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THE TRAJECTORY OF PSYCHOLOGICAL SAFETY IN ENGINEERING TEAMS: A LONGITUDINAL EXPLORATION IN ENGINEERING DESIGN EDUCATION

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ABSTRACT

Although teamwork is being integrated throughout engineering education because of the perceived benefits of teams, the construct of psychological safety has been largely ignored in engineering research. This omission is unfortunate, because psychological safety reflects collective perceptions about how comfortable team members feel in sharing their perspectives and it has been found to positively impact team performance in samples outside of engineering [20]. Engineering team research has also been crippled by "snap-shot" methodologies and the resulting lack of investigation into the dynamic changes that happen within a team over course projects. This is problematic, because we do not know when, how, or what type of interventions are needed to effectively improve "t-shaped" engineering skills like teamwork, communication, and engaging successfully in a diverse team. In light of these issues, the goal of the current study was to understand how psychological safety might be measured practically and reliably in engineering student teams *over time*. In addition, we sought to identify the trajectory of psychological safety for engineering design student teams and identify the potential factors that impact the building and waning of psychological safety in these teams. This was accomplished through a 4-week study with 12 engineering design teams where data was captured at six time points. The results of this study present some of the first evidence on the reliability of psychological safety in engineering student populations. The results also help begin to answer some difficult fundamental questions on supporting team performance in engineering education.

INTRODUCTION

Engineering organizations around the world are becoming increasingly team-based [1, 2]. The motivating premise is the belief that teams are able to generate solutions to complex problems [2, 3] more effectively than individuals alone due to a team's wider range of knowledge and expertise. In other words, the "wisdom of the collective" [4](p. 39) can help a team perform above and beyond the sum of its individual members [5, 6]. This is important, because companies must continually implement new ideas in order to survive and thrive in fast-growing markets that demand continuous product innovations [7]. Because of this, engineering has increasingly been recognized and taught as a team process in engineering education [8, 9], particularly in cornerstone and capstone undergraduate design courses [10].

Despite the heavy emphasis on teamwork in engineering education, however, our understanding of how to cultivate teamwork skills in engineering remains poorly understood [11]. This is due in part to the fact that previous research on the factors impacting team performance in engineering education [12] has been limited in scope, and in part to the fact that most research conducted in this area is based on "snap-shot" ethnographic methods that do not account for the dynamic changes that happen within a team over the course of a project [13]. Specifically, while the general team literature contains extensive research on factors affecting team performance, these studies have not clearly identified *when* these factors are more or less important across an engineering team's project trajectory [14]. These studies also do not show *what to intervene with or how to intervene* to support team performance.

The study of the longitudinal trajectory of psychological safety in engineering student teams can help us begin to address these important issues. Psychological safety is "a shared belief that the team is safe for interpersonal risk taking" ([14] p. 354). In a psychologically safe climate, members are more likely to speak up and overcome fears of incompetence that accompany learning by minimizing the negative ramifications of mistakes and failure. Psychological safety has been shown to be a consistent, generalizable, and multilevel predictor of numerous outcomes important to individuals, teams, and organizations [15]. Although not studied in an engineering context, meta-analytic evidence substantiates that the relationship between psychological safety and learning, as well as performance, is strongest for complex, knowledge intensive tasks involving creativity and sense making. These are the very descriptors that characterize engineering design. However, psychological safety in engineering teams has received limited attention thus far.

Based on these factors, the goals of the current study were three-fold. First, we sought to understand how applicable and reliable the measure of psychological safety was in *engineering* student teams *over time.* Second, we sought to identify trajectories of psychological safety for engineering design student teams. Finally, we sought to identify the factors that impacted the building or waning of psychological safety in these teams. Our work contributes new fundamental knowledge regarding *what type* of interventions may be most useful in engineering education for supporting psychological safety in teams and *when* they should be introduced; it also provides some of the first evidence on the reliability of psychological safety in engineering populations.

WHY SHOULD WE CARE ABOUT PSYCHOLOGICAL SAFETY IN ENGINEERING DESIGN EDUCATION?

Psychological safety has been studied in the field of organizational science since the late 1990's, and has been identified as a predictor of numerous outcomes important to individuals, teams, and organizations [15]. As such, the construct has amassed substantial interest over the past two decades across multiple fields, including healthcare [16], manufacturing [14], geographical dispersion [17], innovation [18], and software development [19].

Although the construct of psychological safety has been largely ignored in engineering teams, there are several reasons why psychological safety is especially applicable in this setting. First, meta-analytic evidence substantiates that the relationship between psychological safety and learning, as well as performance, is strongest for *complex, knowledge intensive* tasks involving *creativity and sensemaking* [20]. This is the very essence of engineering. In addition to these factors, research has also shown that the task conflict or divergence of opinions and ideas that is so critical to engineering design success is more likely to improve team performance when psychological safety is high [21]. For example, research in psychology has shown that the development of psychological safety in teams can enable creativity by enabling individuals to speak up and suggest novel ideas (e.g., during *concept generation)*, provide critical feedback of team members' ideas (e.g., during *concept selection*), and challenge solutions throughout the design process (e.g., during *prototyping*) [22, 23]. That is, a team climate that fosters creative ideas without embarrassment harnesses the advantages of task conflict without incurring its drawbacks. This is particularly important in engineering design education, as the success of a final engineering design is largely contingent on the generation [24] and selection [25] of creative ideas during the design process and the elucidation of sound decisions during the development stages of the project [26, 27]. In addition, the team process surrounding prototyping has been shown to impact the quality of the final prototype [28].

Despite its potential applicability in the engineering context, psychological safety has regrettably been under-researched in student design teams. Responding to this research need, we examine the psychometric properties of psychological safety in undergraduate engineering design teams here. In addition, we also explore the trajectory of psychological safety across the design process, from idea generation to the final conceptual design of a student team project. Because the extant research relies heavily on cross-sectional surveys, adopting a dynamic view to understand how the construct of psychological safety is established, builds, wanes, and/or disappears completely *over time* has been identified as a key research need [15, 29]. As such, the current study begins to qualitatively investigate the factors that influence the building and waning of psychological safety.

RESEARCH OBJECTIVES

Based on the identified research needs, the following research questions (RQ) were explored in the current study:

RQ1: How applicable and reliable is psychological safety in engineering student teams over time?
RQ2: What are categories of trajectories of psychological safety in engineering design student teams?
RQ3: What factors impact the building or waning of psychological safety in an engineering design student team?

METHODOLOGY

To answer our research questions, a four-week study was conducted with two sections of a first-year engineering design course that took place over the summer term (4 weeks) at a large northeastern university. See Figure 1 for the study timeline. The remainder of this section provides details on the study design.

Participants

In total, 44 participants (35 males, 9 females) between the ages of 18 and 19 participated in the study. The participants were all enrolled in a pre-first year summer bridge program in science and engineering at Penn State.

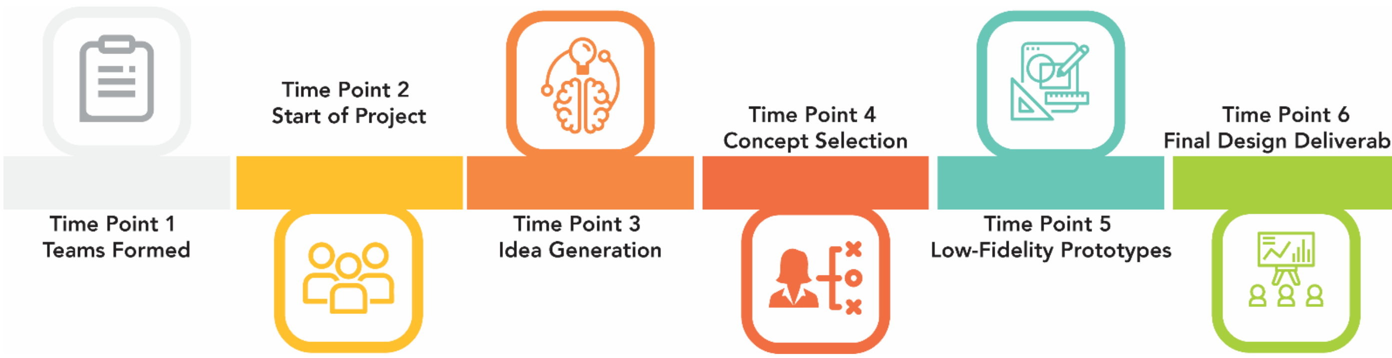


Figure 1: Timeline of study – psychological safety was captured at the end of each time point (total time period: 4 weeks)

Procedure

This study was completed within a condensed summer session of a first-year introduction to engineering design class (EDSGN 100) where students met for three hours each day (Monday-Friday). Two sections of this course were studied in the current investigation; both sections were taught by the same instructor. The study took place over six time points in weeks three to six of the summer term (see Figure 1). The participants consented at the start of the study (Time Period 1) using the Institutional Review Board guidelines set forth at the university.

During ***Time Point 1***, participants were assigned to four member teams by the research team based on previous experience (e.g. CAD modeling, design process knowledge, and communication skills), as well as cognitive style according to Kirton's Adaption-Innovation (A-I) theory [30, 31]. The impact of cognitive style will be addressed in a future publication. In all, **12 teams** were studied as part of the current investigation.

Once teams were formed, they participated in a team-building activity, where they were asked to build the best paper airplane. At the end of this three hour class period, participants completed a seven-question psychological safety survey developed by Edmondson [14], [29], which was administered electronically. Edmondson's measure assesses the extent to which team members perceive that they are able to bring up problems and tough issues, feel safe in taking risks, think that mistakes will be held against them, and find it difficult to ask other teammates for help, among other items. In addition to this Likert-scale survey, we also included several open-ended questions like, "Suggest at least one change the team could have made to improve its performance during the activity."

At ***Time Point 2,*** teams were presented with information on grand challenges, with a focus on the National Academy of Engineering (NAE) Grand Challenges and the United Nation's (UN's Sustainable Development Goals. The students were then introduced to general contextual information about designing for developing countries. Next, they were provided with the following design prompt, which they worked on over the last 4 weeks of the course:

"Across developing countries, there are a host of problems connected to food insecurity and other major agricultural challenges that impede economic and human development. Your team's challenge is to either select a food insecurity problem from the list below, or come up with your own as a team, and come up with a solution to remove or reduce the burden imposed on the world's most vulnerable populations by that specific problem."

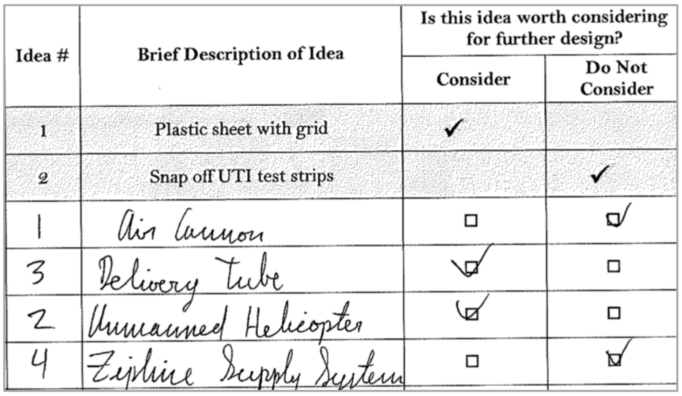
Next, the teams used the remainder of the class time to explore food security issues in developing countries. The teams then conducted in-depth context research on one specific geographic area and food insecurity issue of interest, which would serve as their area of focus for their design project. At the end of the class period, the students completed the psychological safety survey.

During ***Time Point 3***, the participants were led through a customer needs analysis, where they used the Analytical Hierarchy Process to compare the relative importance of each customer need. Next, participants were led through an innovation module that focused on the importance of creativity in engineering design. They were then guided through a series of idea generation exercises where they were asked to *individually* sketch as many ideas as possible in a 15-minute session. At the end of the class, participants completed the psychological safety survey.

During ***Time Point 4***, participants were led through a concept selection activity where they individually assessed all of the ideas generated by their design team. Participants were first provided with a stack of ideas from one of their team members and were given 20 minutes to *individually* assess all of the concepts generated by their team members by categorizing each concept as follows:

Consider: Ideas in this category were concepts that the participant felt would most likely satisfy the design goals; they were the ideas the individual would want to prototype and/ or test immediately.

Do Not Consider: Ideas in this category were concepts that the participants felt had little to no likelihood of satisfying the design goals.



Idea #	Brief Description of Idea	Is this idea worth considering for further design?	
		Consider	Do Not Consider
1	Plastic sheet with grid	✓	
2	Snap off UTI test strips		✓
1	Air Cannon	☐	✓
3	Delivery Tube	✓	☐
2	Unmanned Helicopter	✓	☐
4	Zipline Supply System	☐	✓

Figure 2: Example Individual Concept Assessment Sheet

These two categories were chosen to simulate the rapid filtering of ideas that occur in the concept selection process (see example concept assessment sheet in Figure 2). Once participants rated all the ideas from one team member, they passed the ideas to the next team member to assess. This process was repeated until all the concepts within each team were assessed. Once this rating process was complete, the students used the 6-3-5 method to generate additional ideas as a team. These ideas, in addition to the individual ideas, were then reviewed by the team, and the concepts were physically divided into "consider" and "do not consider" categories. Ideas in the consider category were then ranked by the team. Finally, the teams developed a concept scoring matrix to help them decide which ideas to prototype. At the end of the class session, participants completed the psychological safety survey.

During ***Time Point 5***, participants were led through a low-fidelity prototyping activity where the teams were asked to create low-fidelity models of their most promising ideas (see Figure 3 for example idea progression). These prototypes were shared with other teams within the class through informal presentations to gather feedback on the ideas. At the end of the class session, participants completed the psychological safety survey.

Time Point 6 represented the end of the summer semester and thus the end of the project. During this class period, the students presented their final design ideas, which included a formal PowerPoint presentation and a high-fidelity prototype that included a CAD rendering of the design (see Figure 3). At the end of the class session, participants completed the final psychological safety survey.

RESULTS AND DISCUSSION

This section highlights the results from exploring the longitudinal evolution of psychological safety for 12 first-year engineering design teams. These teams focused on a wide range of food insecurity issues in the developing world, from helping overcome extreme weather conditions in the Philippines, to overcoming a lack of suitable land for food production in Ethiopia, to developing efficient and effective food storage in Burundi. The final designs ranged from floating farms, to underground farming, to new food transportation infrastructures, depending on the problem focus area. The results are presented here with reference to our research questions. The data were all analyzed using the statistical software package SPSS v. 20.

RQ1: How applicable and reliable is psychological safety in engineering student teams over time?

The first step in answering RQ1 was to determine the general reliability of the psychological safety scale to demonstrate that the scale items are consistently measuring the same thing. To check the reliability of the scale, Cronbach's alpha (α) was computed for each of the six time points for which psychological safety was measured. Cronbach's alpha measures the internal consistency of a scale by identifying how similar two responses are to randomly selected sets of items within the scale [32]. The generally accepted standard of reliability for a given scale is a α value at or above 0.70 [33]; the closer α is to 1, the more reliable the scale is considered to be.

The results revealed that psychological safety measured at Time Point 1 resulted in an α of .61, suggesting less internal consistency for the psychological safety scale when assessed during the very first meeting of these engineering student teams. However, for Time Point 2, α equaled .70, just meeting acceptable standards. The remaining α's became even more reliable, ranging from .77 to .85 across Time Points 3-6 (see Figure 4). Because psychological safety takes time to develop, perceptions of psychological safety are not likely to be well formed during the first team meeting. Thus, when tracking

Figure 3: Design evolution of Team 5's ideas, where they designed a floating farm to combat food insecurity problems in Madagascar due to flooding and high wind from cyclones.

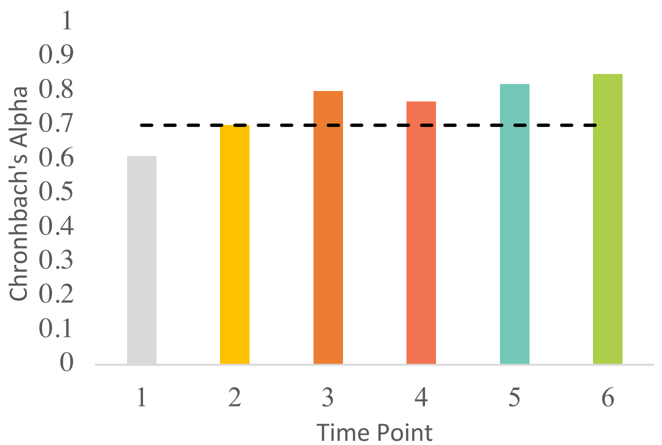


Figure 4: The internal consistency of the psychological safety scale over the six time points as measured by Cronbach's alpha. The dashed line shows the acceptable level of reliability (0.7).

psychological safety longitudinally, it is important to determine the point in team development where the construct stabilizes.

Whereas scale reliability assesses the internal consistency *among items*, it is also important to examine the consistency of scores *among team members*. Therefore, once scale reliability has been determined, the next step is to justify aggregating the scale to the team-level. This step is important because, by definition, psychological safety is a shared group property that manifests at the team level [14]. It commences as a feeling within individual team members, is augmented through interactions with others, and then emerges as a collective team phenomenon [34, 35]. As team psychological safety describes the team and not individual perceptions, it requires that individual members generally agree with each other regarding the overall level of psychological safety [14]. If there were disagreements between team members about perceptions of psychological safety, it would not be considered a shared team level construct [36]. Therefore, in order to establish psychometric integrity in gauging team psychological safety, we must justify aggregation to the team level by demonstrating interrater reliability and agreement within the team [37].

There are two main avenues to establish justification for aggregation. One commonly used measure of interrater agreement is *rwg*, which is a measure of interchangeability between ratings [37]. This index compares the variance in team member responses with the expected variance if members were to respond randomly. The variance among members would be 0 if every member were in perfect agreement, which would result in an *rwg* value of 1. The commonly accepted guideline for acceptable justification is an *rwg* value of .70 [38]. As the *rwg* represents agreement for one question, we computed *rwg*(j) to account for response agreement for all of the psychological safety scale items. Because an *rwg* value is computed for each team in the sample, the average or median *rwg*(j) values across all teams is typically reported. The mean *rwg*(j) was calculated for each Time Point; it ranged from .86 to .92 across all Time Points, indicating acceptable agreement on psychological safety level within teams. See Table 1 for each Time period mean and median *rwg*(j) value.

The second frequently reported measure to justify aggregation that captures both interrater agreement (consensus) and reliability (consistency) is intraclass correlations (ICCs). Two types of ICCs are most frequently noted, called ICC(1) and ICC(2) [38], both of which were calculated for each Time Point in this study (see Table 1). ICC(1) is a measure of relative rater consistency that indicates the amount of variance explained by team membership [37]. ICC(1)s for Times 1 and 2 suggest relatively little variability in psychological safety due to team membership (9% and 4%, respectively, which are interpreted as small effect sizes) [37]. Given that students had limited direct team interactions at Times 1 and 2, it makes sense that only a small percentage of psychological safety would be due to team membership at these points. However, at Time Point 3 and beyond, ICC(1)s reveal greater psychological safety variance due to team membership, ranging from 15% (medium effect) to 32% (large effect) [37]. These increased values reflect greater levels of team interaction, as well as confirm that psychological safety ratings take time to converge across team members.

ICC(2) captures the extent to which mean ratings can be reliably distinguished among groups [37]. ICC(2) takes team size into account to denote how reliable the team means would be based on the consensus and consistency of member ratings [38].

Table 1: Average Team Psychological Safety Descriptive Statistics and Psychometric Properties Across Time

Time	Mean	SD	α	Mean $r_{wg(j)}$	Median $r_{wg(j)}$	ICC(1)	ICC(2)
1	5.98	0.41	.61	.88	.91	.09	.29
2	6.14	0.39	.70	.92	.92	.04	.15
3	5.92	0.60	.80	.90	.94	.25	.57
4	5.96	0.56	.77	.88	.91	.15	.41
5	6.10	0.59	.82	.86	.90	.16	.43
6	6.18	0.67	.85	.89	.92	.32	.65

ICC(2) estimates of the stability of mean ratings are generally higher in magnitude than ICC(1) estimates. Similar to the pattern of ICC(1) results, ICC(2) values at Time Points 1 and 2 indicate a lower level of reliability of group mean ratings of psychological safety, with values of .29 and .15, respectively. Also comparable to the pattern of ICC(1) estimates, Time Point 3 revealed higher ratings with an ICC(2) of .57, and the highest estimate at Time Point 6 of .65. Overall, ICC (1) and (2) results indicate that interrater consistency and reliability begin with values indicating lower variance due to team membership and increase from Time Points 1 and 2 after greater team interaction.

To summarize, across the indicators of scale reliability, interrater agreement, and interrater reliability, results suggest that perceptions of psychological safety may be in an unformed or formative stage at the very start of an engineering design student team project and can be more dependably captured after sufficient team interaction. The present sample implies that this may occur at Time Point 3, when idea generation activities commenced. These findings make intuitive sense, inferring that constructs that emerge at the team level, such as psychological safety, take time to develop and reliably manifest [34]. Based on an initial team interaction, team members may not be able to judge whether they would feel safe sharing risky ideas about task-related activities with others. After several team meetings and idea generation, perceptions of psychological safety solidify.

RQ2: What are categories of trajectories of psychological safety in engineering design student teams?

After establishing the general psychometric integrity of the psychological safety scale, our focus moved to more exploratory methods that consider how psychological safety in engineering design student teams changes over time. To examine the trajectory of psychological safety within each team over the course of the six Time Points, we graphed within-team ratings of psychological safety over time for each team (see Figure 5). This allowed us to investigate whether psychological safety developed similarly across all teams or whether the trajectories varied, and what those patterns were.

The results show that psychological safety did not develop consistently across all teams. Rather, we can observe categories of trajectories. Whereas some teams appear to experience a general increase in psychological safety over time (e.g., Teams 7 and 8), others remain steady with little change (e.g., Team 6). Interestingly, nine of the 12 teams had a decline in psychological safety during idea generation (Time Point 3; e.g., Teams 9 and 12), and four teams had declines during concept selection (Time Point 4, e.g., Teams 4 and 11). Although most of these teams regained psychological safety after this decrease, a small number did not (e.g., Team 2). Time Points 3 and 4 mark the period in which task activities commence, suggesting that fluctuations in psychological safety do not arise during initial team and project introductions, but throughout more substantive discussions and decision making instead. These dips in psychological safety at Time Points 3 and 4 are particularly important in the context of engineering design, because prior research in psychology has shown that psychological safety can facilitate creativity by enabling individuals to speak up and suggest novel ideas (e.g., during *concept generation)* and provide critical feedback of team members ideas (e.g., during *concept selection*) [22, 23]. Thus, dips in psychological safety at these Time Points may have a large impact on the overall effectiveness of the team.

In addition to seeing these significant dips at Time Points 3 and 4, it is important to note that 7 of the 12 teams saw increases in psychological safety between Time Points 1 and 6 in the study, and thus were able to self-correct over the course of the project. However, four of the teams saw *decreases* in psychological safety between Time Points 1 and 6, and therefore might have benefited from some type of intervention, had it been available.

The variability in psychological safety trajectories shown in these initial findings leads to questions about why some teams are able to regain psychological safety and some are not.

RQ3: What factors impact the building or waning of psychological safety in an engineering design student team?

Our final research question sought to understand the factors that impact the building or waning of psychological safety in student engineering design teams. In order to accomplish this, the qualitative responses from the open-ended survey questions included with the psychological safety survey were examined in an exploratory attempt to discover what potential factors impact the forming or fading of psychological safety in these teams. Specifically, open coding was used identify factors reported during times of psychological safety *decline* and those reported at times of psychological safety *building* (see

Table 2).

As a first case, we present Team 8, who started with one of the highest psychological safety scores out of the twelve teams at the start of the study and had no significant dips in psychological safety over the course of the project (see Figure 5). Their survey responses indicated that they were able to "become more open and comfortable while expressing our own ideas" throughout the course of the project. They identified key communication skills that helped their team succeed, such as "everyone listens and takes ideas into account." In addition, one team member mentioned the importance of limited judgement within the team: "no one holds anyone accountable or judges anyone for bad ideas." This sentiment was mimicked by other team members. This team's responses focused on effective communication, respect for others, and openness, which may have helped their team foster the building of psychological safety over the course of the project.

In contrast, Team 9 started the design project at relatively similar levels of psychological safety to Team 8, but experienced a significant decline in psychological safety during idea generation (Time Point 3). However, they were able to regain psychological safety during concept selection (Time Point 4). When analyzing the responses of their team members at Time Point 3, several team members suggested that the team should "focus more on our work." One member specifically articulated

"We work well together, but sometimes our personality can clash if everyone is not giving full effort." This suggests that a lack of focus or effort in the team, paired with incompatible personalities, can relate to decreases in psychological safety, particularly during idea generation. However, when analyzing their responses at Time Point 4, we see that Team 9 was able to come together, or as one team member stated, "collaborate and consider each other's ideas." These comments imply that collaboration, consideration, respect for others' ideas, and expecting differing approaches contributed to the boost in psychological safety. However, this team also saw declines in psychological safety after this boost, suggesting that the effects of may be temporary without other means of intervention.

Similar to Team 9, Team 2 also experienced a decline in psychological safety during idea generation (Time Point 3). However, *this team did not recover*. Member comments from Time Point 3 included: "Get focused quicker" and "We worked relatively well, but argued a bit." Lack of focus again appeared to be a common theme contributing to a decrease in psychological safety, along with arguing. Rather than statements reflecting subsequent increases in collaboration and respect, accounts from Time Point 4 and beyond include: "We laugh at others' ideas that we find silly" and "There is some tension between certain group members." These phrases suggest disrespect for others' ideas, interpersonal tension and irritation; they also suggest that poor communication may have prevented a regain of psychological safety for this team.

As a final case, Team 10 saw increases in psychological safety between Time Points 1 and 5. However, they also saw a significant dip in psychological safety during Time Point 6; the dip was so significant, it returned the team to the initial levels of psychological safety from Time Point 1. When reviewing survey responses during Time Period 6, collaboration and time management were identified as key issues. Specifically, one team member stated their team should "stop slacking off and use their time effectively," while another stated, "we could collaborate a bit more so we're all on the same page."

Commentary from additional teams at times of psychological safety decline suggest themes of absentee members, miscommunication when laughing about an idea, and a general lack of communication. Statements reflecting increases in psychological safety include acceptance, open-mindedness, encouraging idea sharing, and sharing diverse thoughts.

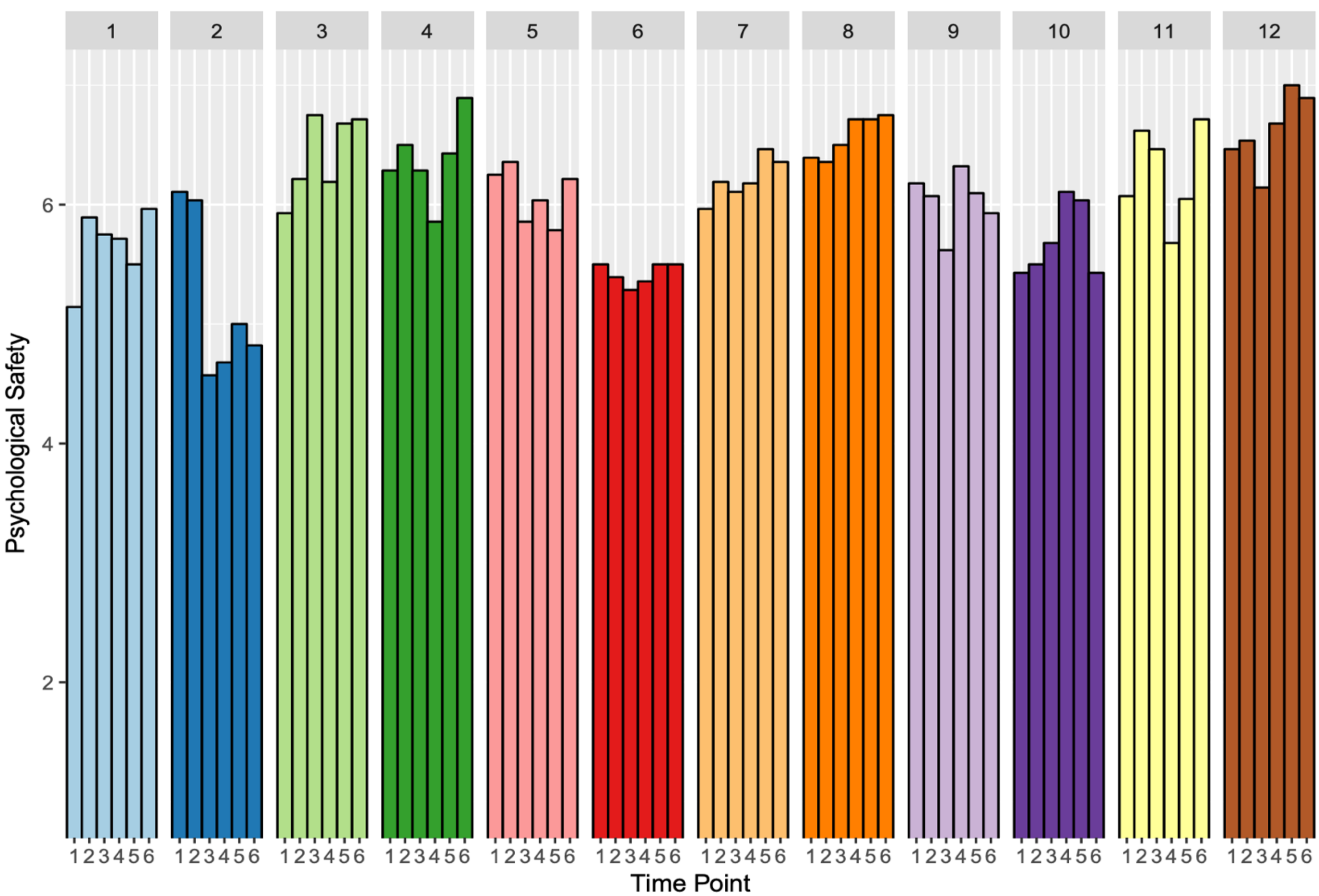


Figure 5: Psychological safety for each team over the six time periods (each color represents a different team).

Table 2: Quotations from case study teams that identify factors that impact the building and waning of psychological safety.

Team #	Time of Psychological Safety Waning	Time of Psychological Safety Building
2	"Get focused quicker" "We worked relatively well, but argued a bit" "Focus on what we are supposed to be doing instead of only thinking of solutions" "We laugh at others ideas that we find silly" "There is some tension between certain group members" "Be less controlling and listen more", "The group is starting the get a little irritated with each other since the deadline is coming up and there is a lot of stress. It is very clear there is tension between people at times"	
4	"Today someone made an interesting comment about fish farms, and it was taken very literally, which was funny and perhaps psychologically damaging." "The fish farm idea was taken quite literally and it was hilarious and fantastic" "We need to work on communication and organization"	"I think very differently than my team members. They are able to share other thoughts than I would normally have. I think it is very cool that we all bring different things to the table." "At this point, we've gotten very good at working together and I feel that our team is being extremely productive"
8		My team and I are beginning to know each other better and become more open and comfortable while expressing our own ideas. We all worked well together. We talked together to find a country and issues and asked questions when needed. Lots of brainstorming and ideas are being talked about and everyone listens and takes ideas into account. All ideas were brought fourth and deliberated equally Very open group, no one holds anyone accountable or judges anyone for bad ideas.
9	"focus more on our work" "do work sooner rather than later" "full focus" "We work well together but sometimes our personality can crash if everyone is not giving full effort"	"collaborate We all and consider each other's ideas" "my team respects every idea that someone brings up and we encourage each other to do our best" "I learned that we all approach problems differently so we have different solutions for the same problem"
10	"Stop slacking off and use your time effectively." "We could collaborate a bit more so we're all on the same page" "We need to communicate a little better." "Increase communication"	"I was encouraged by my team for my ideas and contributions" "I think me and my team work perfectly together. They are very open to help and also very open to accept new and weird ideas."
12	"We could as a whole work better on our communicating of our values."	"I learned that my team members and I can have some differing views but discussed it well together." "Our team is very inclusive and accepts each other's criticisms and encouragements."

Although this study is based on a relatively small sample, it enabled an exploration into factors that may impact the building or waning of psychological safety in engineering design student teams. Team member comments during each time point suggest that ineffective or lack of communication, deficiency of focus, disrespect for others' ideas, and interpersonal tension are likely linked to declines in team psychological safety. Teams that experienced a gain in psychological safety imply that collaboration, respect for others' ideas, and anticipating variation in opinions possibly contribute to increases in psychological safety. These results also suggest that a "one size fits all approach" to teaming interventions in engineering design education may not prove useful, as different reasons underlie teams' building or waning of psychological safety.

Overall, these findings are consistent with meta-analytic results indicating that interdependence, role clarity, and a supportive work setting are positive predictors of psychological safety [20]. Although creative design success depends, in part, on the willingness of team members to disagree with each other on ideas and opinions, this task conflict can detract from rather than facilitate team performance if teams do not have a high degree of psychological safety [21]. Task conflict can easily degenerate into more detrimental types of conflict involving tension and animosity between members if psychological safety is low.

CONCLUSIONS, LIMITATIONS, AND FUTURE WORK

The main aim of this study was to understand how applicable and reliable the measure of psychological safety was in *engineering* student teams *over time.* In addition, we sought to identify categories of psychological safety trajectories for engineering design student teams and identify potential factors that impact the building and waning of psychological safety in these teams. The main findings from this study were as follows:

1. Psychological safety takes time to develop and accurately manifest [34]. As such, when engineering design teams are first assigned, perceptions of psychological safety are in a formative state and will solidify with team interaction. Thus, when tracking psychological safety longitudinally, it is important to determine the point in team formation *when* the construct stabilizes. In our sample, this period occurred at Time Point 3, when idea generation activities had commenced, and several team interactions had transpired.
2. There were large variations in the trajectories of psychological safety in the engineering student teams studied. However, Concept Generation (Time Point 3) and Selection (Time Point 4) appear to be critical points in a team's development, as evidenced by significant dips in psychological safety for several teams.
3. These results indicate that "one time fits all" and "one size fits all" approaches to engineering student team interventions may not be fruitful. The question of *when* to intervene, as well as *how* to intervene, remain key questions.
4. Early evidence suggests that ineffective or lack of communication, deficiency of focus, disrespect for others' ideas, and interpersonal tension are likely linked to a decline in team psychological safety. On the other hand, collaboration, respect for others' ideas, and anticipating variation in opinions possibly contribute to increases in psychological safety over the course of a design project. These findings begin to help us identify *what types* of interventions may be useful in engineering design.

While this study was exploratory in nature, the results help us begin to answer some difficult fundamental questions on supporting team performance in engineering education, such as; *when* do teams need interventions to support team performance, *what* types of interventions might be successful, and *how* can we successfully intervene in these scenarios? These are complex questions, however, that the current study only begins to shed light on. Other factors contributing to team performance, such as team expertise, personality, and interaction behaviors also need to be considered.

Although the current study presents some of the first evidence on the reliability of psychological safety in engineering teams and is among the first to examine the longitudinal trajectory of psychological safety, there are several limitations that suggest directions for future work. First, the study was conducted on a small sample of twelve teams. Thus, while this paper provides evidence on the utility of psychological safety in the engineering student population, further work is needed on larger samples to validate the findings and underscore important drivers of the building or waning of psychological safety—such as the composition of the team. In addition, the study was conducted in a condensed summer course of a pre-first year engineering class. Thus, the results may only be applicable to this population. Future work will be geared toward exploring the trajectory of psychological safety on a larger scale, including a larger range of design problems, a larger range of design classes, and a larger range of design education levels. Finally, while prior work has identified the importance of psychological safety in enabling creativity and providing critical feedback [22, 23], the current study did not study the impact of psychological safety on team performance or outcomes throughout the design process. Finally, future work will also examine the role of psychological safety on engineering design team performance throughout the course of a design project. Taken together, these new investigations will lead us even closer to understanding how to support our students within team design activities in ways that encourage and expand their creative performance.

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