Success. CRLT Occasional Paper No. 29, *Center for Research on Learning and Teaching*, 2011.
57. B. Oakley, R. M. Felder, R. Brent and I. Elhajj, Turning student groups into effective teams, *Journal of Student Centered Learning*, **2**(1), pp. 9–34, 2004.
58. J. W. Creswell and V. L. Plano Clark, *Designing and conducting mixed methods research*, Sage publications, 2017.
59. G. R. Gibbs, Thematic coding and categorizing, *Analyzing qualitative data. London: Sage*, pp. 38–56, 2007.
60. V. Clarke and V. Braun, Thematic analysis, *Encyclopedia of quality of life and well-being research*, pp. 6626–6628, 2014.
61. C. Robson and K. McCartan, *Real world research. A Resource for Users of Social Research Methods in Applied Settings*, 4 ed., London, United Kingdom: Wiley, 2016.
62. J. Saldaña, *Ethnotheatre: Research from page to stage*, Routledge, 2016.
63. J. Creswell and V. P. Clark, *Designing and conducting mixed methods research*, 2nd Edition ed., Thousand Oaks, CA: Sage, 2011.
64. A. B. Dellinger and N. L. Leech, Toward a unified validation framework in mixed methods research, *Journal of Mixed Methods Research,* **1**(4), pp. 309–332, 2007.
65. A. J. Onwuegbuzie, R. B. Johnson and K. M. Collins, Assessing legitimation in mixed research: a new Framework, *Quality & Quantity,* **45**(6), pp. 1253–1271, 2011.
66. A. J. Onwuegbuzie and R. B. Johnson, The validity issue in mixed research, *Research in the Schools,* **13**(1), pp. 48–63, 2006.
67. R. B. Johnson, A. J. Onwuegbuzie and L. A. Turner, Toward a definition of mixed methods research, *Journal of Mixed Methods Research,* **1**(2), pp. 112–133, 2007.
68. H. Murzi, J. Karlovsek, B. Ruiz and L. Virguez, WIP: Using a teamwork model to manage large teams in a large lecture, in *ASEE Annual Conference and Exposition, Conference Proceedings*, Columbus, OH, 2017, vol. 2017: American Society for Engineering Education. [Online]. Available: https://peer.asee.org/29133
69. P. Aggarwal and C. L. O'Brien, Social loafing on group projects: Structural antecedents and effect on student satisfaction, *Journal of Marketing Education*, **30**(3), pp. 255–264, 2008.
70. J. A. Buckenmyer, Using teams for class activities: Making course/classroom teams work, *Journal of Education for Business*, **76**(2), pp. 98–107, 2000.
71. J. Burdett, Making groups work: University students' perceptions, *International Education Journal,* **4**(3), pp. 177–191, 2003.
72. J. G. Chapman, S. Arenson, M. H. Carrigan and J. Gryckiewicz, Motivational loss in small task groups: Free riding on a cognitive task, *Genetic, social, and general psychology monographs*, 1993.
73. N. Franz, Self-directed work teams: the antidote for "heroic suicide," *Journal of Extension*, **42**(2), 2004.
74. S. E. Humphrey, F. P. Morgeson and M. J. Mannor, Developing a theory of the strategic core of teams: A role composition model of team performance, *Journal of Applied Psychology*, **94**(1), p. 48, 2009.
75. M. C. Paretti, Audience awareness: Leveraging problem-based learning to teach workplace communication practices, *IEEE Transactions on Professional Communication*, **49**(2), pp. 189–198, 2006.

Homero Gregorio Murzi, PhD is an Assistant Professor in the Department of Engineering Education at Virginia Tech and leader of the Engineering Competencies, Learning, and Inclusive Practices for Success (ECLIPS) Lab. He holds degrees in Industrial Engineering (BS, MS), Master of Business Administration (MBA) and in Engineering Education (PhD). Homero has 15 years of international experience working in industry and academia. His research focuses on contemporary and inclusive pedagogical practices, industry-driven competency development in engineering, international engineering education, and understanding the barriers that Latinx and Native Americans have in engineering. Homero has been recognized as a Diggs Teaching Scholar, a Graduate Academy for Teaching Excellence Fellow, a Diversity Scholar, a Fulbright Scholar and was inducted in the Bouchet Honor Society. Homero holds honorary positions at the University of Queensland in Australia and the University of Los Andes in Venezuela.

Tahsin Mahmud Chowdhury is a PhD student at Virginia Tech in the department of Engineering Education. Tahsin holds a bachelor's degree in Electrical and Electronics Engineering and has worked as a manufacturing professional at a Fortune 500 company. As an Engineering Education researcher, he is interested in enhancing professional competencies for engineering workforce development in academia and beyond. He is actively engaged in different NSF funded projects at the department focusing on teamwork and leadership competencies in engineering. His current research focuses on using quantitative and qualitative tools and techniques to diagnose, analyze and improve teamwork competencies among engineering students to help comprehend with the fourth industrial revolution.

Jurij Karlovšek, PhD is an Assistant Professor at the University of Queensland (UQ) in Brisbane, in the School of Civil Engineering. His professional career to date spans four continents, with experience in both industry and academia including design and consulting, research and lecturing of university course content. Jurij's broad area of expertise is in Geotechnical Engineering: Tunnelling and Underground Space, Infrastructure Information Modelling and Non-Destructive Testing. Jurij was fortunate to gain international professional practice in Tokyo, Japan, where he found his passion for underground space exploration. He is member of the Young Members International Platform at the International Tunnelling and Underground Space Associations (ITA), Geneva, Switzerland. Jurij chaired the Young Members Group for 2 years and in 2015, and received an International Young Tunneller of the year award for best contribution to future industry development. As a representative of UQ, he engages with the community by creating and implementing associations that seek to inform, educate and empower young professional tunnelling engineers. In addition, he actively engages in the mentorship of undergraduate students, in supporting their industry engagement activities, and in general helping to make their experience as students a more enriched and profitable one. This is highlighted with recently awarded Commonwealth New Colombo Project funding to bring 15 UQ students to China for a summer research program to obtain an international professional practice.

Bianey Cristina, Ruiz Ulloa, PhD is currently a Professor of Industrial Engineering at the National Experimental University of Táchira, Venezuela, and Organizational Development Manager in a medium size company. She received her PhD and MS degrees in Industrial and Management Systems Engineering from the University of Nebraska-Lincoln. She holds a MBA and BS in Industrial Engineering from the National University of Táchira – Venezuela. Her research interests are teamwork, transfer of knowledge, and organizational development. She worked for nine years in the manufacturing and service industry as an Industrial Engineer prior to her academic career.

Appendix A. TEQ Survey

Team effectiveness questionnaire (TEQ)

You are being invited to voluntarily participate in a UQ research project aimed at enhancing teamwork skills in engineering students.

Project title: Learning teamwork effectiveness: Applying a teamwork model to manage large teams in a large lecture.

Researcher details:

Dr Homero Murzi (Principal Investigator, Postdoctoral Fellow in Engineering Education, School of Civil Engineering). E-mail: h.murzi@uq.edu.au
Dr Jurij Karlovsek (Co-Investigator, Lecturer in Civil Engineering). E-mail: j.karlovsek@uq.edu.au

The purpose of this research project is to implement a teamwork model to manage large teams in a large design lecture, which serves as a model for how teamwork initiatives may be incorporated into other large classes. Project objectives are supported by the literature on best practices of teamwork and education, so the project will only make learning opportunities in the course better and will not have a negative effect. Data will be collected quantitative and qualitative. Engineering students enrolled in CIVL 4516 will be asked to voluntarily participate by filling out a pre- and post-test. All assessment data will be de-identified so that responses are not attributable to individuals. Participation in this study over the course of Semester 2 2016 is strictly voluntary. Choosing not to participate will not influence outcomes or marks in the class. Students have the freedom to withdraw at any time without penalty and there are no risks to students for participating in this study. Students will receive no immediate benefit for participation, but the study could inform participants on how to improve their teamwork skills. Results from this project will be disseminated across Civil, EAIT, and the wider engineering education community. Students who wish to learn about the study's findings will be welcome to read the final report or publications.

The Bellberry Human Research Ethics Committee has reviewed this study in accordance with the "National Statement on Ethical Conduct in Human Research (2007)-incorporating all updates. Should you wish to discuss the study or view a copy of the Complaint procedure with someone not directly involved, particularly in relation to matters concerning policies, information or complaints about the conduct of the study or your rights as a participant, you may contact the Committee chair, Bellberry Human Research Ethics Committee on 8361 3222.

Please provide your informed consent below:

I am 18 years old or older, and have read and understand that participation in this study is strictly voluntary and agree to participate in this study.

Full Name (printed): ______________________________

Name (signature): ______________________________

Date: ______________________________

Demographics:

First, we'd like to know a few things about your background.

1. What is your gender?
   - Male
   - Female
   - Other
   - Prefer not to answer
2. What type of student are you?
   - Domestic
   - International
   - Prefer not to answer
3. Are you an Icarus student?
   - Yes
   - No
   - Prefer not to answer
4. What is your race?
   - Please specify______________________
   - Prefer not to answer
5. What is your Current GPA?
   - ______________________

Teamwork perceptions:

In the following sections, please select the response that better express the way you feel about the statement. Please have your previous experiences working in teams in mind when you answer the questions.

How frequently . . .? [1: Never 2: Rarely 3: Sometimes 4: Frequently 5: Always]

Question	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
6. I believe that working in a team prepares me for the workplace.					
7. I think teams are an effective way to learn engineering.					
8. I believe that teaming experiences in the engineering curriculum will contribute to my career success.					
9. I believe teaming activities will assist me in attaining the goals of the course(s).					

How frequently . . .? [1: Never 2: Rarely 3: Sometimes 4: Frequently 5: Always]

10. You are able to satisfactorily resolve differences with your team members?	1	2	3	4	5
11. You carefully listen to the other team members?	1	2	3	4	5
12. You stay focused on the team goals?	1	2	3	4	5
13. You clearly understand the team purpose?	1	2	3	4	5
14. You are able to ask members of your team for help with your task?	1	2	3	4	5
15. You actively participate in the assignment of roles for the team members?	1	2	3	4	5
16. After solving a conflict with a team member, you are able to maintain a positive relationship with him/her?	1	2	3	4	5
17. You clearly express your ideas?	1	2	3	4	5
18. You are committed to the team purpose?	1	2	3	4	5
19. You are able to bring up and discuss team issues?	1	2	3	4	5
20. You are clear about the expectations the team has about your individual contribution?	1	2	3	4	5
21. You accept disagreements when working in the team?	1	2	3	4	5
22. You trust that your team members will do their tasks effectively?	1	2	3	4	5
23. You are open to discuss ideas?	1	2	3	4	5
24. You participate in the development of the team goals?	1	2	3	4	5
25. you participate in the development of the team purpose?	1	2	3	4	5
26. You feel comfortable discussing difficult issues in the team?	1	2	3	4	5
27. You make sure you understand what your job is in the team?	1	2	3	4	5
28. You participate or intervene in the team conflicts to make sure they contribute the accomplishments of the team goals?	1	2	3	4	5
29. You communicate with other team members to make sure they understood your ideas and opinions when working in the team?	1	2	3	4	5
30. You make sure you clearly understand the team goals?	1	2	3	4	5
31. You support other team members with the accomplishment of their tasks?	1	2	3	4	5
32. You ask for clarification when you don't understand something in the team?	1	2	3	4	5
33. You help other team members clearly understand the team goals?	1	2	3	4	5
34. You focus your attention in accomplishing the team purpose?	1	2	3	4	5
35. You make sure you clearly understand the expectations of each team member so they can all contribute to the success of the team?	1	2	3	4	5
36. You feel responsible for the team performance?	1	2	3	4	5
37. You feel that when the team has a conflict, you have the same level of influence in the decisions made to resolve the conflict tan other members of the team?	1	2	3	4	5

38. You clearly know what is expected for the team performance?	1	2	3	4	5
39. You feel intimidated to make mistakes working on the team?	1	2	3	4	5
40. You feel motivated to accomplish your individual tasks as a result of the team work?	1	2	3	4	5
41. You are satisfied with the experience of working in a team?	1	2	3	4	5

As part of this study, we are interested in talking to some survey respondents in more detail to better understand your responses. If you would be willing to be contacted for an interview, please provide your email address. Otherwise, leave this field blank.

Appendix B. Interview protocol

Interview protocol

In the first few questions, I'll ask you to respond by thinking of previous teamwork experiences not related to this particular course.

1. Can you describe a typical teamwork experience in a course?
   (a) How work is developed
   (b) Communication
   (c) Team size
   (d) Main problems

Now, I would like to think about your recent teamwork experience. So, please think of such project and answer the same questions:

2. Can you describe a typical teamwork experience in a course?
   (a) How work is developed
   (b) Communication
   (c) Team size
   (d) Main problems
3. Please think about the similitudes, and the differences
   (a) What worked well
   (b) What didn't work
4. The following question is about how students interacted in the team. In that project, how did you interact with the team?
   - What did you typically do on class? (Description)
   - What did you typically do on a team meetings?
   - How valuable was the team and your teammates for you?
     i. What makes you say that/would you give me an example?
5. How did other people in the team interacted with you?
   - How would you characterize typical team members' interactions in your course?
     i. What makes you say that/would you give me an example?
6. The next question is about how work is developed in the team, for this experience:
   - How did you approach the project?
   - How did you divide the work?
   - Who was in charge of assigning the roles?
     - How comfortable were you with your role?
   - How was the communication in the team?
   - How do you know when you've learned something from the teamwork experience?
     i. What makes you say that/would you give me an example?

7. Now I'm going to ask you a few questions about conflict/disagreements. How do you approach conflicts in your team?
   - Can you provide an example of a conflict in your team?
   - Do you tend to solve it individually or in the team as a whole? Why?
   - Do you prefer clear roles since the beginning or have the room to be creative with your responsibilities in the team? Why?
   - What was the main problem the team had to face? Can you give me an example?
   - Who was in charge of conflict resolution?
8. If you could do the project again, what would you do different and why?
9. So far, we've been talking about your experiences in working in a large team in this class, but now I'd like to take a step back and ask you about how you feel regarding your teamwork skills?
   - Do you feel prepared to work in teams when you are a professional engineer? What makes you say that? Can you provide an example?
   - How important it is for engineers to understand how to effectively work in teams?
   - To what extent has this class helped you develop your teamwork skills?
10. Finally, given all the things we've talked about today, is there anything I didn't ask that you believe is important for me to know about your experience in the team, or your perceptions of teamwork in general?

Appendix C. Test of normality results.

Shapiro-Wilk		**Statistic**	**df**	**Sig.**
Importance of teamwork (IMP)	Pre	0.2061	161	0.6574
	Post	0.8882	164	0.8341
Productive conflict resolution (PCR)	Pre	0.3952	161	0.6833
	Post	0.4425	164	0.2642
Mature communication (MC)	Pre	3.639	161	0.7562
	Post	3.856	164	0.1395
Clearly defined goals (CDG)	Pre	1.7441	161	0.3793
	Post	1.8241	164	0.2634
Common purpose (CP)	Pre	4.3827	161	0.0572
	Post	2.217	164	0.4912
Accountable interdependence (AI)	Pre	1.9532	161	0.2956
	Post	0.1995	164	0.0991
Role clarity (RC)	Pre	3.5578	161	0.4441
	Post	2.0668	164	0.8199
Psychological safety (PS)	Pre	0.2548	161	0.0734
	Post	0.5447	164	0.4112