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CAN WE GET AN INTERVENTION, PLEASE? THE UTILITY OF TEAMING INTERVENTIONS ON ENGINEERING DESIGN STUDENT PSYCHOLOGICAL SAFETY

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ABSTRACT

Research on psychological safety has been growing in recent years due to its role in promoting creativity and innovation, among other items. This is because teams with high levels of psychological safety feel safe to express ideas and opinions. While we are becoming more aware of the importance of psychological safety in teaming, there is limited evidence in how to facilitate or build it within teams, particularly in an educational context. This paper was developed to respond to this research void by identifying the impact of teaming interventions aimed at improving psychological safety in engineering design student teams. Specifically, we studied two cohorts of students in a cornerstone design class (N = 414 students), one who received a series of video interventions and introduced role playing (intervention) and one who did not (control). These role assignments — referred to as the Lenses of Psychologically Safety - were created to promote key leadership attributes that have been shown to be crucial in facilitating psychologically safe teams. To compare the utility of the intervention, Psychological Safety was gathered at 5 key time points of a multi-week design project. The results identified three key findings. First, the interventions were successful in increasing psychological safety in engineering teams. In addition, the results indicated the utility of the Lenses of Psychological Safety throughout the design process. Finally, the results identified that groups who used these lenses had higher perceptions of Psychological Safety in their teams. Overall, these results indicated that psychological safety can be improved in engineering education through the intervention methods described within.

Keywords: design theory, design education, design theory and methodology

INTRODUCTION

"Psychological safety and courage are simply two sides of the same coin. Both are – and will continue to be – needed in a complex and uncertain world." Amy Edmondson [2].

Engineering teams often face uncertainty when making complex decisions that can impact the lives of others. One famous case is the 1986 Challenger space shuttle disaster, where lack of consensus led to the death of seven astronauts [3]. In such instances, it has been said that the lack of psychological safety can be to blame for allowing others to carry out such careless acts [4]. Engineering has become increasingly dependent on teamwork, substantiating the importance of psychological safety. Specifically, psychological safety is defined as the “shared belief that the team is safe for interpersonal risk taking” ([5], p.354). For these reasons, understanding how to foster psychological safety in an engineering context remains a crucial goal.

Psychological safety has proven to be a key influence in team-based projects across many industries [6-8]. For example, a study conducted by Google investigated the key to successful teams in a project code named “Project Aristotle” [9, 10]. What they found was surprising. They found that Psychological Safety, more than anything else, was the key to making a team successful. This is because the ability for team members to share ideas openly, express concerns, and exchange ideas can lead to an increase in innovation and learning [9]. High psychological safety in design teams has proven to impact the project outcome [11, 12].

Despite the efforts in investigating psychological safety and its role in team processes [5, 9, 10], there have been few studies aimed at fostering it in engineering teams. What we do know is that engineering design depends on creativity and problem solving [13], which is nearly impossible without a psychologically safe team, as prior work has identified a direct correlation between creative problem solving and psychological safety [14]. Furthermore, literature suggests that when pairing teams’ psychological safety with trust and innovation, the likelihood of success with a design task increases [15, 16]. In addition, research on engineering teams has shown the effects of psychological safety on team communication and performance [1]. This research provides clear evidence that innovation is much less likely to occur without a psychologically safe environment.

While we know psychological safety can impact innovation processes, how to foster psychological safety in engineering design teams is a different question that has not been thoroughly researched. One such method for fostering psychological safety is through an intervention which is meant to make improvements through multiple touch points [17]. The concept is simple; ideas that are repeated are more likely to have a longer impact on learning outcomes [18]. As such, it is no surprise that most interventions have proven to be successful [19-21]. For example, while there have been limited investigations into interventions and how to foster psychological safety in teams, there have been successes in using interventions in engineering to improve team performance and team interactions [19, 22, 23]. In addition, findings in healthcare teams suggests that interventions involving simulation, videos, and case studies can improve psychological safety by increasing participation and advocation in teams [22]. Because research has shown that team communication, conflict, trust, and leadership styles can impact the psychological safety of a team [24], interventions focused on these aspects may be useful in increasing team psychological safety [22, 25]. However, how to develop an easily deployable intervention in an educational context that has a significant effect on psychological safety has yet to be developed.

Considering this, the goal of this paper is to identify the impact of teaming interventions to improve psychological safety in engineering design student teams. This was achieved through longitudinal study of 414 engineering students in a first-year engineering design course. We compare this data to a previous cohort that received no psychological safety training. The results are used to distill the utility of the intervention methods used here and facilitate discussion of how to best foster psychological safety in engineering teams.

RELATED WORK

Prior to reviewing literature on how intervening can improve psychological safety, it is crucial to understand why psychological safety must be implemented within a design process. Studies have proven higher psychological safety to be an accurate indicator of high performance in teams [11]. However, limited research has been conducted on the effectiveness of psychological safety interventions for engineering design teams. To promote psychological safety in teams, prior work has shown that assigning individuals active roles can increase team performance [26, 27]. Using interventions, this study encourages the continuous rotation of the different role assignments.

To promote stronger team interactions and performance throughout the project, a variety of intervention methods have been developed for facilitating psychological safety. Recent studies have also focused on further understanding how role assignments affect psychological safety [28]. It has been shown that assigning roles to individuals in a team can encourage team participation [29]. This study specifically utilized video-based interventions.

This study uses interventions to further encourage the importance of role assignments. Not only must educational interventions measure an individual’s conceptual understanding, but they must also measure the student’s ability to use the concepts while problem-solving [30]. Furthermore, educational interventions on leadership roles can use design challenges or projects to help assess how effective the intervention is on the individual’s performance [31]. Research specific to engineering design has proven that shared team leadership is a necessity to the team’s success [32]. Design projects in engineering education have been successful in promoting students’ learning and problem-solving skills [33]. Design typically consists of different phases, where positive team dynamics are essential for the success of the project.

The design process begins with the design team formulation. This formulation is where the culture and norms of the team will start to form [34-36]. Rotating leadership role assignments throughout the semester has been proven to promote participation and equality, specifically among minorities within groups [37]. Working in teams and enforcing turn taking during discussions has shown to increase psychological safety levels [38]. Turn taking encourages more team discussions and diverse prospective [38]. Having an individual whose role in a group is to make sure everyone’s voice is heard can help boost participation among group members, especially those within minority groups [39]. Teams with a negative start to a project are more likely to have a lower psychological safety when compared to teams that have a strong start [35, 36, 40], further proving that turn taking is essential during the start of a design process.

After teams establish norms, students brainstorm solutions to the given problem [41, 42]. Research has shown that individuals within a team with high psychological safety will be more likely to feel safe to take risks while generating ideas [6], further promoting creativity and novelty. During idea generation, creativity is an essential part of creating innovative ideas [11]. Individuals within the group should be encouraging team building and introducing new points and ideas [43]. Having people specifically assigned to promote creativity throughout the process will allow students to share ideas freely, increasing team performance [44]. Along with creativity promoter, another important role in teamwork is someone who moderates the conversation. This individual is responsible for asking critical questions and promoting deeper discussions [43] throughout the design process. Specifically, promoting creativity by pushing the team to pick creative or risky concepts to move forward with.

After brainstorming, students should select an idea that is both creative and novel for the remainder of the project [45]. Psychological safety is particularly important during this phase because conflict may arise while team members are selecting and screening each other's ideas [46, 47]. Conflict within a team is not inherently bad. Conflict can be beneficial if psychological safety is high [1]. Research has shown that affirmation from oneself or teammates has been proven to boost creativity and project success [48]. During the selection phase, teammates are tasked with critiquing all previously generated ideas. It is important to keep a positive attitude without harming teammates feelings. For example, people who felt valued on sports teams performed better compared to individuals with no affirmation from coaches or teammates [49]. The individual with the role of giving affirmations to themselves and teammates is important throughout the entire lifespan of the project.

Following this, teams are tasked with prototyping to accurately represent their design. Prototyping allows designers to share their final ideas [50, 51], and helps the team discover any issues with their design [52]. The team will use their final selected design and create their final deliverables for the project. Team members must come together to meet project requirements and deadlines at this phase. Stress and frustration during this stage can be elevated, causing negative impacts on team psychological safety [53, 54]. Although interventions in engineering have seen little attention under a psychological safety lens, recent work aimed to improve team interactions through designating a facilitator for each team [55].

Outside of engineering, interventions focused on improving the psychological safety of teams. Specifically, one study looked at how Agile, an iterative method for improving project management [56], improved team psychological safety and improved team performance and creativity [57]. Other work in team-based classes found that while training teams was not necessarily impactful on psychological safety, the authors suggested that targeted training may help to increase it [23], although the results do not fully support this conclusion. Finally, meta-analysis of previous interventions in healthcare pointed to educational interventions using video presentations, case studies, and workshops as a means of promoting psychological safety and speaking up behaviors at various levels of effectiveness [58]. The findings of this study pointed to longitudinal interventions as a more effective means for studying an intervention and perhaps a more meaningful intervention. As these various interventions in the study helped to improve team interactions and performance overall to varying degrees, this calls for an investigation of how a role assignment-based intervention can influence psychological safety. To further encourage the importance of role assignments, this study uses interventions this study specifically utilized video-based interventions. Video-based education has been proven to be an effective method to improve student behavior [59, 60].

Overall, literature has discussed psychological safety and role assignments as separate entities, proving to be important for team-based education. The literature falls short to combine these concepts while looking at engineering design teams. To fill this gap, we strived to improve psychological safety through the use of interventions throughout the engineering design process.

THE PSYCHOLOGICAL SAFETY INTERVENTION

To improve psychological safety in engineering student teams, an intervention was developed. Specifically, the intervention was developed to include: (1) a 10-minute introduction video to psychological safety [61], and (2) 3 short (3-5 minute) primer videos of how to support psychological safety during concept generation [62], concept selection [63], and during the final stages of design [64]. This intervention focused on multiple touch points for promoting psychological safety and practicing supporting it rather than a one-and-done approach because previous research has shown that multiple-time point are beneficial for intervention success [17]. In addition, to provide students with tangible take-aways that they can use in their teams, the end of each of the four videos introduces the lenses of psychological safety and asks each team to assign a role to each team member in their team into one of four roles: turn-taking equalizer, point of view shifter, affirmation advocate, and creativity promotor. These lenses were created for this study based on previous literature as detailed next [38, 43, 48, 49].

The ***Point of View Shifter (PoVS)*** role assignment focused on making sure that team members have the chance to give different perspectives in the design process. Specifically, they were directed to ask questions such as "who has a different perspective?" or "what are we missing about this design?". This lens is important because it provides a safe environment for people to challenge design ideas or problems in a natural and constructive manner. In an educational context, these critical questions are important because they have been shown to lead to more thoughtful discussion and enhance learning [65].

The ***Creativity Promoter (CP)*** is used to ask questions that help the team continue to generate ideas and promote creativity throughout the design process. In other words, this role helps promote creativity beyond idea generation [65] and seeks to normalize the discussion and contribution of interesting and unique thoughts. As such, the Creativity Promotor is tasked with asking questions such as: "how can we build off of this idea to make it more novel?".

The ***Affirmation Advocate (AA)*** role focuses on listening to and respecting all team members' contributions. As such, the affirmation advocate is tasked with making statements like "that was a good point" or "that's a unique perspective we needed to hear". This lens is important because if a team member speaks up and are met with silence, it will reduce their likelihood of speaking up in the future. This is because previous research has shown [48]. As such, this lens plays an important role in making sure that team members are affirmed when they contribute to the team to help increase the likelihood of them participating in the future.

The ***Turn-Taking Equalizer (TTE)*** role assignment focuses on team members providing feedback on the design ideas the team has developed. When an individual is assigned this role, they are responsible for giving supportive feedback that the team needs to make optimal decisions while ensuring that everyone has a chance to participate. It is important to note that this role does not mean that everyone *speaks* equally on a team, but instead it focuses on making sure everyone is invited and encouraged to participate. People in this role are instead tasked with asking questions such as "What are your thoughts on this?". This role is important in the context of psychological safety because encouraging turn taking has shown to increase team involvement, inclusiveness, and team performance [38].

The utility of the intervention study was based on pilot work that compared the use of the lenses to non-lens students in an introduction to engineering design course [66]. This work supports the use of the lenses as a potential utility of psychological safety. However, it did not compare to a no-intervention group as such, limiting our knowledge of the effect the videos and lenses have on psychological safety.

RESEARCH OBJECTIVES

This paper was developed to identify the impact of teaming interventions for improving psychological safety in engineering design student teams. Specifically, the following research questions (RQs) were examined.

RQ1: What impact does the intervention have on team psychological safety in engineering student teams?

The first research question was developed to study the impact the intervention had on engineering design student teams' psychological safety. We hypothesized that teams who were in the intervention condition would have higher levels of psychological safety than those in the no intervention (control) condition. This was hypothesized based on prior work in education that has shown that interventions can be successful in improving psychological safety and overall team performance [23, 56, 57]. Although not studied in the context of psychological safety, interventions that use role assignments have been shown to positively impact student outcomes [28, 30].

RQ2: Do the lenses of psychological safety have different perceived utilities throughout the design process?

The second research question was developed to analyze how the perceived utility of the psychological safety lens changed throughout the design process. We hypothesized that the psychological safety lenses would be beneficial throughout the life span of the project, but that the utility of the lens would vary throughout the time points studied. Specifically, we hypothesized that the Creativity Advocate Lens would be most useful earlier in the design process when students were working on identifying the problem and developing solutions as it is the biggest focus of these stages [40, 46]. In contrast, we hypothesized that the Turn-Taking Equalizer and Point of View Sifter would be most beneficial when the team was working collectively on tasks earlier in the design process and have a need to share ideas openly rather than later in the project when teams tend to 'divide and conquer' [11]. Finally, we hypothesized that the Affirmation Advocate would be equally important through the design process because affirming team member participation is a vital component of teaming [49].

The individual with these leadership roles will have to continue to promote turn taking and continuous flow of new ideas even when students are working individually, to ensure no one is becoming a dictator during the end of the project [53, 54].

RQ3: Is there a relationship between the perceived utilities of the lenses and the psychological safety of the team?

The final research question was developed to compare individual perceptions of the utility of the lens and their perceived psychological safety at each of the design stages. We hypothesized that students who had a high perceived utility of the lenses would be statistically significant with the student's psychological safety. This hypothesis was formed based on prior work showing how leadership roles have been shown to improve team dynamic and project success [32]. Other work suggested that leadership styles have a direct correlation to psychological safety within a team [24].

MATERIALS AND METHODS

To address the research questions above, a study was performed at a northeastern university observing the first-year cornerstone design project over five semesters. The remaining details and outline of the research study will be depicted within the rest of this section.

Participants

A total of 148 students in 38 design teams from a first-year engineering design course participated in the study. The

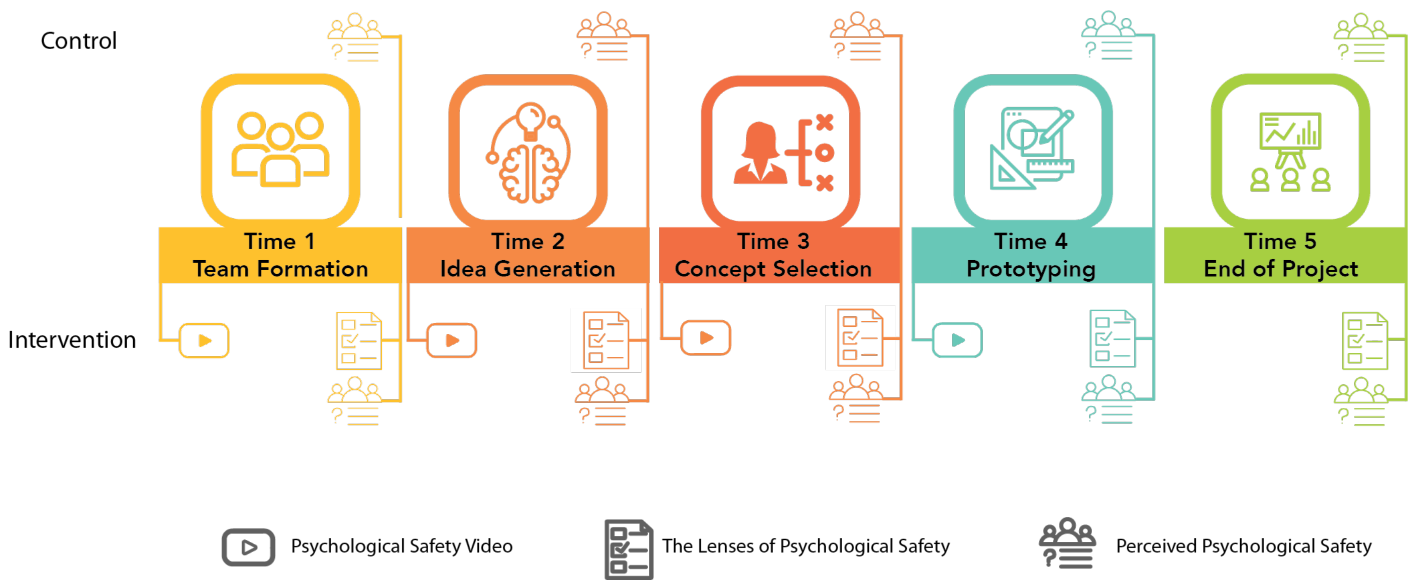


Figure 1: Study timeline of the study – the intervention condition is denoted at the bottom and the timeline for the intervention condition is denoted at the top.

demographic make-up (gender and ethnicity) can be seen in Table 1. As this study seeks to compare the effect of a psychological safety intervention, these students are compared to a previous study of the same course at the same university [1] that consisted of 69 teams with 263 students henceforth referred to as the control group, see Table 1.

Procedure

The study was completed within a semester-long session of a first-year cornerstone engineering design class where students met for two hours, three days a week. Six sections of this course with 4 instructors were studied in the current investigation. Specifically, the study took place over 5 time points during the semester [1]. Following Institutional Review Board [IRB] approval, IRB Number, the participants consented at the start of the study using the IRB guidelines set forth by the university. The same procedures were followed in the current investigation as was done in the control group [1], however the control group did not receive any form of psychological safety training or intervention. Figure 1 details the demographic similarities and differences in these two cohorts.

Table 1: Gender and ethnographic make-up of participants from the current study and the control study given interventions throughout the project.

		Intervention (this study)	Control Data [1]
Gender	Male	121	188
	Female	27	75
Ethnicity	White	102	159
	Black	7	6
	Asian	24	30
	Native American	1	2
	Multiracial	5	6
	N/A	9	1
Other	# sections	6	11
	# participants	148	263
	# teams	38	69

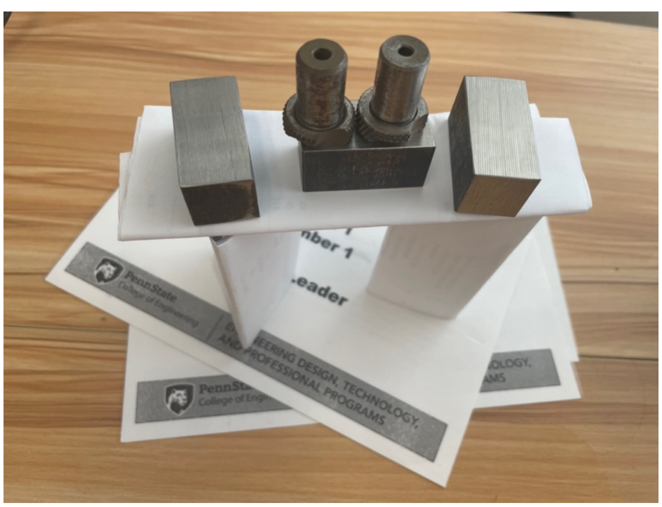
During ***Time Point 1 (TP1)***, participants were assigned to four member teams by the research team based on previous experience (e.g. CAD modeling, design process knowledge, and communication skills), as well as cognitive style according to Kirton's Adaption-Innovation (A-I) theory [67, 68]. The impact of cognitive style will be addressed in a future publication. In all, 38 teams were studied as part of the intervention group. In addition, at the start of **TP1,** individuals in the intervention group were asked to complete a pre-psychological safety self-efficacy survey, which is described in detail in the metrics section.

Next, the students were asked to work in teams to build a toll bridge using tape and paper at the start of the intervention. Specifically, they were notified that the goal of the activity was to make the most money from the toll bridge by minimizing material costs while supporting a required number of vehicles at any given time 0 where 6 inches of tape equaled one sheet of paper for cost. The teams "paid points" for paper and tape that they used to build the bridge. The total weight the bridge could hold was measured using small metal tokens. Large tokens were used to represent 2 Lincoln Navigators, small blocks represented 2 BMWs, and nuts and bolts represented 2 Honda Fits. See Figure 2 for example bridges. With 20 minutes to complete the challenge, the team that used the least amount of paper (including the paper equivalent of tape) while supporting the greatest number of vehicles and meeting the design specifications won.

Each team then received 3- or 4- role assignment cards based on the number of team members. Two of these cards represented one of the roles of the psychological safety lenses (without describing it as that). For example, the card that resembled the affirmation advocate stated “Make sure your team members feel valued and appreciated. Give them positive affirmations when they contribute ideas or successfully get part of the build done.” In addition, 1-2 team members received cards that purposely made it difficult for their team to succeed. For example, one card asked the team member to “not even bother to help your team during the challenge. Act like you have no idea what’s going on. You can just check out for a while – you deserve it. Go check out Twitter on your phone or computer. Don’t like Twitter? – how about TikTok. Not a TikTok user – Candy Crush? Nap Time? Just have some fun on your own in your own little world but still stay at your team’s table.”

Once the twenty minutes expired, the instructor led a discussion about what worked and did not work in their teams and told that the hidden goal of this challenge was not to make the best design, but rather facilitate a discussion about what makes a team successful. Following this discussion, the participants in the intervention condition were showed the 10-minute Introduction to Psychological Safety Video [61] which includes an introduction to the concept, and an introduction to the lenses. As instructed at the end of the video, the team then assigned each of the four lenses within their teams. From there, instructors explained the design challenge for the semester and the teams spent 35 minutes researching their design problem. Once the time allotted for research was complete, students took the second Psychological Safety Self-Efficacy Survey and the first Psychological Safety Survey (detailed in the next section). Students were not provided with the lenses of psychological safety survey because each team was provided different lenses during the bridge building activity.

Figure 2: Example bridge created during team building exercise during Time Point 1 (TP1). The weights represented different vehicles.



At ***Time Point 2 (TP2),*** participants were led through an innovation module that focused on the importance of creativity in engineering design. Following this discussion, the participants in the intervention condition were shown the 5-minute Psychological Safety during Concept Generation video [62] which includes an introduction to why psychological safety is important in idea generation, and how the lenses could be used to facilitate psychological safety at that time period. As instructed at the end of the video, the teams in the intervention condition assigned each of the four lenses within their teams. The teams in both conditions were guided through a series of idea generation exercises where they were asked to generate and sketch as many ideas as possible as a team. At the end of the class, participants completed the second Psychological Safety Survey and the first Lenses of Psychological Safety survey.

During ***Time Point 3 (TP3),*** participants were introduced to the importance of creativity throughout the design process, including during concept screening. Once this was discussed, the participants in the intervention condition were shown the 5-minute Psychological Safety during Concept Screening video [63] which includes an introduction to why psychological safety is important in idea screening, and how the lenses could be used to facilitate psychological safety at that time period. As instructed at the end of the video, the teams in the intervention condition then assigned each of the four lenses within their teams. The teams in both conditions were then asked to go through the ideas generated in time point 2 and screened the ideas into ‘consider’ or ‘do not consider’ piles [11, 12]. The students then chose 4 ideas to discuss in more detail. Next, the students were tasked with completing Concept Selection Matrix of these four top ideas. At the end of the session, the students took their third Psychological Safety Survey and the second Lenses of Psychological Safety Survey.

During ***Time Point 4 (TP4)***, the students in intervention condition were shown the 5-minute Psychological Safety during the Final Stages of Design video [64] which includes an introduction to why psychological safety is important in the final design stages, and how the lenses could be used to facilitate psychological safety at that time period. As instructed at the end of the video, the teams in the intervention condition then assigned each of the four lenses within their teams. The students were given a short lecture on low-fidelity prototypes and asked to create their own physical prototype based on the ideas from Time Point 3. The students were given some basic building materials such as cardboard, Legos, post-it notes and others. Once the prototypes were complete, the students went to surrounding teams for feedback on their prototypes. The students were given one last opportunity to make any changes to their prototype ideas and make a functional and higher-level prototype. Following this, the students took their fourth Psychological Safety Survey and the third Lenses of Psychological Safety Survey.

Time Point 5 (TP5) was the end of the project after the final presentation and report were collected. These final deliverables gave the teams the opportunity to explain their design process and show their high-fidelity prototypes. After these items were complete, the students completed their fifth and final Psychological Safety Survey, their third Psychological Safety Self-Efficacy survey, and their fourth Lenses of Psychological Safety survey. This concluded the design project.

Metrics

To answer our research questions, several metrics were computed. This section serves as a summary of these items.

The Lenses of Psychological Safety: At time points 2-5, each participant in the intervention completed a survey that asked them, "To what extent did your team use each of these lenses today in class (TP2-4)/ throughout the project (TP5)?". The participants were provided with the four lenses and a Likert scale from 1 (not at all) to 5 (extensively). They were also asked to denote (through an open text box) which lens they thought was most and least useful, and why.

Perceived Utility of the Lenses: Psychological

Perceived Psychological Safety: Psychological safety was captured five times at the end of TP1-TP5. Specifically, the students were provided with the 7-item scaled developed by Amy Edmondson which requires participants to provide ratings to these items on a 7-point Likert scale from '*Very Inaccurate* ' to '*Very Accurate'* [5]. Similar to previous work, the validity of team aggregations of psychological safety at each of the time points needed to be verified [27, 69]. To do this, Cronbach's alpha was calculated to confirm scale validity [32], where values for the team perceptions ranged from 0.70 to 0.82, and 0.77 for the peer evaluations at Time Point 5.

Team Psychological Safety: Psychological safety on the team level is calculated by using the individual psychological safety scores of each team member and taking the average of all participants' scores at each time point. Next, interrater agreement calculations showed an acceptable level of agreement for all the five time points, with the mean r_{wg} ranging from 0.79 to 0.93, ICC(1) ranging from 0.03 to 0.25, and ICC(2) ranging from 0.10 to 0.51 [70]. This study used LeBreton and Senter (2008) acceptability criteria [70], where the ICC(1) estimates are, for the most part, medium to large effect sizes, and the r_{wg} values indicate strong agreement.

RESULTS AND DISCUSSION

The remainder of this section displays the results of this study with reference to our research questions. SPSS v.28 was used to conduct the statistical analysis and a value of $p < .05$ was used to determine statistical significance [71]. Results are presented as Mean ± Standard Deviation unless otherwise denoted.

RQ1: What impact does the intervention have on team psychological safety in engineering student teams?

Our first research question was designed to identify the effect interventions have on psychological safety in design teams. It was hypothesized that interventions would have a positive effect on the students' psychological safety scores. This is because prior work has shown that interventions can be successful in teams [19, 22, 23]. To explore this research question, a two-way mixed ANOVA was conducted. This statistical test was chosen because the analysis considers both within subject and between subject observations. Specifically, our between-subjects factor was the intervention condition (intervention or non-intervention), and time points are the within-subjects factor. Furthermore, in this calculation, the independent variable is whether the team received a psychological safety intervention, where the dependent variables are psychological safety scores at each of the 5 time points.

Prior to running the analysis, statistical assumptions were checked. There was homogeneity of covariance, as assessed by Box's test of equality of covariance matrices (p = .440). Mauchly's test of sphericity indicated that the assumption of sphericity was violated for the two-way interaction, $\chi^2(2) = 35.67, p < .001$. Using a Greenhouse-Geisser correction, there was a significant interaction result, $F(4.374, 338.129) = 13.926$, $p < 0.001$, $\eta^2 = 0.121$.

There was no statistically significant interaction between the intervention and non-intervention groups, $F(1, 101) = 1.179$, $p = .280$, partial $\eta^2 = .012$. However, after comparing the confidence intervals between the intervention conditions and the time points at which psychological safety was collected, a difference occurred at Time Point 5. Specifically, psychological safety was higher for the intervention (M=6.387, SE=.090), 95% CI [6.208, 6.565] than the control condition (M=6.077, SE=.063), 95% CI [5.951, 6.202].

Overall, the finding showed that interventions aimed towards the psychological safety lens are not impactful when looking at the entire design project. However, when looking at each individual time point, Time Point 5 showed significant findings. The control group had a statistically significant lower

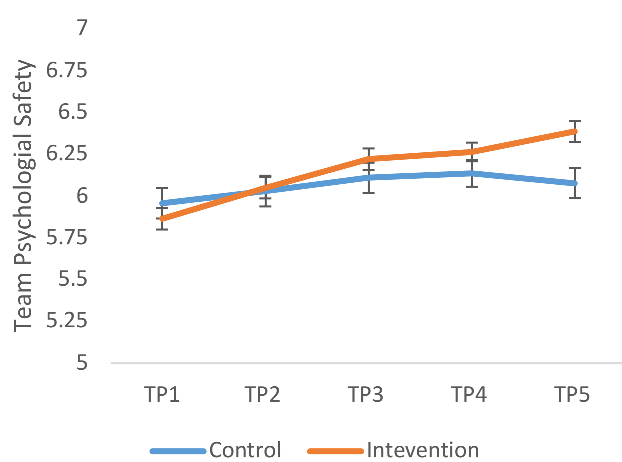


Figure 3: The Estimated Margin Means for each Time Points between control and intervention conditions

psychological safety when compared to the experimental group. These results raise the question, "Why are the psychological safety interventions taking so long to work?". When reviewing the literature, it was stated that psychological safety is a construct that takes time to foster in teams [5]. This supported that the use of interventions improved psychological safety, but the results observed here showed that it happened at a slower rate than anticipated. This information could be useful when instructors are assessing the need for interventions in a design project. The results from this research question could be used to prove that project length, along with multiple touch points, can lead to an increase in team dynamic. These results could provide insight that psychological safety interventions could be particularly useful in longer projects, such as senior capstone.

RQ2: Do the lenses of psychological safety have different perceived utilities throughout the design process?

Our second research question was designed to identify if the four psychological safety lenses have different significance throughout a design problem. Our hypothesis was that the psychological safety lenses would be beneficial throughout the life span of the project, but that the utility of the lens would vary throughout the time points studied. To answer this research question, results from the Likert Scale responses to the Lenses of Psychological Safety survey were used. Specifically, the dependent variable was the lens, and the independent variable was the time points for each of the analyses. See Figure 4 for summary of analyses. Prior to running these analyses, assumptions were checked. The remainder of this section breaks down these results for each lens.

The first repeated Measure ANOVA was conducted to determine whether there were statistically significant differences in students perceived utility of the Point of View Shifter (PoVS) over the four time points. Our hypothesis was that the PoVS lens would be most beneficial when the team was working collectively on tasks earlier in the design process when they had a large need to share ideas openly compared to later in the project when teams often 'divide and conquer' and focus more on individual work [11]. The results showed that the perceived utility of the PoVS lens was statistically significantly different across the four time points, $F(2.661, 252.772) = 8.038$, $p < .001$, partial $\eta 2 = .078$. Post hoc analysis with a Bonferroni adjustment revealed that perceived utility of PoVS lens was statistically significantly lower during Prototyping (TP4, 3.552 ± 0.127)) than during Concept Selection (TP3, 3.833 ± 0.107), mean difference M = 0.28, 95% CI [.009, 0.554], $p = .039$, as well as Idea Generation (TP2, 3.927 ± 0.094, M = 0.375, 95% CI [.022, 0.728], and also when compared to the End of the Project (TP5, 4.125 ± 0.107, M = 0.573, 95% CI [.226, 0.920]. There were no other significant differences. These results support our hypothesis that the PoVS was perceived to have the most utility earlier in the design process, and when the students reflected on the lens at the end of the project.

The second repeated measures ANOVA was conducted to determine whether there were statistically significant differences in students perceived utility of the Creativity Promotor (CP) over the four time points. We hypothesized that the Creativity Promoter Lens would be most useful earlier in the design process when students were working on identifying the problem and developing solutions because it is the biggest focus of these stages [40, 46]. The results revealed that the perceived utility of CP was statistically significantly different throughout the design process, $F(3, 282) = 24.636, p = .004$, partial $\eta^2 = 0.047$. Specifically, post-hoc analysis with a Bonferroni adjustment revealed that the students perceived utility of CP was statistically higher at the end of the project (TP5, 4.35 ± 0.796) compared to Idea Generation (TP2, 4.07 ± 0.866; $M = -.274$, 95% CI [-.543,-.005], $p = .044$), Concept Selection (TP3, 4.02 ± 1.072; $M = -.326$, 95% CI [-.635,-.018], $p = .032$), and Prototyping (TP4, 3.96 ± 1.051; $M = -.389$, 95% CI [-0.684,-.095], $p = .003$). There were no other significant findings. These results suggest that the CP lens is useful throughout the design process but is

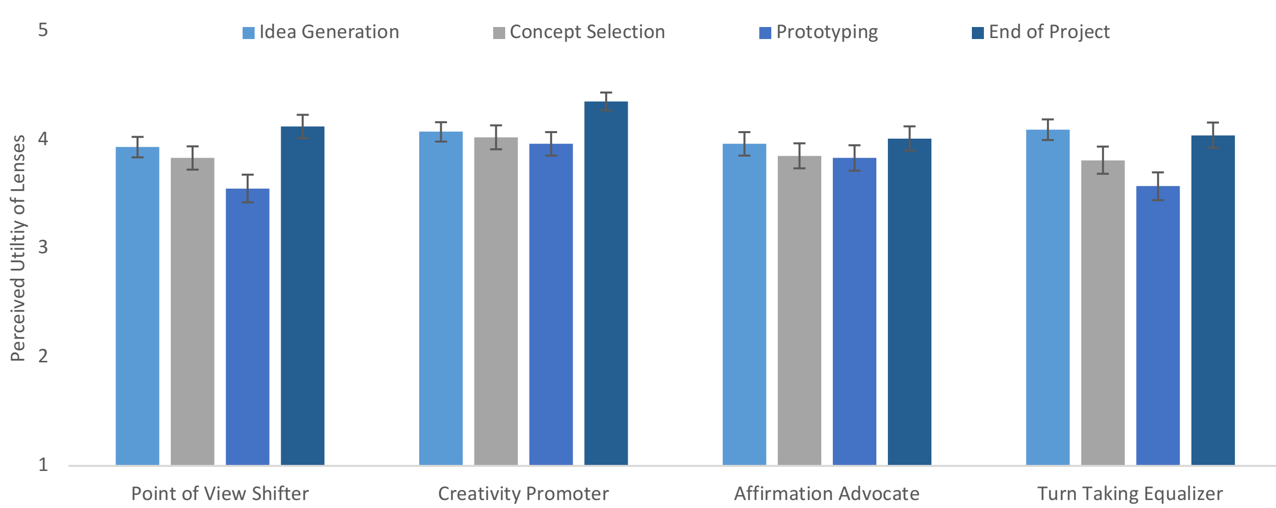


Figure 4: Comparison of the perceived utility of Psychological Safety Lens at each Time Point

most useful to students when reflecting on its utility throughout the design process (TP5).

The third repeated measures ANOVA was conducted to determine whether there were statistically significant differences in students perceived utility of the Affirmation Advocate (AA) over the four time points. We hypothesized that the AA Lens would be equally useful throughout the design process because affirming team member participation is a vital component of teaming [49]. The results of the one-way repeated measures ANOVA failed to reveal a statistically significant difference in students perceived utility of AA over the four time points, $F(3, 285) = 1.005$, $p = .391$. These results support our hypothesis that the AA lens would be equally useful throughout the design process.

The final repeated measures ANOVA was conducted to determine whether there were statistically significant differences in students' perceived utility of the Turn Taking Equalizer (TTE) over the four time points. We hypothesized that the TTE Lens would be most beneficial when the team was working collectively on tasks earlier in the design process and have a need to share ideas openly rather than later in the project when teams tend to 'divide and conquer' [11]. The results of the one-way repeated measures ANOVA indicated that there was a statistically significant difference in the students' perceived utility of the TTE lens over the four time points, $F(3, 276) = 6.192$, $p < .001$, partial $\eta^2 = 0.063$. Post hoc analysis with a Bonferroni adjustment revealed that the students perceived utility of TTE was statistically lower at during Prototyping (TP4 3.57 ± 1.237) compared to both Concept Generation (TP1, 4.09 ± 3.81; $M = .516$, 95% CI [.158,.875], $p = .001$) and at the End of the Project (TP5, 4.04 ± 1.122; $M = 0.473$, 95% CI [.117,.829], $p = .003$). These results support our hypothesis that students' perception for the TTE would be more useful when they were engaged in more group activities compared to when they are working more individually, such as during prototyping.

Overall, these results indicated that within this study, individuals perceived utility of the four lenses do, in some cases, had different utilities throughout the project. We found, that PoVS and TTE were both statistically significant at Time Point 4, while CP was statistically significant at Time Point 5. However, AA did not show any statistically significant difference across the time points. This outcome was expected. Literature showed that affirmation throughout an entire project was important for having positive outcomes and project success [48]. Furthermore, the results showed that during the prototyping stage, students felt their utility of PoVS and TTE was lower than other stages. During prototyping, individuals often work independently, so turn taking and point of view shifting was less essential. As far as lens 2, CP, findings suggested that the students felt that CP was utilized significantly more at the end of the project. These finding were interesting; creativity was essential throughout the entire design process [72]. However, students were less likely to be creative when providing their final deliverables, so promoting creativity when creativity was inherently lower increased the utility of this lens. Furthermore, the need for a leader who promoted creativity during the end of the design task would increase.

Table 2: Repeated Measures ANOVA by Lens

	Time Point 2		Time Point 3		Time Point 4		Time Point 5	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
PoVS	3.927	.094	3.833	.107	3.552	.127	4.125	.107
CP	4.074	.089	4.021	.110	3.958	.108	4.347	.082
AA	3.958	.108	3.854	.115	3.833	.117	4.010	.111
TTE	4.086	.095	3.806	.125	3.570	.128	4.043	.116

RQ3: Is there a relationship between the perceived utilities of the lenses and the psychological safety of the team?

Our final research question was developed to explore the relationship between the use frequency of the lenses with the team's computed psychological safety. Our hypothesis was that teams with a high perceived utility of the lenses will have a higher team psychological safety. Prior work suggested that leadership roles have shown to be beneficial to team dynamic and project success [32]. Also, leadership styles have shown to have a direct correlation to psychological safety [24].

To answer this question, a multiple regression model was computed run to predict Perceived Psychological Safety at each time points: Idea Generation (TP2), Concept Selection (TP3), Prototyping (TP4) and the end of the project (TP5). Prior to running the analysis, the proper assumptions were checked. The summary of these results is shown in Table 2. The remainder of this section outlines each regression model.

For Concept Generation (TP2), the multiple regression model statistically significantly predicted Perceived Psychological Safety $F(4,123) = 6.54, p < .001$, $R^2 = 17.5\%$, adjusted $R^2 = 14.9\%$, which is considered a large size effect

Table 3: Multiple Regression Analysis by Time Point

Level	*t*	*p*	*β*	*F*	*df*	*p*	**Adj.** R^2
Time Point 2				6.54	4	**<.001*** **	.149
PoVS	1.437	.153	.169				
CP	1.652	.101	.193				
AA	.198	.843	.023				
TTE	.889	.376	.103				
Time Point 3				4.275	4	**.003*** **	.103
PoVS	.762	.447	.102				
CP	1.686	.095	.208				
AA	1.122	.264	.148				
TTE	-.471	.639	-.056				
Time Point 4				2.581	4	**.041*** **	.050
PoVS	.342	.733	.045				
CP	.953	.342	.116				
AA	2.239	**.027*** **	.306				
TTE	-2.45	**.016*** **	-.330				
Time Point 5				1.662	4	.163	.020
PoVS	.487	.627	.057				
CP	.686	.494	.080				
AA	.373	.709	.044				
TTE	.951	.344	.100				

[73]. However, the four lenses did not statistically add to the model (p > 0.05). Similarly, for Concept Selection (TP3), the multiple regression model statistically significantly predicted Perceived Psychological Safety $F(4, 110) = 4.28, p = .003$, $R^2 = 13.5\%$, adjusted $R^2 = 10.3\%$. However, the four lenses did not statistically add to the model (p > 0.05).

For Prototyping (TP4), the multiple regression model statistically significantly predicted Perceived Psychological Safety $F(4, 115) = 2.58, p = .041$, $R^2 = 8.2\%$, adjusted $R^2 = 5.0\%$. Two of the variables significantly added to the model: Turn Taking Equalizer and the Affirmation Advocate, see Table 3 for a summary.

Lastly, for Final Deliverables (TP5), the multiple regression model failed to statistically significantly predict Perceived Psychological Safety, $F(4, 126) = 1.66, p = .163$, $R^2 = 5.0\%$, adjusted $R^2 = 2.0\%$. Therefore, the four lenses did not statistically add to the model (p > 0.05).

The findings displayed in Table 3 showed that at time points 2 through 4, students' perceived utility of the lenses had an impact on psychological safety at those points. In addition, these results revealed that Perceived Psychological Safety could be predicted at TP2, TP3 and TP4. Previous literature had suggested that over time, psychological safety stabilizes [1]. These results supported this theory because in the beginning of the project, the utility of the lenses can promote psychological safety until the construct is established. It was found that teams who are more psychologically safe at the beginning are more likely to end the project that way [6]. The results depicted this theory where at the end of the project, the team had already established a psychologically safe environment, proving the lenses have "done their job".

CONCLUSION, LIMIATIONS AND FUTURE WORK

This paper aimed to find the overall impact of interventions on design teams' psychological safety. To do this, we conducted a study with 414 engineering students in a first-year engineering design course. We used this data to compare to a previous semester that received no psychological safety training. The results from this study are used to identify the utility of these intervention methods and encourage further discussion on how to best promote psychological safety in engineering design teams. Specifically, the main findings from the study were:

- Teams in the intervention condition had significantly higher psychological safety than those in the control condition at the end of the project (Time Point 5).
- The perceived frequency of using the Point of View Shifter, Creativity Promoter and Turn Taking Lens varied significantly different across the four time points while the Affirmation Advocate remained constant.
- The perceived frequency by which participants felt their team used the lenses significantly predicted the perceived psychological safety at Time Points 2, 3, and 4.

These finding allowed us to make interesting inferences. Although RQ1 found that the overall success of interventions was not statistically significant, we do see a statistically significant difference of the psychological safety scores at Time Point 5. Previous studies have identified that psychological safety scores within a team will foster over time [5], allowing us to suggest that the interventions were successful, but the results were not immediate. To further support this claim, results from RQ3 showed that the students' perceived utility of the psychological safety lenses were no longer significant at the end of the project. This gives us insight that by the end of the project, the psychological safety within the team has already been established, reducing the use of the role assignment lens. We encourage future researchers to continue to explore the use of interventions and their impact on psychological safety within engineering design teams, potentially exploring how interventions can be improved to foster an improvement of psychological safety earlier in the design process. Future work may also investigate psychological safety interventions within other domains outside of engineering. This research is engineering specific, but it may be possible to use our findings and create similar interventions that would apply to different fields.

RQ2 allowed us to explore the utility of the lenses throughout the duration of the design process. The results revealed that the lenses were significant at different stages of the process. The results showed the use of AA was not significantly different across the time points, where PoVS and TTE were significantly lower at TP4 (prototyping), and CP was significantly higher at TP5 (final deliverables). Prototyping often consists of independent work, where stress and anger may be increased [53, 54]. This aligns with the findings from this study, because when stress is elevated, individuals may express their frustrations without focusing on turn taking or the shift of ideas. So, during the prototyping stage, TP4, the need for a leader to continue to ensure a safe, equal environment is essential. The increase of the perceived utility of CP at the end of the project shows the need of a leader who promotes creativity when creativity is inherently lower.

While this paper identified some interesting results on the impact of interventions throughout a design process on psychological safety, this study does have some recognizable limitations. First, the results from the experimental group and the control group were collected from different semesters, where some design teams were from a summer session, which was a shortened semester. We know that psychological safety is a construct that takes time to foster in teams [5], so project lengths can have an impact on teams psychological safety scores. Furthermore, while the control and experimental group were held in person, the control group was pre COVID10 and the experimental was post COVID19 with the additional protocols of masks and social distance. As such, the results may have varied due in part to these additional measures. Future work should seek to explore if these results hold true. Finally, this study did not account for outside variables such as gender or ethnicity break down among team members. The sample was not diverse enough to make any conclusions based on these factors. We recognize that race and ethnicity of team member has proved to have an impact on team dynamic and psychological safety [74].

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