Assessing Levels of Psychological Safety and Teamwork Satisfaction in Engineering Senior Capstone Teams

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Abstract

Developing a team into a learning organization has been shown to create high-performing teams. Amy Edmondson's work showed that forming a learning organization requires a psychologically safe environment. The current research comes from studies into industry and professional organizations, but there is little work showing if teams of university students are developing psychologically safe teams. The current study is a work-in-progress focusing on improving teamwork experiences in senior capstone teams. Driving the current study are two questions: What is the state of psychological safety and teamwork satisfaction in engineering capstone teams? What teamwork-related instruction do faculty provide their senior capstone teams? The data collected also help us determine if different student populations experience different levels of psychological safety on their capstone teams. The results help us establish a satisfactory level of psychological safety and teamwork satisfaction and they show that the majority of students actually work on teams with satisfactory levels of psychological safety and teamwork satisfaction. There is a gap in the psychological safety levels between male and female students. The race/ethnic analysis showed no gap between underrepresented minorities (URM) and Non-underrepresented minorities (Non-URMs). Future work includes surveying faculty regarding the amount of teamwork training is happening across all capstone teams at the given institution. Future work will also focus on assessing the impact of specific interventions to improve psychological safety in senior capstone teams and provide tools to faculty to implement more intentional teamwork interventions for their capstone teams.

Introduction

ABET Outcome 5 is known as "the teamwork outcome." It invites programs to demonstrate how they help students to function effectively on a team. ABET Outcome 5 mentions leadership, collaboration, inclusivity, and several management tasks, such as setting goals, planning tasks, and meeting objectives, to clarify the meaning of effective team functioning.

Because our programs have courses that require groups of students to work as a team, our programs generally meet Outcome 5. However, we would like to do better than merely meet the outcome. Standing in our way are two challenges: As engineers with expertise in other topics, curating instructional materials (learning activities and assessments) related to teamwork effectiveness is challenging. There are so many options for teaching students how to work better in teams that it is overwhelming, making it challenging to select the most appropriate.

Secondly, even if we had the "right" learning experiences in our courses, how would we measure team performance or growth in team effectiveness over time? Finding an adequate assessment that is simple enough for the average engineering instructor is critical to disseminating teamwork learning experiences throughout the curriculum.

We decided to start by finding a way to measure teamwork that is simple to use, simple to grade, and simple to interpret at the course level as well as the program level. Once selected, we can look at curating (or creating) learning experiences to use as interventions to help improve the scores related to teamwork effectiveness.

There are a variety of studies that look at assessing teamwork in engineering teams. These studies fall into one of three categories: First are the studies that use the final product to assess team performance but test instructional techniques or teamwork frameworks. The objective of this first category is to observe if they can modify teamwork inputs to achieve improved teamwork outputs (designs or reports). Examples of this kind of assessment study include the work by Rodriguez et al. [1] and Ogot and Okudan [2], where they measured the diversity of a team or the personality of each member to determine the impact on team performance.

The second category of teamwork assessment focuses on the ability of a team to adopt and employ a specific teamwork framework. The work by Senaratne & Gunawardane [3] is a good example of applying a specific team role theory and measuring the impact on how the team adopts the selected theory. We do not expect colleges to adopt only one teamwork framework or one team role theory, so we wanted to identify an approach that was not as prescriptive.

A third category of teamwork assessment studies focuses on measuring the satisfaction of instructors and students with a teamwork experience. These studies are similar to the work of Natishan et al. [4], where focus groups of students evaluated their perception of the new teamwork instruction method. Similar to the previous category, we were not interested in measuring the impact of adopting a specific intervention. Our current goal is to establish benchmark data for the health of teamwork in our senior capstone teams, so any assessment of the impact of a given intervention is premature.

A final group of studies used selected metrics to describe effective teamwork. These metrics include clarity of roles, technical competence, collaboration, social support, shared purpose,

communication, and adoption of engineering identity, similar to the work of Davis and Wolfinbarger [5] and Tseng et al. [6]. This approach has tremendous appeal because it gives the researcher a measuring stick to quantify growth. However, the choice is overwhelming when confronted with the variety of metrics to choose from. What would make us use one, five, or all of the metrics available? Are all of them equally impactful (or relevant) on team performance?

In 2016, Google completed a project named "Aristotle" to find the components of an effective team. The internal report concluded that psychological safety is the foundation of effective teamwork [7]. The report continued that after psychological safety is present other attributes (team dependability, team structure & role clarity, work meaning/sense of purpose, and impact of the work) begin to impact team effectiveness significantly [8]. However, teams need psychological safety first.

Other researchers correlated psychological safety with leadership through individuals collectively experiencing situations with shared expectations to create value. Psychological safety measures team members' ability to take small risks when working with others [9]. A study by Schaubroeck et al. [10] indicated that the behavior of individuals in authority roles influenced trust, psychological safety, and team performance. Where the work of Huang et al. examined the links between psychological safety and team performance and concluded that the ability of individuals to have open modes of communication was a determinant of successful team performance [11], Edmondson identified the need for psychological safety while studying how hospital teams become learning organizations [12]. Edmondson's work developed a seven-item survey to help measure PS. The items address topics such as how we handle mistakes as a team, ask for help, discuss difficult topics, and respect each other's contributions, among other things.

Since introducing PS into the organization's behavior lexicon, numerous studies have shown the impact of PS on team performance. These studies are mentioned broadly in work by Edmondson and Lei [13], who also clarified the need for PS to enable performance, adapt to change, and help team members to speak up at work.

A recent study also used Edmondson's work in the context of engineering students' team performance. Cole et al. [14] examined the factors impacting PS in engineering teams. They found that PS was reliable across multiple engineering teams. Their work provided some places where interventions can be crafted, especially in helping students to communicate more effectively. Their work showed very few studies related to psychological safety in engineering student teams. There are more opportunities to research the current PS level in engineering teams.

In addition to psychological safety, we also looked for an assessment of teamwork satisfaction. Tseng et al. [6] studied the concept of satisfaction in teamwork. Their work found that trust among team members and organization practices helped explain teamwork satisfaction. We wanted to add additional metrics to see if there is a correlation between PS and team satisfaction or if they are addressing separate performance issues.

The present study is the starting point for a multi-year effort to understand the current state of teamwork performance in engineering student teams. We begin asking the following questions: What is the expected level of psychological safety in engineering student teams? Are there

gender gaps in the data? Are there racial/ethnic gaps in the data? At the end of the current paper, we outline the next steps in the study.

Methods

The target audience for this study is students participating in their senior capstone courses at Cal Poly Pomona, a public institution with around 5800 undergraduate engineering students. We selected students participating in the capstone course as the starting point for our study because students work together in teams for longer than one semester, so they should have plenty of experience working together to assess the team's performance. Future work will assess other populations within our programs.

We use the seven-item survey created by Edmondson [9] and the survey developed by Tseng et al. [6]. Both surveys use a 5-point Likert scale to rate agreement with each item. Edmondson [9] phrased items 1, 3, and 5 negatively, and the responses are reverse coded such that a score of 1 converts to 5, 2 into 4, and vice versa. Using positive and negative statements was intentional to ensure that participants read through each question and did not simply default to writing the same number for each item. The TS worded all the items positively, so no reverse coding is necessary with those results.

Tseng et al. [6] administered the TS survey to virtual teams. Two TS survey items focused on virtual interactions, which we omitted from our study. We retained 8 of 10 survey items that focused on teamwork satisfaction regardless of the venue.

The typical way to show results from a 5-point Likert scale is to show the values in distribution bars. Visualizing in this way is helpful for research when measuring impact but less helpful to inform decisions on actions to take based on the results. In this work, we convert the responses into a percentage to support program benchmarking and facilitate goal setting and then use that to assign a letter grade. We then convert the results from each student to a percentage by summing up all the scores given by the student and dividing by 35 (i.e., seven items x five-point scale). For example, a student who responds to the PS items with 5's to six items and 4 to one item, provides a score of 34 out of 35 possible points. As a percentage, this is computed as 0.97 or 97%.

Grades of A, B, C, D, or F are assigned on traditional break lines ($A > 90$, $90 < B < 80$, $80 < C < 70$, $70 < D < 60$, and $F < 60$). With these results, we can look at the "grade distribution" and set goals for the percentages of A & B grades (i.e. > 0.80) versus C, D, and F (< 0.80). We hope this approach might resonate with people using assessment data to inform goals for improved performance.

We use a two-tailed student t-Test to identify any significant gaps between PS reported by female and male students and between underrepresented minorities (URM) and non-underrepresented minorities (Non-URM). In each gap analysis, the null hypothesis is that the means between the two groups are similar. We use the t-Test on the Spring 22 data because of the sample size. For the Fall 22 data, we use the Wilcoxon Rank-Sum method [15] to test if the samples come from different distributions because there are fewer data collected from that term (fewer students completed their capstone course during the Fall '22 semester).

134 study participants responded to the survey (N(Sp22) = 119; N(Fa22) = 15) from across the college. This number is large enough to begin making general observations in the data, assess gender gaps, and discuss where interventions may be needed. However, the number of responses is insufficient to compare the institutions, analyze differences between different capstone sections, or assess the race/ethnicity gaps. For now, those questions are part of future work.

Results

Overall results show that most students are experiencing teams with high levels of psychological safety (>0.80). Note that the break line is arbitrary, and we need to examine this breakpoint more in our future work.

Figure 1 presents the overall survey results with the bars representing the number of students whose average response over a given instrument falls within an A, B, C, D, or F category. The results from the Teamwork Satisfaction survey show a heavy skew toward the "A" category. There is a significant minority of students who selected 5's for each item in the teamwork satisfaction survey (N = 44). The PS data, on the other hand, are less skewed and have fewer respondents who selected all 5's in the (PS) survey (N = 8).

As mentioned earlier, the (PS) survey has three negatively phrased responses that are reverse-coded. Table 1 shows the average score from each item in both surveys. If negative wording and reverse coding impacted the respondents, we should see a significantly lower response from 1, 3, and 5 than the other survey items. The t-Test analysis reveals no significant difference between the average results of items 1, 3, and 5 and items 2, 4, 6, & 7. Edmondson's [16] comments since her original paper introduced PS in 1999 also corroborate the finding that there is no significant difference between the responses of items 1, 3, 5, and 2, 4, 6, and 7 because of the wording.

Pearson R correlation values between psychological safety and team satisfaction are significantly correlated (R = 0.27 and 0.51 for the Spring 22 and Fall 22 data, respectively), given their sample sizes [17]. Figure 2 shows the comparison of these two data sets. There is more nuance in the Psychological Safety data set than in the teamwork satisfaction data. Given that they are significantly correlated, we may not continue to utilize the teamwork satisfaction data beyond this work in progress.

Table 1 shows the results of the gender gap analysis. For this analysis, the results show that there is a gender gap observed in the Psychological Safety data ($P = 0.039 < 0.05$) but no significant difference in the TS data ($P = 0.174 > 0.05$).

Discussion

Our general observation is that there are higher psychological safety levels than expected across all our senior capstone teams. 59% of respondents reported psychological safety at greater than 0.8. Based upon our anecdotal observations of working with problem teams, resolving conflict, and motivating challenging students, we thought there would be a much lower percentage of respondents who reported levels of psychological safety above 0.80.

That said, there is a large minority (41% of respondents) who we are classifying as having a difficult time (< 0.80). Part of the motivation for this study is to ensure students have positive

teamwork experiences, especially during the capstone project. The capstone project is the final dress rehearsal for professional work, and we hope students enter professional life with the skills and attitudes to work effectively in teams.

The gender gap between male (0.82) and female (0.75) psychological safety scores students is, unfortunately, not a surprise. Based on anecdotal observations and conversations with engineering students in our respective programs, we hypothesized that this might be the case.

Analysis of the race/ethnicity gap needs additional work and more data to be conclusive. There is no observed statistical difference between URM (0.79) and Non-URM (0.77) populations regarding psychological safety or teamwork satisfaction. However, students in the "unknown" category experienced the highest levels of psychological safety (0.88), which was just ahead of Non-Resident Aliens (0.85). The categories of URM and Non-URM do not include students listed in the "unknown" or "Non-Resident Alien" categories. This may not be consistent with other institutions.

Conclusion

This preliminary step helps us see that we are working on a problem that needs a solution requiring significant effort over time. It also helps us see an acceptable baseline (expected value) for PS on engineering capstone project teams. The purpose of submitting this as a work in progress is to solicit input from the broader engineering education community and identify potential partners interested in running parallel studies at other institutions. Once we enter the phase where we test the impact of specific teamwork interventions having additional partners may reveal more questions that need answering.

Future Work

We are considering several tasks as the next steps for this work. We want to help students have positive teamwork experiences. Where negative experiences arise, we want them to have tools they can use to improve their teamwork situation or not have it negatively impact the formation of their identity as professional engineers. To that end, we identify the following future tasks:

- *Expand the study to other institutions.* Some of the observations could be only applicable to local conditions. We plan to run the survey at Texas A&M University and should have some results to present during the 2023 conference. We also have a partnership with James Madison University to distribute the survey at that institution as well. Cal Poly is a medium-sized engineering program, Texas A&M has a large engineering program, and James Madison is a small general engineering program. Each institution has very different demographics, so we hope these three institutions will help provide sufficient data to build confidence in the results of the survey.
- *Expand the study to students outside of the capstone course*. For example – each campus has a freshmen-year experience course specifically for engineers. These courses could assess student teamwork experiences as they enter the university to determine the psychological safety they encountered during their high school years. Students could be bringing bad teamwork experiences with them into the university. Assessing them as freshmen may also show if their engineering programs impact PS during their time at the university.

- *Define the break line between high and low levels of psychological safety*. For practicality, we use 0.80 as the break line between high and low levels of psychological safety, but this is arbitrary. We need to follow up with students above and below this break line with interviews to flesh out the line between high and low levels of psychological safety. We may find the level of 0.80 to be too low (i.e. students who reported psych safety at 0.80 and their faculty advisors might describe their team as ineffective) or too high.
- *Compare the results across multiple institutions to determine the general data baseline, including variance.* With a larger sample from each institution, we can identify the expected data distribution and assess data from a specific program as above or below the baseline.
- *Survey faculty to identify best practices.* This survey should reveal existing practices already embedded in courses and help distinguish between teams with teamwork learning experiences and those without. Work by Daradoumis and Xhafa [18] concluded that groups working together become viable learning teams when there is a deeper level of understanding between team members. The instructor survey will show best practices to build understanding between team members as one of the interventions for improvement.
- *Support programs looking for better continuous improvement tools related to ABET Outcome 5*. Many programs seek accreditation, so it would be beneficial if there were more specific guidance on assessing teamwork within any engineering program. The future comparison between institutions will help show if there are different levels of PS for different sizes of institutions and capstone experience configurations.

Figures and Tables

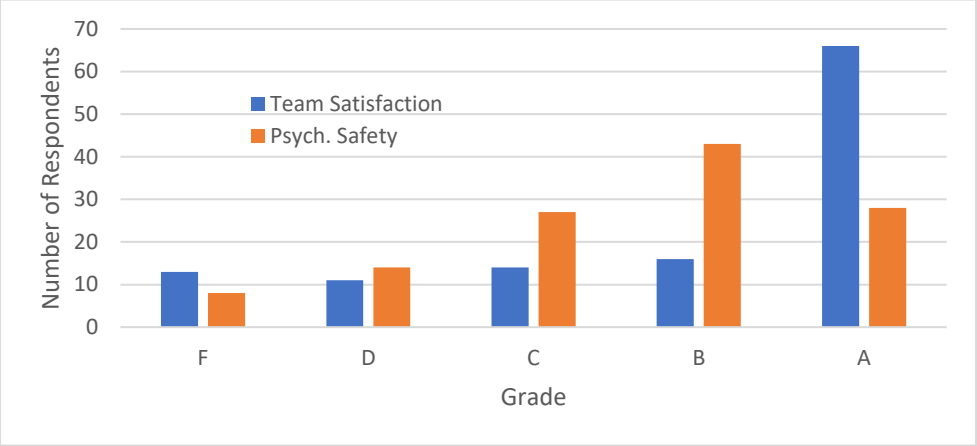

Figure 1. Bar graph showing the distribution of average scores by student.

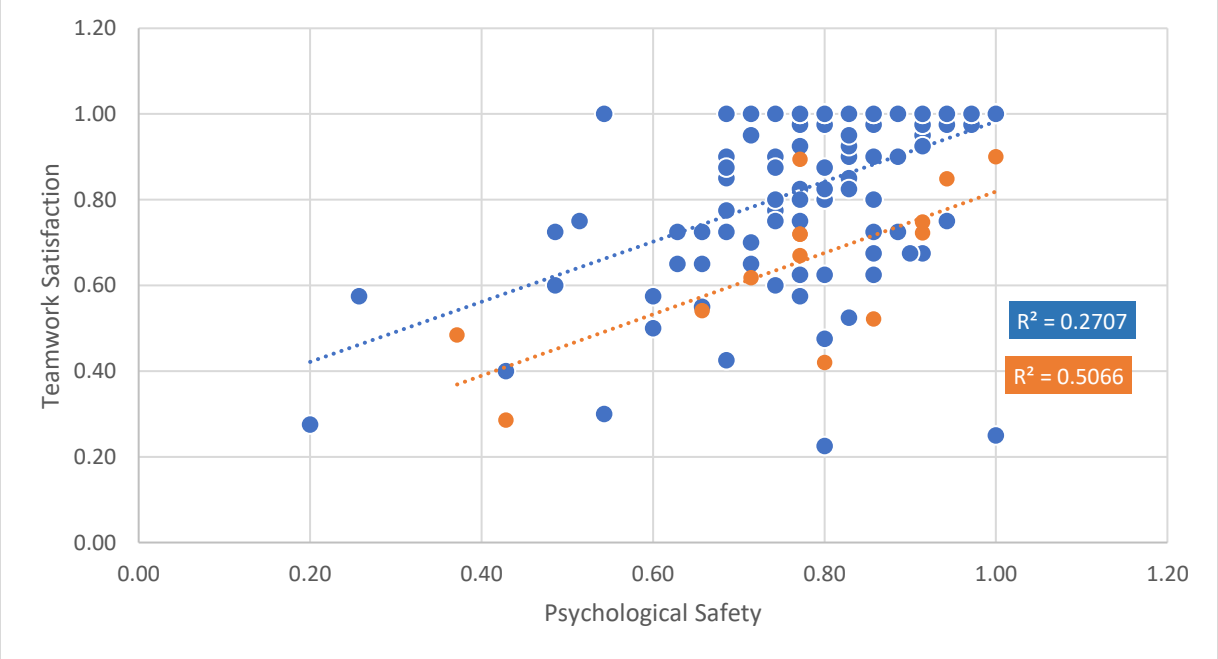

Figure 2. Correlation plots between Psychological Safety and Teamwork Satisfaction for Spring 2022 (Blue) and Fall 2022 (Orange).

Table 1. Gender Gap Analysis for Psychological Safety and Teamwork Satisfaction

	N	PS Mean	TS Mean
Male	80	0.82	0.84
Female	39	0.75	0.84
Missing	1	P	
Total	120	0.039	0.174

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Survey items

Psychological Safety Survey (Edmondson, 1999)

1. If you make a mistake on this team, it is often held against me. (R)
2. Members of this team can bring up problems and tough issues.
3. People on this team sometimes reject others for being different. (R)
4. It is safe to take a risk on this team.
5. It is difficult to ask other members of this team for help. (R)
6. No one on this team would deliberately act in a way that undermines my efforts.
7. Working with members of this team, my unique skills and talents are valued and utilized.

Teamwork Satisfaction Survey (Tseng et al., 2009). The items we omitted are 7 & 10 (in grey text).

1. I really like working in collaborative group with my teammates.
2. I like solving problems with my teammates in group projects
3. Interacting with the other members can increase my motivation to learn.
4. I benefit from interacting with my teammates.
5. I benefit from my teammates' feedback.
6. I like working in a collaborative group with my teammates.
7. Online teamwork promotes creativity.
8. Working with my team helps me produce better project quality than working individually
9. My team members share knowledge during the teamwork process.
10. I gain online collaboration skills from the teamwork process.