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THE IMPACT OF GENDER ON INDIVIDUAL PERCEPTIONS AND TEAM PSYCHOLOGICAL SAFETY IN ENGINEERING DESIGN TEAMS

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ABSTRACT

Improving team interactions in engineering to model gender inclusivity has been at the forefront of many initiatives in both academia and industry. However, there has been limited evidence on the impact of gender-diverse teams on psychological safety. This is important because psychological safety has been shown to be a key facet for the development of innovative ideas, and has also been shown to be a cornerstone of effective teamwork. But how does the gender diversity of a team impact the development of psychological safety? The current study was developed to explore just this through an empirical study with 38 engineering design student teams over the course of an 8-week design project. These teams were designed to be half heterogeneous (either half-male and half-female, or majority male) or other half homogeneous (all male). We captured psychological safety at five time points between the homogenous and heterogenous teams and also explored individual dichotomous (peer-review) ratings of psychological safety at the end of the project. Results indicated that there was no difference in psychological safety between gender homogenous and heterogenous teams. However, females perceived themselves as more psychologically safe with other female team members compared to their ratings of male team members. Females also perceived themselves to be less psychologically safe with male team members compared to male ratings of female team members, indicating a discrepancy in perceptions between genders. These results point to the need to further explore the role of minoritized groups in psychological safety research and to explore how this effect presents itself (or is covered up) at the team level.

Keywords: design theory and methodology, design theory, decision making

INTRODUCTION

In recent years, understanding how to increase retention of women in engineering has been at the forefront of many academic [1-5] and industry-based [6-8] initiatives. Importantly, initiatives have spanned to including other genders as well to promote greater inclusion in the male-dominated field that is engineering [9-11]. While these initiatives are important from the perspective of perceived learning gains among diverse individuals that work together [12], how to promote safe environments for communication in gender-diverse teams remains a challenge.

To address this challenge, recent work in engineering design education has looked at increasing team effectiveness from the perspective of psychological safety [13, 14]. Importantly, psychological safety is defined as "the shared belief that the team is safe for interpersonal risk taking," ([15] p. 354). While outside of engineering, psychological safety has been validated as a consistent, generalizable, and multilevel predictor of team performance and learning [16]. To build a culture of safety, individuals engage in interpersonal interactions that develop from perceptions of one another to group-level phenomenon [17, 18]. It's important to note that these feelings of safety have been shown to grow and diminish throughout the lifespan of a team [16], pointing to impacts on group processes [19, 20]. This emphasizes the need for a dynamic view of psychological safety in teams.

While recent work has begun to examine psychological safety from a dynamic perspective in engineering design [13, 14, 21, 22], examinations of gender-based interactions in engineering design have seen limited treatment from a single time point [23]. In other instances, studies on gender and individual perceptions of psychological safety showed conflicting results, where some studies found that controlling for gender did not impact results [24, 25], but others found quite the opposite [26, 27]. Furthermore, studies in business teams focused showed that gender diversity shared a positive relationship with psychological safety [28]. Conversely, prior work in engineering design education found that team psychological safety did not vary between teams of varying gender compositions [23]. These discrepancies can be due to any number of reasons, calling to attention the need for a more detailed view of psychological safety and gender. Thus, this begs the question as to *when* in the design process that gender composition has an impact on individual perceptions and team psychological safety. For the purposes of the literature review, we use *nonmale* to refer to both female and nonmale. However, we use *female* to describe our results, as the nonmale sample was fully female.

In light of the prior work, the objective of this paper was to explore the relationship between gender and psychological safety throughout the design process. Specifically, we sought to understand this relationship at both the individual level through pairwise perceptions of psychological safety. In addition, we sought to understand this relationship at the team level through comparisons of two combinations of team gender composition over time. Furthermore, we looked at whether team gender composition contributed to improvements in psychological safety from the start of the project to the end.

RELATED LITERATURE

Although what drives gender-based differences in engineering design team interactions under a psychological safety lens remains sparse, other works provide a means for studying these factors throughout the design process. Outside of engineering, gender diversity shared a positive relationship with psychological safety in industry settings [28, 29], alluding to the importance of studying psychological safety in an engineering context. Specifically, prior work on gender interactions in teams has shown that members in single-gender teams tend to employ aggressive tactics [30], where evolutionary psychology points to males in particular for having a stronger desire to compete for status and exhibit dysfunctional behaviors that promote group hostility [31]. Conversely, mixed gender teams tend to stray away from engaging in hostile behavior [32], suggesting that such negative interactions are less likely to occur in mixed gender teams. This is problematic for achieving high psychological safety, as hostile environments can be perceived as not psychologically safe [33]. When studying team gender composition under a STEM lens, conclusions from prior work showed that while women still remain underrepresented, gender composition from the perspectives of homogeneous and heterogeneous groups showed support for enhancing group processes and performance in general [34]. Interestingly, other work in science further supports this notion, as heterogeneous gender teams tended to produce publications with higher performance (quantified by citation count) than their homogeneous counterparts [35]. However, due to the extreme underrepresentation of nonmales in engineering [36], it is less common for teams to be homogeneously nonmale. As a result, comparing homogeneously male teams to mixed gender through giving participants to identify as a gender other than cisgender would help to change the paradigm of how researchers view gender composition in STEM.

As nonmales continue to experience underrepresentation, the lack of knowledge on engineering teams is problematic. Particularly, prior work from the perspective of engineering teams showed that male dominant teams tended to engage in more clarifying and standard-setting during team interactions [37]. However, how these interactions impact psychological safety lacks emphasis in the engineering design literature. Prior work in problem-based learning in engineering education showed that some individuals may perceive members of genders different from their own to be a challenge for working in teams or may refuse to work with these individuals [38]. These interactions help to explain why nonmale engineers still face adversity, where females in a workplace setting have been judged negatively for their gender at first [39], and only until recently has there been a push to examine impacts on other genders [10]. Additionally, females in majority-female groups report feeling less anxious than when on minority teams [40], alluding to the notion that females can give other females strength in male-dominated fields such as engineering. However, even in gender-balanced groups, prior work showed that females are more likely to assume non-technical, traditional female roles that involve secretarial work, while males assume more technical roles [41], which may negatively impact how team members perceive one another and themselves due to lack of appreciation for non-technical skills [41, 42]. Other factors can build into these interactions as well, such as gender status beliefs, which have imposed burdens on minoritized genders that leave males better off [43, 44]. Although outside engineering, lower psychological safety in females in healthcare has been shown to be indicative of status issues as a result of gender [45]. Discrimination can be further compounded if an individual comes from a minoritized group, where qualitative studies have shown that being both female and multi-minority can complicate how welcome such individuals feel in engineering, especially when interacting with other non-minority individuals [46, 47]. Interestingly, both

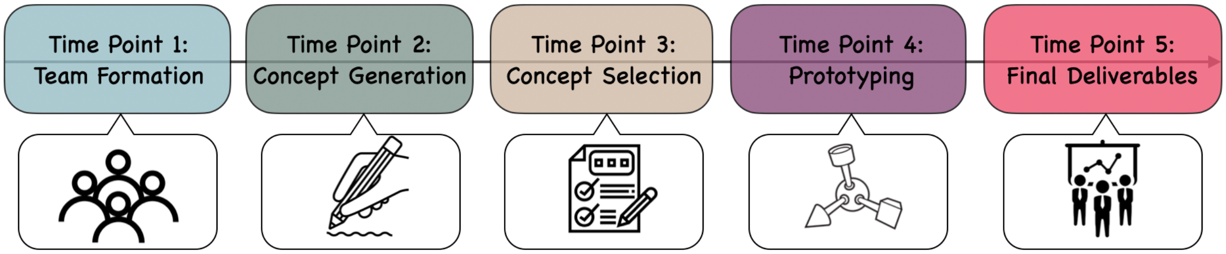

Figure 1: Study timeline – all participants took the psychological safety survey at each time point (total time period: 8 weeks).

minority and White females expressed experience with microaggressions from non-minority individuals, where the effects were especially elevated for minority women [48]. While not the focus of this paper, work with the same participants aimed to improve psychological safety through role-based assignments and video-based training from the beginning of the project [49, 50]. Importantly, prior work advocates for assigning roles and rotating roles to ensure equity among minority groups in STEM [51], whereas video-based education can be an effective method for changing individuals' behavior and how they interact with others [52, 53]. Although these studies leave out psychological safety as a component of what helps or hinders performance in these individuals, such findings point to a discrepancy in how underrepresentation of certain genders in general can lead to frustrations among these groups. Thus, these prior works emphasize the need for a better understanding of how team gender composition relates to psychological safety in the engineering design process.

In general, the engineering design process is encompassed by three main phases: generation of concepts, evaluation of concepts, and team communication [54, 55]. Prior to generation, however, teams undergo team formation, where they establish a sense of leadership, norms, and culture [56-59]. This can set the stage for the lifespan of the project, where prior work showed that ensuring team members are given an active role in decision-making and taking on tasks suitable for their abilities can affect overall team performance [60, 61]. Additionally, leaders can play a role in establishing norms, as prior work showed how higher expectations from the leader can positively impact team and individual norms for collaborative problem solving in a classroom setting [62]. However, in the engineering design team context, prior work suggested that a shared sense of project ownership and shared team leadership is necessary for project success [63]. For nonmales in engineering, this is a critical time period, as prior work in engineering suggests that females in their first year of undergraduate education may lack the confidence needed to provide contributions at the beginning of a project [37]. Although outside of engineering design, controlling for gender diversity was not found to significantly impact the positive relationship between psychological safety and collective leadership that builds over time, including the beginning of a project [64]. At the individual level, similar findings showed lack of a relationship between individual perceptions of the team's psychological safety and gender at the beginning of data collection [65, 66]. However, how long these team members were working with each other prior to the study, or which team they were in was not explicitly stated. Similarly, investigations in the engineering design context remain limited, as prior work showed only a static view of the impacts of gender [23]. Lack of clarity in how gender can influence psychological safety is problematic, as these studies fail to describe the trajectory of psychological safety over time from the individual (gender to gender) and team levels (team gender composition). Particularly in engineering design, to overcome gender-related issues such as the reluctance to contribute, it is important to identify clearly as to how psychological safety may play a role promoting team members to help individuals and teams share a similar sense of leadership and belonging from the start.

After establishing team norms, engineering design teams collectively work towards their established problem during the concept generation stage. Here, teams are tasked with developing creative solutions; a common focus in engineering design [67-71]. In prior work, teams with lower psychological safety were shown to feel unsafe for interpersonal risk-taking, causing individuals within the teams to feel reluctant to share novel ideas [72]. Similarly, feeling safe to speak up and learn from mistakes has also been shown to promote creative behavior in teams [73-75]. Interestingly, prior work in business teams found an indirect relationship between status conflict and team creativity via team psychological safety [28]. Specifically, greater gender diversity mitigated the negative effects of status conflicts that harm creative outputs, demonstrating the relevance of studying gender composition in our own engineering design teams. However, even in a mixed-gender team, females tend to require a more positive social interaction culture than males before they feel safe to engage in knowledge sharing [76]; an output of psychological safety [15, 16]. As knowledge sharing plays a role in allowing design teams to develop new concepts [77], investigating psychological safety remains a crucial first step for improving generation practices.

Following generation practices, teams screen and select ideas to move forward with pursuing [54]. Here, risk aversion is a prominent obstacle for teams to overcome when selecting creative ideas [78, 79]. Importantly, because lower psychological safety can promote greater risk aversion [15], and females are more likely to be affected by risk aversion [80], investigating how gender impacts psychological safety at this stage is important as well. From there, teams transform these concepts into prototypes of varying levels of fidelity to convey their design [81-84] and detect potential design issues [85]. Prototyping shares some similarities with concept screening as well, where prior research showed that engineering design

TABLE 1: DESCRIPTIVE STATISTICS OF INDIVIDUALS BASED ON GENDER AND RACIAL BACKGROUND

Individual Gender Count	*N*	*Individual Racial Count*	*M*
Male	121	*White*	102
Female	27	*Black*	7
Transgender Male/Female	0	*Asian*	24
Non-cisgender	0	*Native American*	1
		Multiracial	5
		Prefer Not to Say	9

Note: N represents the number of individuals that identified as a particular gender, whereas M represents the racial background of these individuals that they identified with.

TABLE 2: DESCRIPTIVE STATISTICS OF TEAMS BASED ON GENDER AND RACIAL BACKGROUND

Team Gender Composition	*N*	*Team Racial Background Composition*	*N*
0 Females	19	*0 minoritized members*	26
1 Females	11	*1 minoritized member*	11
2 Females	8	*2 minoritized members*	1
3 Females	0	*3 minoritized members*	0

Note: N represents the number of teams that have a specified number of females on their team (0 females=all male). M represents the number of teams with minoritized individuals in STEM, or individuals who do not identify as White or Asian (0 minoritized members=all White and/or Asian).

students tend to perceive more unique ideas as riskier if the fidelity is lower [86]. Consequently, psychological safety may compound the outcome of overlooking potentially successful ideas if they do not feel safe for risk-taking [15, 16]. Gender composition could further impact such outcomes due to the aforementioned risk aversion [80], substantiating the importance of studying gender's impact on psychological safety during prototyping.

After deciding on and building the final prototype, teams compile their work as a final deliverable to demonstrate how they solved their design problem. This end stage can be affected by poor communication, which can promote interpersonal tension and irritation [16], and lack of time management [13]. In the case of low psychological safety, such issues can fester if team members do not feel safe to question the status quo [15]. Particularly, prior work shows that females in an engineering team typically assume more stereotypical roles, such as the communicator or planner [44]. However, males tend to dominate more in the presence of females and control team conversations [41, 87, 88]. This can be problematic for nonmales wanting to take part in team decisions, lowering perceptions of psychological safety through making them feel less important [15]. As a result, lack of ability to coordinate and come together could be plagued by low psychological safety, emphasizing its importance even at the end of a project.

While findings from prior work provide a foundation for why gender may impact psychological safety in engineering design teams, evidence remains limited within engineering design. Therefore, this calls for an investigation of how gender from the perspectives of peer ratings and teams can impact individual perceptions of and team psychological safety, respectively.

RESEARCH OBJECTIVES

The goal of this paper was to explore the relationship between gender and psychological safety throughout the engineering design process. Specifically, the following research questions (RQ) were explored:

RQ1: How does gender impact individuals' perceptions of psychological safety with other team members? We hypothesized a team member's perception of their psychological safety with another individual whose gender does not match their own will be different from individuals who share the same gender. This hypothesis is based on prior work that has shown that females perceive biases from male counterparts in feeling negatively judged based on their gender [39] and feeling less anxious on female-majority engineering teams [40]. Furthermore, knowledge sharing, which is mediated by psychological safety [15, 16], has been shown to require more positive social interaction culture from females than males to feel safe to engage in knowledge sharing [76]. Through facing similar challenges in adversity [39], we predict that members of the same gender orientation will be more likely to feel more psychologically safe with one another.

RQ2: What is the impact of team gender composition on psychological safety over time? We hypothesized that over a trajectory of time, a team's gender composition will impact *team* psychological safety throughout the design process. Specifically, we hypothesized that mixed gender teams (gender heterogeneous) would have higher psychological safety than teams that are all male (gender homogeneous). This hypothesis is based on prior work that showed that teams of company employees with more gender-diverse teams reported higher psychological safety [28], while other work supports the notion of higher performance outputs from heterogeneous gender groups [34]. Furthermore, while prior work in engineering education shows lack of a difference between teams of varying gender composition [23], this study only analyzed psychological safety from a single point in time. As prior work shows that the trajectory of psychological safety for an engineering design team can vary over time between teams [13], this emphasizes the need to analyze how gender composition impacts the trajectory explicitly.

RQ3: Does the gender composition of a team impact psychological safety by the end of a project? Building onto RQ2, we aimed to investigate if team gender composition contributed to a difference in psychological safety from the start to the end of the project. Specifically, we hypothesized that mixed gender composition teams' (gender heterogeneous) psychological safety would differ from all male teams (gender homogeneous). This hypothesis is based on prior work that showed that psychological safety is lower when gender diversity is lower [28, 29], and that psychological safety tends to suffer even more in the presence of conflict [28]. Importantly, prior work emphasized how males in general tend to approach interpersonal problems through aggression when there is lack of agreement [30]. However, mixed gender teams tended to stray from using hostile actions and words [32], creating a climate more conducive for overcoming problems and building psychological safety [74]. Starting from the team formation stage (Time Point 1), we predicted that teams of heterogeneous team gender compositions will exhibit greater psychological safety at the end of the project (Time Point 5) than the homogeneous teams.

METHODOLOGY

To answer the research questions, an empirical study was conducted at a large northeastern university in the United States over the first project of a first-year cornerstone engineering design course over five semesters. Further study details and the experimental design are presented in the remainder of this section.

Participants

In total, 38 engineering design student teams, comprised of 148 participants (121 males and 27 females), participated in the study. All participants were enrolled in a first-year cornerstone engineering design class at a large northeastern university. Table 1 shows the breakdown of individual gender and racial backgrounds. Table 2 shows gender and racial background of teams, the where minoritized members in STEM excludes majority races such as White and Asian [47]. Importantly, all participants were given the option to identify as transgender male/female, genderqueer/non-conforming, or a different identity. However, none of the participants identified as a gender besides the cisgender categories. Therefore, our nonmale sample was fully female and is referred to as such throughout the remainder of this paper.

Procedure

This study was completed during the Fall 2021 semester with six sections of the same course. The course schedule remained consistent across all sections, where the all participants took the psychological safety survey by Edmondson [15] at each of the time points (see Figure 1). All participants consented at the beginning of the study based on the Institutional Review Board guidelines established at the university. The remainder of this section emphasizes the methodologies used to deploy the intervention.

After consent was obtained, all students completed a psychological safety knowledge self-efficacy presurvey at ***Time Point 1***. These questions focused on being able to explain psychological safety to a peer, being able to state why and when it is important, and being able to identify factors that impact psychological safety, for example. Specifically, one of the items was, "I can describe to a peer what psychological safety is." From there, 3- and 4-member teams were formed to come up with a roughly equal distribution of gender compositions within each class. Specifically, approximately half of the teams were constructed as gender heterogeneous (either half-male and half-female, or majority male), while the other half were constructed as homogeneous (all male). At the beginning of first session the teams spent together, the teams watched the first video in the series of videos on the four lenses of psychological safety. Specifically, these lenses were: Turn-Taking Equalizer, Creativity Promoter, Point of View Shifter, and Affirmation Advocate, which are presented in detail in [50]. The purpose of these roles was to encourage students to take specific viewpoints that promote stronger communication and explore the problem space. Prior to the start of working on the main project, all teams in the intervention condition worked on building a paper bridge as a team-building activity. Here, each participant in each team was assigned a role as based on the lenses of psychological safety, as described in the video. Then, instructors assigned a design challenge to each of the newly-formed teams, where teams researched the context of their design problem for approximately 35 minutes. Importantly, sections in the previous studies [13, 14] were assigned the same research task as well. Following this, all students took the first psychological safety survey.

During ***Time Point 2***, all sections were presented with the same series of lectures in [14] that led up to teams generating problem statement for their project. Importantly, sections under the intervention condition watched the second video on the psychological safety lenses, which focused on concept generation. Then, the participants sketched as many ideas as possible individually in a 15-minute concept generation session. From there, using the same roles described before, each student was assigned a role different from what they did during the first time point. Next, the participants discussed the ideas they generated in their teams and sketched additional solutions as a team. After this, all students took the second psychological safety survey.

During ***Time Point 3***, watched the third video on the psychological safety lenses, which was related to concept screening and how to use the roles to foster communication. From there, students followed a concept screening activity, where they screened the ideas from concept generation. The ideas were mixed up randomly to avoid any ordering biases, where students screened ideas as "Consider" or "Do Not Consider," similar to [13, 14]. From there, the teams discussed the ideas using the role assignments and decided on which of the four ideas they would rate in more detail. To assess these ideas, students attended a presentation on using concept selection matrices, and then applied this method to rate the ideas they selected. Finally, all students took the third psychological safety survey.

At ***Time Point 4***, students watched the fourth and final video on the psychological safety lenses. Specifically, this video focused on how to apply each role for the remainder of the project. From there, the students watched a brief presentation on low-fidelity prototypes, and were then tasked with making their own prototypes as a team while using commonly available materials (e.g., cardboard, post-it notes, etc.). After they finished the prototypes, students split from their teams while each student took one of the prototypes to share with another group for feedback. After this period, students decided on their final design for the functional prototype and worked together to make this higher fidelity prototype. After this, the students took the fourth psychological safety survey.

At ***Time Point 5***, the project ended with students presenting their final deliverables as a team and turning in the final report. Specifically, these deliverables focused students explaining their design process that led up to the high-fidelity prototype based on a computer-aided design (CAD) rendering. Then, they completed the final psychological safety survey, along with peer reviews and the same psychological safety knowledge self-efficacy survey from the beginning of the study.

METRICS

To investigate the impact of gender on teams' psychological safety, several metrics were applied, including: individual gender-to-gender peer ratings of perceived psychological safety, team psychological safety, and team gender composition. Each metric is defined in detail in the remainder of this section.

Individual Dichotomous Perceptions of Psychological Safety: At the individual level, psychological safety is a perception of the individual's view of how safe they feel the team atmosphere is for interpersonal risk-taking [15]. To uncover feelings of being safe for interpersonal risk-taking with another individual within the team, participants were asked the same psychological safety questions from Edmondson [15] with respect to each of their team members at the final time point. From there, these responses were categorized under four groups to capture dichotomous perceptions of psychological safety based on a member of a particular gender rating another individual of some gender. Specifically, males were included as the dominant gender, whereas females and other minority genders were included under the "nonmale" category. However, our sample reflected just females in this category, thus we will refer to this minoritized group as such. Using the dichotomous structure, psychological safety scores fell into one of four categories: male perceives male, male perceives female, female perceives male, and female perceives male. An example of how these perceptions were coded is shown in Figure 2.

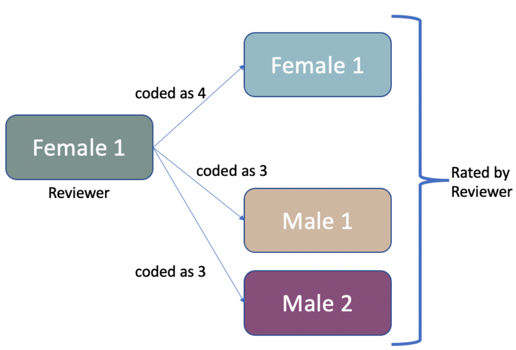

Figure 2: Example of how gender-based perceptions were coded. All individual ratings were nested within teams.

Team Psychological Safety: Psychological safety at the team level, or the team's belief of feeling safe for interpersonal risk taking [15], is computed from individual psychological safety scores of each team member and aggregated as an average at each time point. To ensure consistency across individual responses such that all team members share similar perceptions, interrater agreement must be computed [89]. The score ranges from 1 to 7 and is a continuous value, and is calculated as such:

$$team\ psychological\ safety_j = \frac{\sum_{i=1}^{K} X_{i,j}}{K} \qquad (1)$$

where $X_{i,j}$ represents the individual psychological safety score of the ith participant on team j, up to K participants on team j.

Team Gender Composition: To investigate psychological safety at the team level, a team's gender composition was either categorized as gender homogeneous (in this case, all males) or gender heterogeneous (at least one participant was female). This metric is based on how team gender composition was analyzed under two groups in prior work [34, 35] in various contexts including STEM. In an engineering context, females remain underrepresented [36], thus this viewpoint allows us to compare historically dominant all-male teams to mixed teams.

RESULTS

Thirty-eight (38) teams comprised of 148 participants (121 males and 27 females) were included in the analysis. Of these teams, 19 were homogeneous and 19 were heterogeneous in terms of their gender composition. Over all time points investigated, homogeneous and heterogeneous teams' average psychological safety scores were 6.15 (SD=0.596) and 6.17 (SD=0.522), respectively. The remainder of this section presents the results in reference to our research questions. The statistical data were analyzed via SPSS v.28. A value of $p < .05$ was used to define statistical significance [90]. Prior to the analyses, the validity of team aggregations of psychological safety at each of the time points were verified, similar to prior work [13, 14]. Specifically, Cronbach's alpha was calculated as the first step to ensure scale validity [91], where values ranged from 0.70 to 0.82 for the team perceptions, and 0.77 for the peer evaluations at Time Point 5. Then, interrater agreement calculations revealed an acceptable level of agreement at the five time points, with 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 [89]. The acceptability is based on the criteria defined in LeBreton and Senter (2008) [89], where our ICC(1) estimates are, for the most part, medium to large effect sizes, and the r_{wg} values indicate strong agreement. The remainder of this section presents the main results of this study.

RQ1: How does gender impact individuals' perceptions of psychological safety with other team members?

The objective of our first research question was to examine if a team member's perception of their psychological safety with a team member of a different gender differed from members of the same gender. To answer this research question, 361 ratings of perceived psychological safety was analyzed across the 38 teams. We hypothesized that team members' psychological safety ratings of individuals whose gender did not match their own would be different from individuals who shared the same gender. This hypothesis was based on prior work that has shown that females tend to feel negatively judged by their male counterparts based on their gender [39] and feel less anxious in female-majority engineering teams [40]. Through enduring similar challenges together [39], we also predicted that female participants would have higher levels of perceived psychologically safe with other female team members compared to male team members.

To test these hypotheses, a nested ANOVA was conducted to examine the main effects of individual gender-based perceptions, team membership, and individual gender-based perceptions nested within teams on dichotomous perceptions of psychological safety. Specifically, individual gender-based perceptions refers to when a team member of a specific gender *perceives* how psychologically safe they feel with another team member of some gender. The groups were classified into four groups with the following group sizes, unweighted marginal means, and standard deviations: male perceptions of males (n=242, M=6.50, SD=0.652), male perceptions of females (n=49, M=6.71, SD=0.441), female perceptions of males (n=55, M=6.31, SD=0.826), and female perceptions of females (n=15, M=6.84, SD=0.119), see Tables 1 and 2 for the demographic breakdown and Figure 3 for a graph of these differences.

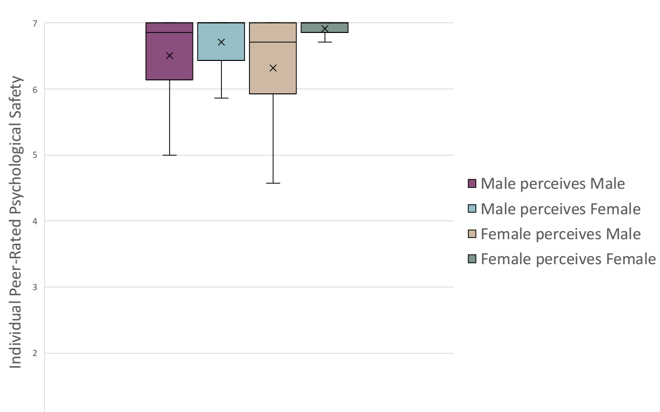

Figure 3: Average individual peer-rated psychological safety scores for each gender combination, *F*(3, 283) = 6.260, *p* < 0.001. X on the graph represents the mean for each category.

Prior to the analysis, assumptions were checked. Specifically, outliers were assessed by inspection of a boxplot, and the few outliers were transformed into less extreme values. Data was not normally distributed for each group, as assessed by the Shapiro-Wilk test ($p < .001$), and homogeneity of variances was violated, as assessed by Levene's Test of Homogeneity of Variance ($p < .001$). Because the nested ANOVA is robust to deviations from normality and homogeneity [92], the analysis proceeded as planned.

The results of the nested ANOVA showed that there was a statistically significant main effect of dichotomous individual perceptions of psychological safety, $F(3, 283) = 6.260$, $p < 0.001$, partial $\eta^2 = .062$. Additionally, there was a statistically significant main effect of the teams themselves, $F(37, 283) = 2.676$, $p < 0.001$, partial $\eta^2 = .259$. This showed that teams' psychological safety scores varied significantly in comparison to each other. However, there were no significant main effects of dichotomous individual perceptions of psychological safety nested within teams, $F(37, 283) = 1.272$, $p = .144$, partial $\eta^2 = .143$. This conveyed that team membership did not have a significant impact on dichotomous perceptions of psychological safety. All pairwise comparisons were computed with 95% confidence intervals and Bonferroni-adjusted *p*-values. The results showed that female participant perceptions of psychological safety with other female team members was higher by 0.5971 points, 95% CI [0.1434, 1.051] compared to their perceptions of a male team member ($p = .003$). Additionally, female team member perceptions of a male team member were associated with a lower psychological safety by 0.3949 points, 95% CI [-.7009, -.0890] compared to males perceived psychological safety with a female team member ($p = .004$).

These results support our hypothesis that gender would influence dichotomous individual perceptions of psychological safety. Specifically, females found themselves to feel less psychologically safe with males than they do with other females. This aligns with prior work that showed females to feel less anxious around other females in engineering [40], alluding to the idea that females tend to feel greater support when working with a minoritized gender such as themselves. Interestingly, females feel less psychologically safe with males than males feel with females, further supporting the notion that females in engineering have more intensified feelings of discomfort than males face when interacting with females. This can be attributed to the greater presence of males, as males do not face the same adversity that females would encounter [39, 41]. In fact, males' perceptions of other males compared to perceptions of females were not significantly different. This further substantiates that females are more at risk for lower perceptions of psychological safety in engineering teams. Taken together, these findings imply that to increase psychological safety within an engineering design team, placing two females on a team together can allow these individuals to empower one another to feel psychologically safe.

RQ2: What is the impact of team gender composition on psychological safety over time?

The objective of our second research question was to examine how team gender composition impacts team psychological safety over five time points in the engineering design process. Specifically, we hypothesized that mixed gender teams (gender heterogeneous), that contained at least one female, would have higher psychological safety than teams that were all male (gender homogeneous). This hypothesis was based on prior work that showed that individuals reported higher psychological safety in more gender-diverse teams [28]. Furthermore, mixed gender teams have been shown to stray away from engaging in hostile behavior [32], suggesting that the negative interactions that could break down psychological safety are less likely to occur in mixed gender teams.

To answer this question, we generated a repeated measures mixed linear model (LMM), with team gender composition and the time points in the engineering design process as fixed effects, and class section and team number as random effects using diagonal components covariance. This model was used over other simplified models to account for non-independence in the data (see [93] for full explanation), where the outcome (psychological safety) was measured more than once on the same teams split among multiple class sections. Additionally, random effects allow us to generalize the findings to other engineering design teams and classrooms using random effects, similar to prior work in engineering education [94]. Importantly, aggregations to the team level were supported by scale validity and interrater agreement values, presented in beginning of the "Results and Discussion" section.

To compute this, we first ran the full model while accounting for an interaction effect between gender composition and the time points. This analysis failed to show statistical significance, $F(4, 47.844) = .465$, $p = 0.761$, and was removed. After removing the interaction effect, results indicated that there was no significant main effect of team gender composition on team psychological safety scores, $F(1, 34.704) = .002$, $p = 0.968$, Cohen's d=0.0438. However, the main effect of the time points was statistically significant, $F(4, 48.725) = 11.174$, $p < 0.001$. Specifically, estimates of fixed effects showed that there was a significance mean difference with higher psychological safety at Time Point 5 than Time Point 1, M= 0.468, 95% CI [0.306, 0.631], $p < .001$, Cohen's d = 0.650. Similarly, there was a significance mean difference with higher psychological safety at Time Point 5 than Time Point 2, M= 0.31, 95% CI [0.164, 0.456], $p < .001$, Cohen's d = 0.308. A graph of these differences is shown in Figure 4.

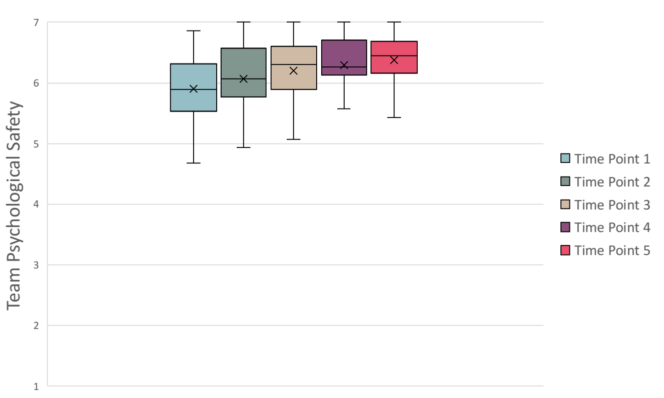

Figure 4: Average team psychological safety scores at each time point, $F(4, 48.725) = 11.174$, $p < 0.001$. X on the graph represents the mean for each category.

These results refuted our hypothesis, as team gender composition was not shown to contribute to differences in team psychological safety. While prior work suggests that interactions in mixed gender teams tend to be less hostile and aggressive than single gender teams [31, 32], where hostile environments can be perceived as not psychologically safe [33], that was not the case here. However, results did show psychological safety to be statistically significantly different over time, regardless of gender composition. Specifically, psychological safety was highest at the end of the project (Time Point 5), and was significantly higher than teams' psychological safety at the team formation (Time Point 1) and concept generation (Time Point 2) stages. While not explicitly related to gender, this indicates that teams in the earlier stages of the design process could be subject to lower psychological safety. This could impact how teams establish norms at the beginning of the project, impacting the entire lifespan of a project [56-59]. Furthermore, generation processes could be at risk as well, as lower psychological safety could impair teams' capabilities to engage in creative behavior [75-77]. However, while these differences may seem concerning, the increase in psychological safety is actually beneficial. Thus, we can assume that team members can become more psychologically safety with each other over time, and not the other way around.

RQ3: Does the gender composition of a team impact psychological safety by the end of a project?

The objective of our final research question was to investigate how team gender composition impacted psychological safety by the end of the project. Specifically, we hypothesized that teams of mixed gender composition (gender heterogeneous) would have different psychological safety scores compared to all male teams (gender homogeneous). This hypothesis was based on prior work that showed that psychological safety is lower when gender diversity is lower [28, 29]. Particularly, the link between psychological safety suffering due to unmanageable conflict [28] could be associated with negative interactions that are characteristic of certain genders. For example, prior work emphasized how in general, males on a team tend to approach interpersonal problems through aggression when there is lack of agreement [30]. However, mixed gender teams tended to stray from using hostile actions and words [32], creating a climate more conducive for managing issues and building psychological safety [74].

Table 3. Adjusted and Unadjusted Means and Variability for Psychological Safety (PS) at Time Point 5 with Time Point 1 PS as a Covariate.

		Unadjusted		*Adjusted*	
	N	*M*	*SD*	*M*	*SE*
Gender Homogeneous	19	6.46	.352	6.46	.087
Gender Heterogeneous	19	6.33	.466	6.32	.087

To answer this question, an ANCOVA was run to determine the effect of homogeneous and heterogeneous team gender compositions on team psychological safety at Time Point 5 after controlling for team psychological safety at Time Point 1. Prior to conducting the analysis, scale validity was validated for Time Points 1 (α=0.75) and 5 (α=0.70). From there, interrater agreement was also validated for Time Points 1 (ICC(1)=0.154, ICC(2)=0.38, mean r_{wg}=0.89) and 5 (ICC(1)=0.092, ICC(2)=0.268, mean r_{wg}=0.90). Unadjusted means are presented, unless otherwise stated.

The results showed that team psychological safety was greater in gender homogeneous teams (M = 6.46, SD = 0.352) compared to the gender heterogeneous teams (M = 6.33, SD = 0.466) (see Table 3, where N=number of teams, M=mean, SD=standard deviation, and SE=standard error). Of the heterogeneous teams, 11 had one female and 8 had two females. Prior to conducting the analysis, several assumptions were verified. First, we determined that there was a linear relationship between Time Point 1 and Time Point 5 team psychological safety scores for both gender homogeneous and heterogeneous groups, as assessed by visual inspection of a scatterplot. Also, there was homogeneity of regression slopes as the interaction term was not statistically significant, $F(1, 34) = .139$, $p = .711$. Standardized residuals for the gender groups were normally distributed, as assessed by Shapiro-Wilk's test ($p > .05$). Additionally, standardized residuals for the overall model were normally distributed, as assessed by Shapiro-Wilk's test ($p > .05$). There was homoscedasticity, as assessed by visual inspection of the standardized residuals plotted against the predicted values, and there was homogeneity of variances, as assessed by Levene's test of homogeneity of variance ($p = .288$). Finally, there were no outliers in the data, as assessed by no cases with standardized residuals greater than ±3 standard deviations. After adjustment for team psychological safety at Time Point 1, results failed to show a statistically significant difference in team psychological safety at Time Point 5 between the two gender composition types, $F(1, 35) = 1.206$, $p = .280$, Cohen's d = .343.

These results did not support our hypothesis, as team gender composition did not impact whether teams' psychological safety changed by the end of the project. Although prior work showed that psychological safety tends to be lower when gender diversity is low [28, 29], such differences between the teams were not apparent here. These results convey that there are factors beyond team gender composition, such as the environment (education versus industry) that can influence psychological safety by the end of a project.

DISCUSSION

The main objective of this paper was to explore the relationship between gender and psychological safety throughout the design process at the individual and team levels. The main findings of this study were as follows:

- Females perceive themselves as being less psychologically safe with males than males perceive themselves with females
- Females perceive themselves as less psychologically safe with males than they do with other females
- Team gender composition was not shown to significantly impact psychological safety over time, although psychological safety did significantly vary when comparing both Time Point 1 and 2 to 5
- Psychological safety did not change significantly under the influence of team gender composition at the end of the project

To understand the implications of these findings, we provided a discussion on each of the main analyses. Specifically, results from the first research question indicated that while constructing teams as all-male or mixed gender (one or two females) does not necessarily elicit differences in psychological safety, individual dichotomous perceptions of psychological safety were significantly impacted by gender. The finding that females had lower perceptions of psychological safety complements prior work that found that females felt less anxious when teams consisted of more females than males [40]. Furthermore, females perceived their psychological safety to be lower with males than males did with females. This conveys a heightened sense of discomfort for females when interacting with males. In contrast, males do not perceive the same level of discomfort when interacting with females, remaining unaffected by the presence of females. Possible causes suggest that gender status beliefs, which can promote issues for minoritized genders in engineering that do not impact males [43, 44], may be at play. Importantly, such differences in dichotomous interactions raise concerns for interactions at the team level. Individual interactions could transpire as negative interactions that impact the entire team and harm performance due to perceptions between two individuals. While outside of engineering, meta-analysis showed that females tend to have lower perceptions of psychological safety that impair their ability to contribute as much as their male counterparts in teams [45]. Such findings leave implications for engineering design teams, where hesitation in contributing ideas can limit the creativity of design outputs [75-77]. In addition to sharing fewer ideas, lower psychological safety can decrease feeling safe interpersonal risk-taking [72]. Particularly, risk-averse individuals are more against selecting ideas perceived as risky, or "too creative" [78, 79], where risk aversion already tends to be greater in females [80]. As a result, findings at the individual level indicate a need to improve females' psychological safety in predominantly male teams.

In contrast with findings at the individual level, team level analyses for the second research question did not indicate differences in psychological safety due team gender composition. While prior work showed that greater gender diversity was associated with higher psychological safety [28], our findings aligned with prior work that found no significant relationship [24, 25]. This could be due to the fact that other factors may be at play, such as team characteristics (e.g., personality), team leadership, and problem-solving efficacy [16]. Similarly for the third research question, psychological safety was not found to change significantly by the end of the project as a result of team gender composition. While not analyzed longitudinally, our findings align with prior work in engineering design [23]. Furthermore, while not a direct result of team gender composition, psychological safety was statistically significantly higher at the end of the project in comparison to both the team formation and concept generation stages. From the perspective of design outputs, our findings hint at other factors beyond gender that could impact teams' productivity and abilities to work together.

CONCLUSION, LIMITATIONS, AND FUTURE WORK

The main goal of this paper was to investigate the impact of gender on psychological safety at the individual and team levels. To achieve this goal, we investigated the psychological safety of 19 all-male teams and 19 mixed-gender teams over five distinct time points. The main findings from this study indicated that while a team's gender composition did not have a significant impact on psychological safety, individual dichotomous perceptions of psychological safety were significant. Specifically, females' perceptions of psychological safety with other females were significantly higher than their perceptions with males. Similarly, females had a significantly lower perception of psychological safety with males than males had with females.

While this paper presents results to broaden our view of gender on team interactions in engineering design, this paper does not come without limitations. First, we analyzed gender as two categories for the sake of comparing homogeneous gender composition to heterogeneous gender composition. While dividing the heterogeneous teams into "majority male" and "half male" would have been advantageous for more detailed differences in team gender composition, the given sample size made this impractical. The equal split between homogeneous (N=19) and heterogeneous (N=19) teams was determined to be more statistically sound than breaking up the heterogeneous group into smaller sample sizes for half-male (N=8) and majority male (N=11). Interestingly, prior work pointed to differences between equally split and gender dominant teams, where psychological safety was slightly higher in teams with an equal split [28]. However, these findings were crowdsourced using a scripted team interaction, and not an actual longitudinal team project. Hence, conclusions on team gender composition should be interpreted conservatively until more data is collected.

In addition to difficulties with analyzing teams of a heterogeneous gender composition at a more detailed level, this study cannot be generalized to genders beyond cisgender. Although we gave participants in this study the option to identify as a gender beyond the conventional "male or female" choices that most studies in engineering design use, none of our participants identified as such. To push for a change in the paradigm of how researchers study gender in engineering education [9, 10], we included these options to allow participants of different genders to feel included. Even in a fully cisgender sample, we encourage future work to include more inclusive options when surveying gender demographics.

Future work is also needed that explores these effects in marginalized racial groups. While we collected racial background data, we were not able to analyze it as a variable of interest it due to the extremely low sample size of minoritized races in STEM and at the university being studied. As members of a minoritized race tend to experience microaggressions when interacting with majority race members in STEM [47], future work should investigate how team composition from this perspective impacts psychological safety. Furthermore, work should investigate effects on females of a minoritized race as well, as these individuals tend to experience even more difficulties than majority race females [48].

Aside from limitations with generalizing results to specific demographic backgrounds, reasons behind the lower perceptions of psychological safety for females with males remain limited. Regardless, findings present important implications for studying psychological safety in engineering teams. Particularly, as males remain the dominant gender in engineering [36], constructing female-dominant teams for the sake of making females feel more psychologically safe may not be a feasible solution. As first-year females may lack the confidence needed to provide contributions early on [37], our findings contribute to the knowledge on gender-based issues in engineering design teams in education. Such findings show that problems still exist, and more work is needed to create psychologically safe environments for all individuals. Furthermore, while not the focus of this paper, the participants in this study were under an intervention condition that focused on role assignments [49]. While this intervention could have had impacts on communication patterns similar to anti-bias training, we would anticipate there to be little impact on psychological safety in combination with team gender composition. Thus, we suggest future work to focus on intervention methods that focus on increasing nonmale members' intentions to participate in all design sessions. Finally, while this paper did not focus on increases in team psychological safety at each of the time points alone, the differences between the team formation and ideation sessions with the end of the project point to directions for future work. As psychological safety can impact these design sessions [14, 21], investigating performance outputs from a gender lens could yield interesting implications for how these variables are related.

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