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DEPARTMENT OF INDUSTRIAL AND MANUFACTURING ENGINEERING

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

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ABSTRACT

Psychological safety is the perception of individuals and how likely they are to share their ideas without feeling uncomfortable to take risks or vulnerable to criticism. While prior research has indicated that psychological safety is positively related to team performance and outcomes, research related to psychological safety in engineering teams has been less established. There is also a lack of comprehensive methodologies that capture the dynamic changes that occur throughout the design process. This is problematic, because without this knowledge we cannot begin to answer the questions of *what* types of interventions may be useful for bolstering psychological safety in engineering teams, *how* these interventions might be delivered, or *when* these interventions would be most useful. In order to provide results to contribute to answering these questions, a study was conducted with 263 engineering students in 68 teams in a first-year engineering design class. The trajectory of psychological safety was captured for each team over five time points in the engineering design process. This data was used to first identify how reliable and applicable the measure of psychological safety is for the longitudinal tracking of engineering design student teams as well as identifying factors that contribute to the building or waning of psychological safety in engineering student teams. The results of this thesis provide some of the first evidence on the reliability of psychological safety in engineering teams and offer insights as to how to support and improve team performance.

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When I was a sophomore thinking about applying for Schreyer Honors College, I hesitated because I had no dare to promise that I was capable of finishing a thesis. However, here I am, about to graduate with honors, and become a first author to a thesis. There is no way that I could do this alone. With many appreciations, I would like to say thank you to all of the people who have supported me throughout the journey.

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Chapter 1 : Introduction

Engineering organizations around the globe are increasingly relying on team-based activities[1, 2] due to the fact that teams are more likely to solve complex problems over individuals alone [2, 3]. This increase in performance has been attributed to the wide range of knowledge, experience, and expertise present in a team[3]. In other words, the "wisdom of the collective" [4] (p.39) is often better than the output of the sum of the individual team members [5, 6]. In an engineering context, this improvement is essential because companies need to produce market-breaking innovations in order to survive and thrive in the fast-paced market that demands innovations[7]. Because of this demand from engineering industry, engineering education has also recognized and incorporated team processes into the engineering classroom [8, 9]especially through cornerstone (first-year) and capstone (final year) undergraduate design courses [10].

While there has been a rise in the integration of teamwork in engineering education, the understanding of how to cultivate teamwork skills in the classroom is not yet well understood [11]. For example, even though there is a rise in literature focusing on factors that could affect psychological safety, the relative importance remains undiscovered [12]. In order to have a better understanding of team performance, there should be more information on the dynamic assembly of teams, however, is also lacking in current literature [13]. Moreover, there is also little study on *what, how, when* to successfully intervene in team activities for better team performance.

The study of the longitudinal trajectory of psychological safety in an engineering context can begin to answer some of the key questions relating to supporting psychological safety in the engineering classroom. Psychological safety is "a shared belief that the team is safe for interpersonal risk taking" ([14]p.354). When people feel psychologically safe, they are more likely to speak up about their own opinion without fearing the ramification of failure, which would allow them to learn and contribute more efficiently in this rapidly changing world [15]. Psychological safety as an influential predictor has shown its consistency and generalizability when measuring outcomes from individuals, teams, and groups [15].

Prior research has conducted meta-analysis, though not in an engineering context, and substantiated the relationship between psychological safety and performance [14]. Especially when having complex, knowledge-intensive, and innovative tasks, the relationship becomes the strongest. These are the traits that characterize the tasks in engineering design. However, there is limited research on psychological safety in an engineering context so far.

1.1 Research Objectives

The purpose of this thesis was two-fold. First, it sought to understand the longitudinal reliability of the psychological safety construct in engineering student teams. Second, it sought to explore the factors that impact the building or waning of psychological safety in engineering design student teams. The results of this thesis provides a better understanding of *what* kind of intervention might lead to better team performance, *how* to successfully intervene, and *when* is a better time to intervene. The work also provides some of the first evidence of the reliability of psychological safety in an engineering context.

1.2 Thesis Overview

This thesis discusses the reliability and applicability of psychological safety in engineering teams and investigates factors that may affect the climate of psychological safety. This thesis is outlined as follows: Chapter 2 discusses the literature review about the background and prior studies on psychological safety, Chapter 3 details the methodology that used to conduct the study, Chapter 4 presents the results of the study along with discussions about reflections of the results, and Chapter 5 discusses the conclusion to the discussion and suggests potential directions for future work.

Chapter 2 : Literature Review

Psychological safety has been defined as "a shared belief that the team is safe for interpersonal risk taking" ([14] p. 354). The construct of psychological safety first came to focus in organizational research in the 1990s and it has since been identified as a pivotal factor of teamwork, team learning, voice, and organizational learning [15]. The concept can be analyzed at the individual, group, and organizational level [15], making it applicable in a variety of industries such as healthcare [16], manufacturing [14], geographical dispersion [17], innovation [18], and software development [19].

While psychological safety has not yet been studied to a large extent in engineering design, it has been found to have multiple benefits in prior research that support its potential utility in engineering design education. The major theme of psychological safety is that it facilitates the contribution of ideas and thus stimulates the team performance [15]. Specifically, meta-analytic evidence has demonstrated that the relationship between psychological safety and learning, as well as performance is the strongest, especially when having complex, knowledge-intensive tasks that involve creativity and sense-making [20]. Some of the cause-and-effect could be explained by the fact that a higher level of psychological safety has the potential to increase creativity by allowing people to express their opinions a dignified and respectful manner [21]. As creativity becomes one of the essential factors in engineering design, it is worth noticing the relationship between creativity and psychological safety. Studies also suggest that by making use of the development of psychological safety could enable creativity by encouraging speaking up novel ideas (e.g. during idea generation), providing feedback to other members (e.g. during idea selection), and challenging solutions throughout the process (e.g. during prototyping) [22, 23]. Additionally, task conflict has been demonstrated to have a relationship towards team performance [24] by having team members that are less likely to agree on tasks easily, thus aspiring creativity and promoting team performance [14]. Meanwhile, research has also indicated that the task conflict is critical to engineering design success, and it is more likely to improve the team performance when the psychological safety is high [24].

In engineering design, the generation [25] and selection [26] of ideas are contingent on the success of the final design as prior research suggests that creativity and the likelihood of people speaking up could play an important role during design process. These could also have impact on the elucidation of sound decisions during the development stages of the project which are also related to the success of the final design [27, 28]. Based on the fact that creativity and the environment can allow people to share ideas without feeling vulnerable, these are important factors that could lead to success in engineering design, therefore psychological safety should be studied and researched in a more comprehensive way.

As earlier research indicates, psychological safety results from the level of security within an environment that individuals participate in. This implies that psychological safety could be subject to several factors [29]. Interpersonal relationships, group dynamic, leadership, and organizational norms are the four factors that have been identified in a broad way, contributing to the antecedent of psychological safety [30]. There are specific team behaviors or learning behaviors that could positively relate to psychological safety [15]. For example, when people are being respected by other team members, they are more likely to gain confidence by knowing others will not hold the errors against them and thus increase their likelihood to speak up [15]. In addition, listening to each other [31] and the frequency of communication [32] are both proposed to have an influence on psychological safety. Also, some of the personality constructs are posited to have impact on psychological safety [29]. Openness, one of the Big Five personality traits, can potentially increase the possibility of an individual feeling safe to take risks [18]. Additionally, being emotionally stable allows individuals to be less likely to become anxious, hostile, and vulnerable to stress [33]. Based on multiple factors found in prior literature that could contribute to climate of psychological safety, a model of the critical considerations of Teamwork [34] was adapted in this study attempting to summarize all the factors, see Figure 1 for details. The reason why this model is applied is because the core states it defines are consistent with factors found in previous literature. For example, in the model, *Communication* is defined as a process that allows group members to send and receive information while forming team's attitude and behavior [34]. The description reflects factors such as, give and receive feedbacks [15], being respect to others [15], and listening to each other [31]. Also, the definition

of *Conflict* is about incompatibility of team member's interest, beliefs, or views [34] as task conflict has indicated to have relationship with psychological safety [24]. Additionally, while openness [18], neuroticism [14], emotionally stable [33] are indicated to be correlated with psychological safety, *Composition* in this model could encapsulate these factors as it discusses individual factors that are relevant to team performance [34]. As there are many empirical support for the likelihood of the core states in the model to have impact on the construct of psychological safety, the model is adapted in the study to explore factors that can contribute to the climate of psychological safety.

Figure 1: Heuristic of the Critical Considerations of Teamwork [34]

Despite the empirical work on the factors that have impact on psychological safety, some important questions remain; particularly involving *how, what,* and *when* should we intervene in team activities to reach higher psychological safety and better team performance. In order to respond the research needs, we measured the reliability and applicability of psychological safety in an engineering design project in this study. In addition, we explored the factors that could contribute to the construct of psychological safety, as it has been identified as a key research need [12, 15].

Chapter 3 : Methodology

In order to answer the research questions stated as part of this thesis, a longitudinal study was conducted over the course of three years with 263 participants. See Table 1 for the detailed number of teams and participants in each semester. Data collection started during the Summer term of 2018 and concluded in the Spring term of 2020. Over the condensed summer terms, the duration of the study was 4-week, while over the fall and spring terms, the study was 15-week instead as the activities and timeline remained the same. See Figure 2 for the study timeline. The remainder of this section describes the data that was collected as part of the current investigation.

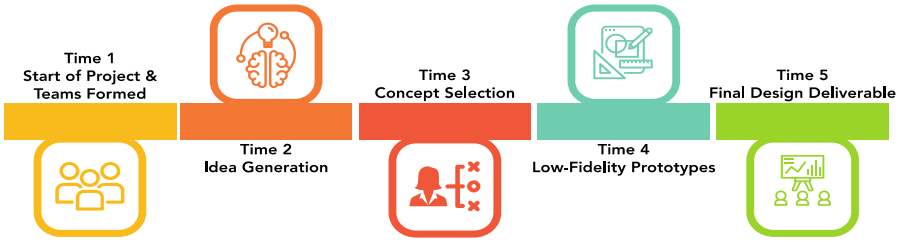

Figure 2: Timeline of study – psychological safety was captured at the end of each time point

Table 1: A total number of teams formed, a total number of participants, and descriptions of design challenges based on instructor and semester

Semester	Instructor	Number of Teams	Number of Participants	Project Description
Summer 2018	A	12	48	Tackle food insecurity in developing countries as a result of climate, conflict, unstable markets, food waste, and lack of investment in agriculture
Spring 2019	A and B	13	49	Ensure healthy lives and promote the well-being for all at all ages through addressing diseases, pollution, and traffic injuries.
Summer 2019	A	12	47	Ensure healthy lives and promote the well-being for all at all ages through addressing diseases, pollution, and traffic injuries.
Fall 2019	A and C	16	61	Ensure healthy lives and promote the well-being for all at all ages through addressing diseases, pollution, and traffic injuries.
Spring 2020	A and D	15	58	Develop a new water toy for children ages 3 to 5 to teach STEM in a fun, safe, novel way.

3.1 Participants

In total, 263 participants between the ages of 18 to 19 formed into 68 teams participated in the study (190 males and 73 females). See Table 1 for summary. The participants were all enrolled in engineering major at a large northeastern university.

3.2 Procedure

The study was completed within a first-year introduction to the engineering design class (EDSGN 200). A total of 11 sections of students were involved in the current investigation. While 7 sections took place during a typical semester (15 weeks), 4 sections happened over condensed summer terms (4 weeks). The study data was collected over the five Time Points throughout the course, including (1)start of the project, (2) idea generation, (3) concept selection, (4) prototyping, (5) final design deliverable (see Figure 2). Specifically, at the end of each time point, a survey included seven questions scaled from developed by Edmondson [14] and two open-ended questions. The first seven questions centered around the level of how comfortable team members felt when made mistakes without criticism, provided suggestions with good intentions, and whether felt accepted as a member of the group [14]. These are followed by two open-ended questions describing the positive and negative interactions that had impact on their answers to the first seven questions. All of the participants consented at the start of the study (Time Point 1) using the Institutional Review Board guidelines set forth at the university.

During ***Time Point 1***, participants were assigned to a group of 3 to 4 people according to Kirton's Adaption-Innovation (A-I) theory [35, 36]. Even though it is not discussed in the current thesis but half of the teams were constructed to be homogeneous and half of the teams were heterogeneous based on the KAI scores. Later on, teams engaged in a design challenge which differed by instructors of each section; see Table 1 for details. Then, students performed research on the contextual area of the design problem in order

to understand the main focus and problem for their design projects. By the end of the class, students completed the psychological safety survey, which included seven questions developed by Edmondson [14].

During ***Time Point 2***, students were given a lecture on how to investigate customer needs and how to develop problem statements. Next, a module was introduced to students on the importance of creativity. Later, students were guided through methods of idea generation, and they were asked to generate as many ideas as possible in 15 minutes. For the next 10 minutes, the teams were encouraged to brainstorm as a group by making modifications to the ideas generated by each team member. At the end of the session, students took the psychological safety survey.

During ***Time Point 3***, teams were led through concept selection activities by instructor where the participants were asked to assess ideas generated by respective their teams in Time Point 2. Specifically, participants were asked to assess ideas individually in a random order by categorizing the ideas using the individual concept assessment sheets into "Consider" or "Do not Consider;" see Figure 3 for an example. Ideas in the "Consider" category were concepts that the participant felt would most likely satisfy the design goals; they were the ideas the individual would want to prototype and/or test immediately, while the "Do Not Consider" category contains ideas that the participants felt had little to no likelihood of satisfying the design goals.

After that, the students were asked to do a final round of screening, which they decided on the final ideas as a group. At the end of the class, all of the participants completed the psychological safety survey.

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

Figure 3: Example Individual Concept Assessment Sheet

During ***Time Point 4*****,** participants were asked to embody the ideas selected in Time Point 3 by building low-fidelity prototypes for 20 minutes while using commonly available materials (e.g. foam cores, cardstock, post-it notes, etc.). From there, participants were asked to give "elevator pitch" to their classmates from other teams introducing their prototypes. After their classmates provided some critical questions such as those related to the technical feasibility and economic impacts, participants gathered the feedback from their classmates and made additional changes in their design. At the end of the class, all of the students completed the psychological safety survey.

During ***Time Point 5***, teams presented their final design ideas with a PowerPoint presentation and a final rendered prototype using CAD (see Figure 4). At the end of the class, all of the students completed the psychological safety survey.

Figure 4 : Design evolution of Team 5's ideas, where they designed a floating farm to combat food insecurity problems in Madagascar due to flooding and high wind from cyclones.

3.3 Content Analysis

In order to analyze the open-ended questions in the survey, "Please describe any positive and negative team interactions or activities that impacted the rating," a qualitative analysis was conducted.

By reviewing prior literature, factors such as group dynamics [30], interpersonal relationships [30], communication [32], and personal traits [29] are known to have influence on the psychological safety. Also, by reviewing the nature of the data collected, a codebook was developed through an abductive content analysis approach [37]. The responses were coded using nine critical consideration subscales (Composition,

Communication, Coordination, Creativity, Cooperation, Conflict, Cohesiveness, Other, and Not Applicable).

Table 2: Description of the Critical Considerations for Teamwork that would positively or negatively affect the psychological safety [34]

Critical Consideration	Description	Examples
Composition	The participant's response indicates a quality or characteristic that distinguishes the character, action and attitude of a team member.	"My teammates were all kind and nice." "Some too attached to ideas."
Communication	The participant's response indicates the steps of how people provide and receive ideas and information.	"Ability to talk out ideas and receive criticism." "Didn't feel as if ideas were heard as much."
Coordination	The participant's response indicates the behavioral patterns when performing tasks.	"We have equally shared the work load …when researching info on our topic." "We waited last minute for everything."
Creativity	The participant's response indicates the quality of quantity of ideas generated in a team.	"We came up with many unique and good ideas." "Sometimes it's hard for us to think deeply."
Cooperation	The participant's response indicates the action of working as a team.	"We all collaborated in way that successfully helped the design process of our project." "We were doing our own thing not collaborating."
Conflict	The participant's response indicates the incompatibility of the perspectives.	"We came to a consensus on what we should do." "It seems we had a split decision on ideas..."
Cohesiveness	The participant's response indicates the extend that team members stick together for a common goal.	"Team bonding with goldfish and water." "Isolation."
Other	The participant's response indicates factors other than personal traits, communication process, and work coordination/flow.	"When one of the teammate arrived late, we accepted him with open arms." "We disagreed heavily with design selection."
Not Applicable	The participant's response indicates that there is no activity that can be applied.	"None" "N/A"

After coding the qualitative data into the themes above, a further axial-coding [38] and re-grouping of the answers into secondary themes was conducted. To ensure the interrater reliability, two raters, one PhD Industrial Engineering student and one undergraduate Industrial Engineering student coded using the same codebook at an overlap of 20% of the open-ended questions using Nvivo Pro [39]. An interrater reliability (Cohen's Kappa) [40] of 0.76 was reached. A more detailed codebook which includes secondary themes is presented in Appendix A.

Chapter 4 : Results and Discussion

This section highlights the results from exploring longitudinal study on psychological safety. During the study, the average psychological safety scores for all 68 teams from Time Point 1 to Time Point 5 were 5.59, 6.02, 6.10, 6.12, 6.07, respectively. The remainder of this section presents the results in reference to our research questions. The statistical data were analyzed via the SPSS v.26.

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

In order to justify the reliability of the psychological safety scale used for RQ1, Cronbach's alpha (α) was computed based on the data collected from five different time points throughout the course of each team project. Cronbach's alpha was used because it measures the internal consistency of a scale by identifying how similar two responses are to randomly selected sets of items within the scale [41]. Generally, a Cronbach's alpha value greater than 0.7 would be considered as acceptable [42].

The results computed for each of the five time points demonstrate that the scale was reliable since Cronbach's alpha values range from 0.70 to 0.82 across Time Points 1 through 5, as shown in Figure 5. These values were equal to 0.70, 0.72, 0.75, 0.74, and 0.82 for each time point, respectively. Among these values, Time Point 1 exhibited the lowest value at $\alpha=0.7$. This may because psychological safety in a team takes time to develop over the course of a project because it begins at the individual level and manifests at the team level over time [43, 44]. Since Time Point 1 represented the first meeting, this signaled that there might have been not enough time for the perception of psychological safety to manifest. After Time Point 1, the Cronbach's alpha increased over time while the survey length remained the same. Therefore, it can be concluded that at Time Point 1 when the team construct might not have been stabilized, it could have caused difficulties in examining the psychological safety in this longitudinal study. Therefore, it is important to know when the team construct stabilizes in order to study the longitude of psychological safety.

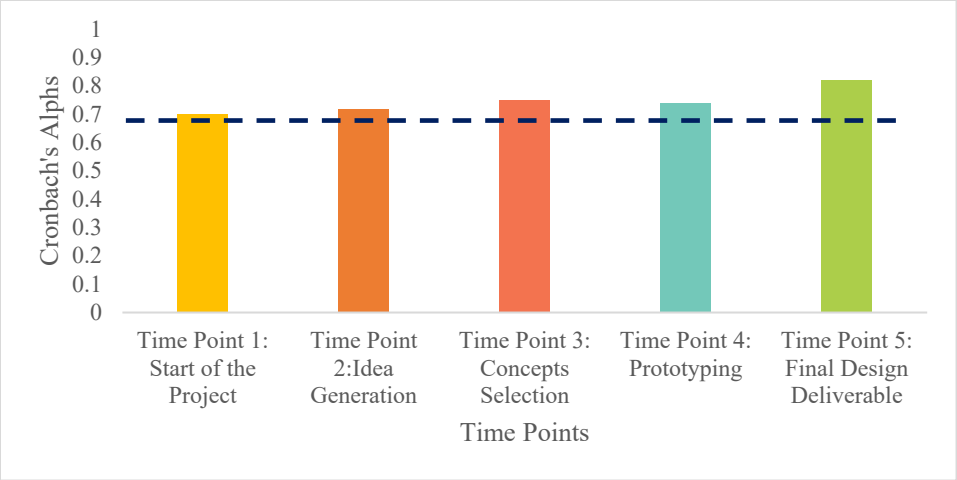

Figure 5: The internal consistency of the psychological safety scale over the five time points as measured by Cronbach's alpha. The dashed line shows the acceptable level of reliability (0.7).

After assessing the internal consistency of the scale's reliability, the consistency of scores among the team members is also important to examine. This is because psychological safety is a shared group property that manifests at the team level [14]. It commences with individual feelings but as more interaction takes place, psychological safety turns into a collective team phenomenon [43, 44]. Therefore, it is necessary to justify aggregating the scale to the team level since psychological safety describes team perceptions instead of individual [14]. When all the individual members in the team agree with each other on the overall psychological safety level, psychological safety can be considered a shared team level construct [43]. As a result, it is important to justify aggregation to the team level through interrater reliability and agreement within the team to establish psychometric integrity in assessing team psychological safety [45].

One of the two ways to justify aggregation is using the measure of interrater agreement with r_{WG} *indices* [46]. The interrater agreement is assessed using r_{WG} since there are multiple members rating the same questions while using the same internal scale [45]. This index compares the actual variance to the expected variance to check whether the team members are answering the psychological safety survey randomly. Therefore, when the members reach a perfect agreement on the questions, the observed variance will equal 0 and result in an r_{WG} value of 1[45]. The commonly accepted value for r_{WG} is 0.70 and above [47]. While the r_{WG} accounts for the agreement of one question, the $r_{WG(J)}$ has been computed to represent a

multi-item index since a total of 7 questions are included in the psychological safety survey [14]. Because an $r_{WG(J)}$ value has been calculated for each team, an average and median $r_{WG(J)}$ value have been reported for each of the time points. The average of the $r_{WG(J)}$ ranged from 0.88 to 0.91, and the median of the $r_{WG(J)}$ ranged from 0.91 to 0.94. These results demonstrate that the interrater agreement of the psychological safety level within teams is acceptable. See Table 1 for mean and median $r_{WG(J)}$ for each time point.

Time	Mean	SD	α	Mean $r_{wg(j)}$	Median $r_{wg(j)}$	ICC(1)	ICC(2)
1: Start of the Project	5.95	.54	.70	.91	.91	.26	.57
2: Idea Generation	6.02	.50	.72	.88	.93	.18	.43
3: Concept Selection	6.10	.49	.75	.89	.94	.13	.35
4: Prototyping	6.12	.46	.74	.88	.92	.08	.24
5: Final Design Deliverable	6.07	.56	.82	.89	.93	.11	.31

Table 3: Average Team Psychological Safety Descriptive Statistics and Psychometric Properties Across Time

The second commonly used measure to justify aggregation that captures both interrater agreement (consensus) and reliability (consistency) are the intraclass correlations (ICCs) [46]. Two types of intraclass correlations, ICC(1) and ICC(2), were calculated for this study (see Table 1). ICC(1) uses team membership to estimate the total proportion of variability [47], which can be explained by the extent to which one team member could represent every member who took the survey in the group. A larger ICC(1) value indicates a larger degree of interchangeability between the team members [47] . In the study, ICC(1)s ranged from 0.08 to 0.26 throughout five different time points. Results from Time Point 1 suggest that the greatest psychological safety variance due to team membership was varied by 26%. This is logical since at Time Point 1, teams had limited interactions, which could ultimately cause the ratings to reflect a higher total proportion of variability in psychological safety scores due to team membership. As time progressed, results from Time Point 2 and 3 reveal decreases in ICC(1) values at 18% and 13%, respectively. However, Time Point 4 suggests relatively little variability in psychological safety due to team membership. This is because Time Point 4 represented a later point of time in the semester, therefore team members were likely to be working on different projects, such as some focusing on building prototypes and others working on different assignments [34]. When team members were not expecting to work together on tasks, the team developed

less of a shared mental model over time, which resulted in a small percentage of psychological safety due to team membership at this time point [34]. The ICC(1)s recovered at Time Point 5, where the total percentage of variability in psychological safety scores amounted to 11%. This increased value exhibits that when the team worked together on the same task, the shared mental model [34] helped to increase the amount of variance explained by team membership.

While ICC(1) captures the interrater agreement, ICC(2) captures the reliability of the mean ratings [45]. In this case, ICC(2) takes into the account of how many people there are in a group to denote how reliable the team means would be based on the consensus and consistency of member ratings [47]. Estimation of ICC(2) on the reliability of mean ratings are generally higher in magnitude than ICC(1) estimates since it is adjusted based on group size [46]. Similar to the pattern of ICC(1) result, ICC(2)s display the highest value at Time Point 1, where ICC(2)=0.57. From Time Point 1, the ICC(2) decreased at Time Point 2, 3, and 4 with values of 0.43, 0.35, and 0.24, respectively. As comparable to the pattern of ICC(1), the ICC(2) also recovered a little at Time Point 5, where ICC(2)= 0.31. Overall, the ICC(1) and ICC(2) values result in a decreasing pattern from Time Point 1 to 4, which dropped the most at Time Point 4, where students worked on different tasks, causing a less shared mental model. However, the ICC values slightly recovered at Time Point 5, demonstrating that the students were back to working with each other more so than in Time Point 4.

In summary, across the indicators of scale reliability, the interrater agreement and interrater reliability results suggest that at the beginning when the teams were first formed, even though the ICC(1) and ICC(2) remained the highest throughout different time points, the perception of psychological safety might not be well-formed since not many significant interactions have occurred within the group. This may be because at the beginning of the study, little time had been provided for dynamic interactions that would allow individual entities to yield into collective levels, which psychological safety is built upon[44, 48]. The present sample indicates that time points after Time Point 1 should capture a more accurate picture of the team's interactions and psychological safety. This result establishes that psychological safety needs to take time to develop. Also, additional findings conclude that although the average psychological safety

score at Time Point 4 follows an increasing trend, having team members working different tasks could have an impact on the interrater agreement and the reliability of mean ratings as it lessens the shared mental model [34].

RQ2: What factors impact the building or waning of psychological safety in an engineering design student team?

In order to understand the factors that impact the building or waning of psychological safety in student engineering teams, qualitative responses from the open-ended survey questions were analyzed in an exploratory study to attempt to discover the potential factors that could impact psychological safety. Specifically, open coding, which is a method allows qualitative data to be categorized freely [49] was used to identify factors reported during times of potential psychological safety decline and building.

Specifically, this research question sought to discover what factors during team interactions led to building or waning of psychological safety. In order to answer this, the open-ended questions from the survey were analyzed to identify major themes that may have had impact on the climate of psychological safety. In all, 7 main discussion topics and 18 subtopics were defined after the investigation of the data; see Figure 6 for the list of the main topics and the frequency of occurrence. Furthermore, it should be noted that there were answers did not match any of the themes of perceived positive or negative team interactions. For example, a participant from Team 45 commented, “There really were no negative interactions.” Among these responses, there were students provided answers such as, “Not Applicable” or “None” to indicate that there was nothing to report. A total of 21 answers indicated that no positive interactions existed to be reported, and a total of 629 answers indicate that no negative interactions existed during group activities that they could recall. Therefore, the total frequency of topics depicting positive team interactions was larger in comparison to depicting negative team interactions. Another point worthy of attention was that “Communication” contained the highest frequency count for topics depicting positive team interactions, while “Coordination” contained the highest frequency count for depicting negative team interactions. In

other words, more participants mentioned their team communication process when asked to talk about positive interactions. However, when questioned about whether any negative interactions existed, coordination-related topics were the most frequently occurring category. The following section presents detailed descriptions and examples of the discussion topics about positive or negative team activities that may have had an impact on the formation or decline of psychological safety.

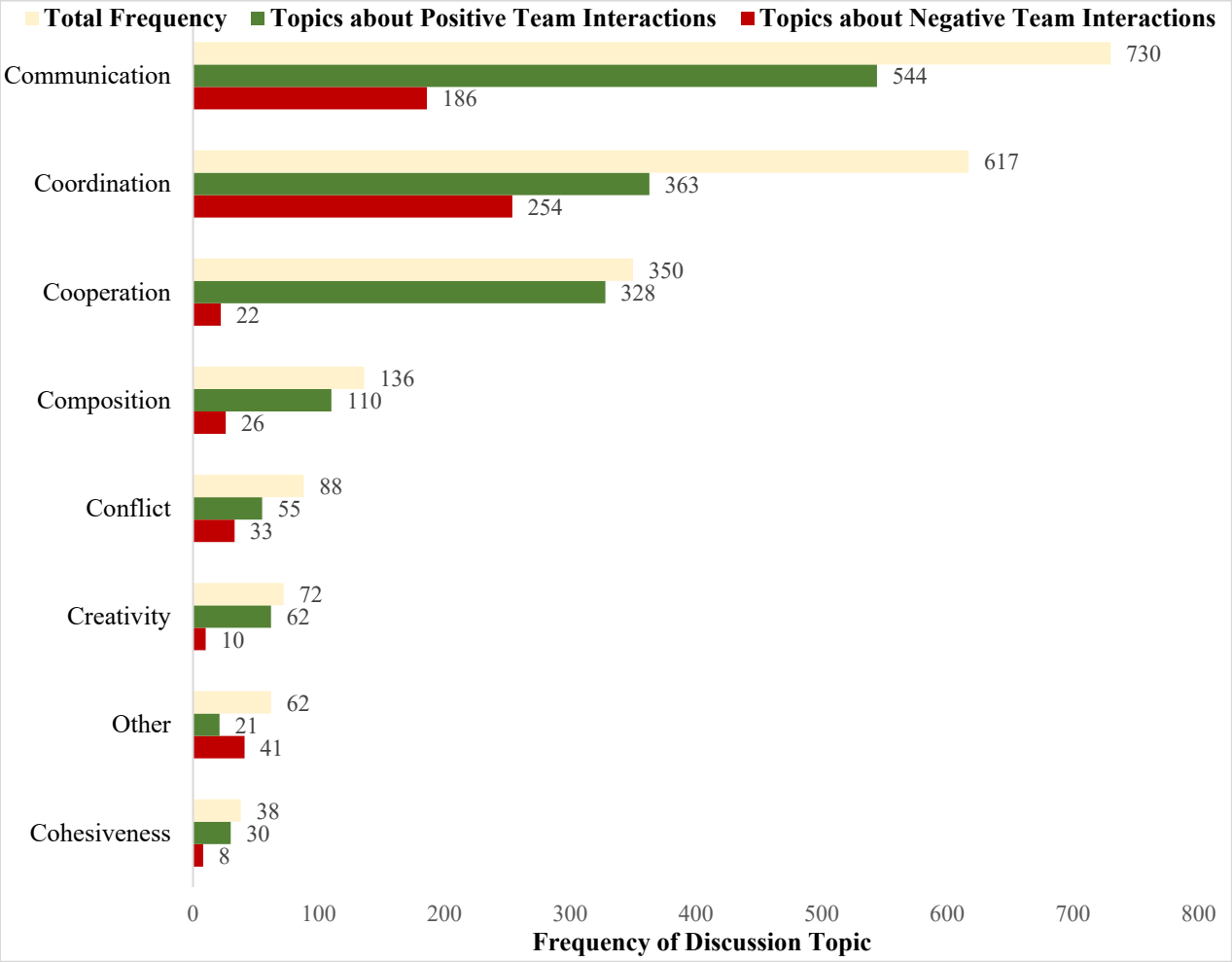

Figure 6: Discussion topics, the total frequency of occurrence, and the number of times the topic contains positive or negative team interactions.

4.2.1 Communication

The discussion topic that was the most frequently cited interaction or activity that impacted participants' ratings of psychological safety during the five time points was the communication (f = 730) within team. Three sub-topics in this area were also identified, including: *being respectful of other's ideas* (f = 136), *listening* (f = 63), and *general communication* (f = 531).

Specifically, under the *general communication* sub-topic, where members provided and received information which led to the attitudinal, behavioral, and cognitional change of a team, teams indicated whether they were able to communicate well throughout the process. There were usually no specific details to explain the communication as presented in the survey responses, but rather it was stated in a general way under this subtopic. For example, a participant in Team 32 expressed that, "We communicated very well without hurting each other's feelings when chose not to consider an idea." Along with general communication, *being respectful to other's ideas* is a topic that participants frequently mentioned. Throughout the design process, especially during the *concept screening* stage where each of ideas was evaluated by every teammate, many team members considered that as a positive activity, which built up the psychological safety when their teammates showed respect toward their ideas. For example, a participant in Team 38 commented that, "Everything we do, is it respectful and considerate of the feelings and ideas of others. Supportive language is used almost always." On the other hand, a participant listed ideas not being considered or dismissed as negative interaction. In addition to showing respect toward others' ideas, participants mentioned *listening* as another subtopic. In *listening*, team members paid attention and did not interrupt the team member who was speaking and trying to convey ideas or information. For example, participant in Team 40 replied, "Sometimes I had to repeat myself a few times to be listened to," in response to the survey question related to negative interactions, which ultimately could have affected their psychological safety.

Overall, these findings demonstrate the possibility of having a correlation between communication and climate of psychological safety. In fact, activities including discussions within the group, seeking

feedback, and providing information were recognized as *team behavior* under the model of work-team learning, which exhibits empirical support for having a relationship with psychological safety [15]. Furthermore, prior work has shown to support that respect toward others could foster the growth of psychological safety [31, 50]. In addition, researchers have demonstrated that listening could be a mediating role in psychological safety [31]. Based on our results, among all of the subtopics, communication is the most-often occurring topic (f = 544) when discussing positive interactions within their groups. Even though there is still a large frequency count for people who mention communication when specifying the negative interactions that impact their ratings (f = 186), communication is not the most mentioned topic that participants brought up when they shared responses about negative activities.

4.2.2 Coordination

The second topic discussed by the participants in this study involved a discussion about coordination. During the process of the team interactions, the work coordination, or the team behavioral mechanism that can cause team recourses to result [34]was also a topic that participants frequently mentioned (f = 617). Discussion about coordination has been categorized into six subtopics, including *efficiency* (f = 158), *work contribution & participation* (f = 185), *task completion* (f = 155), *time management* (f = 57), *absence & lateness* (f = 32), and *not explicitly stated* (f = 30). Specifically, under coordination, one of the most frequent topics was when participants discussed they had accomplished tasks in an efficient manner. For example, a participant in Team 30 indicated that "We did work very efficiently today…" Another topic that participants brought up many times was whether group members actively participated in the activities or whether everybody contributed the same effort without having an idle team member not doing anything. For example, a participant in Team 26 commented that the negative interaction "Not evenly split up the jobs," affected their psychological safety score. Meanwhile, a participant in Team 31 indicated that "Everyone contributes and everyone puts in their work." Evidence also show that positive interactions occurred when students and their respective teams were able to finish certain assignments or

tasks. When some of the groups failed to finish tasks or encounter issues without being successfully solved, they would list it as a negative interaction. For example, a participant in Team 30 stated that, “We were able to successfully get the project done.” Another example from a participant from Team 54 commented that, “The only negative interactions have been our stuck-ness from the difficulty of our problem which is stressing us out.” On other occasions, students commented about how their teams accomplished their tasks in a timely manner. For example, a participant from Team 13 asserted that, “We waited last minute for everything.” Some other students also indicated that when their teammates were absent or were late for meetings, this could affect their psychological safety. For example, a participant from Team 65 indicated that, “Many times we were missing a group member or people showed up late.” Regardless of all the subtopics being mentioned above, there were still discussions relating to work coordination, but these did not fit into any of the subtopics in the content analysis. For example, a participant from Team 15 reported that “We are a little disorganized…”

Overall, the majority of the findings are in support of the prior research, indicating the task performance is positively related with psychological safety [20]. Also, our qualitative results agree with the notion that problem-solving efficacy also correlates with psychological safety in group-level research [15]. More specifically, the results suggest that coordination including team efficiency, members’ contribution and participation, task accomplishment, time management, and the absence and punctuality of team members were likely to be linked to the formation or decline of psychological safety. It should also be noted that coordination was the most frequently occurring topic discussed by the participants when asked about negative team interactions, which demonstrates the likelihood that negative work coordination is related to the decline of team psychological safety.

4.2.3 Cooperation

The third topic participants discussed the most involved cooperation. During team activities, cooperation is a motivation driver for a team, which the team builds upon with attitude and beliefs [34].

Cooperation had been discussed in a high frequency (f = 350). More specifically, there was a higher frequency that a participant mentions cooperation when asked about positive interaction (f = 328) than negative interaction (f = 22). For example, a participant in Team 27 mentioned that, "We all able to collaborate our ideas to make a great product." Another example would be a participant in Team 29 commented that, "We worked well together." There were also participants indicted that during team interaction, there was a lack of teamwork spirit which impacted their ratings. For example, a participant in Team 59 mentioned that "I felt like we did not work together often enough."

This finding indicates that cooperation is likely to be correlated with constructions of psychological safety. This is based on the large frequency of participants who mentioned cooperation when they responded to the survey about positive interactions (f = 328). Therefore, our results show that collaborating well, working together, and helping each other out could have relationship with formation of psychological safety. These results also demonstrate the existence of a relationship between cooperation and psychological safety. For example, research findings suggest that cooperation could facilitate the group's orientation of problem-solving, which allows mistakes or errors being discussed and learned in the group [51]. Based on other studies, it can be concluded that cooperation serves as a predictor for team learning and effectiveness which built on psychological safety [15].

4.2.4 Composition

The fourth most frequent topic involved team composition (f = 136). Discussions about the composition included participants commenting on the characteristics of their team members and the individual factors that are related to the outcome of the team performance [34]. These were broken down into two categories: *personal traits* (f = 94) and *not explicitly stated* (f = 42). Usually, participants discussed two of the personality traits out of the "Big Five," [52] which are openness (f = 59) and extraversion (f = 35). During the team activities, especially for Time Point 2 and 3, which served as the stage for concept generation and concept screening, respectively, these activities required participants to share their own ideas,

and evaluate other's ideas, which was when openness can emerge. For example, a participant from Team 49 discussed that, "Everybody is open-minded to new ideas." Some participants also commented on the sociability of other team members. For example, a participant from Team 53 indicates that "My team is extremely, extremely introverted. They can't open up properly or express ideas…" Other discussions involved characteristics of other team members but did not include topics about openness or extraversion were categorized into *not explicitly stated*. In this topic, participants mentioned characteristics such as temper, stubbornness, and intelligence. For example, a participant from Team 22 mentioned, "They are all smarter than me."

Overall, these results suggest that having open and extroverted team members (f = 85) could promote the building of psychological safety. In comparison to the frequency of involving topics about composition for positive interactions (f = 110), for negative interactions are relatively small (f = 26). Prior research results indicate that an open leader is likely to promote the development of psychological safety [21], which supports some of these findings here. However, the relationship between psychological safety and other personal traits such as extraversion does not seem to be research topic that many researchers have explored. This could be a topic that researchers could investigate in future research.

4.2.5 Conflict

The fifth most frequent topic that participants discussed was about conflict. Conflict describes the incompatibility of ideas and perspectives regarding the tasks and assignments [34]. Throughout the data, teams mentioned about reaching consensus in making decisions when providing answers for positive interactions (f = 55), as they also explained having conflict caused by having different views (f = 33) could also impact their ratings that decreased their psychological safety scores. For example, a participant from Team 37 explained that, "We could all agree on what ideas were good and what ideas were bad." as another participant in Team 26 complained that, "We disagreed heavily with design selection."

Overall, these findings show that in contrast with other topics which had relatively huge differences between the frequency of positive and negative interactions, frequency counts for "conflict" for both cases were relatively close. The results indicate that there is a correlation between having team conflict and the climate of psychological safety, and conflict could act like a double-edged sword when it comes to psychological safety. This in line with the relevant research that conflict is an important factor when it comes to improving team performance [24], as psychological safety is also positively related to team performance [14]. Indeed, psychological safety would thus play a moderating role between task conflict and team performance [14]. The research indicates that conflict in a team process could inspire innovative ideas by not easily coming to an agreement which allows for more meaningful discussions, thus eventually promote team performance [14]. Even though conflict could be beneficial in a way, if the disagreements are being taken personally or the method of expression hurts feelings, then this kind of conflict should be avoided, as it might become a negative interaction among team members.

4.2.6 Creativity

The sixth most frequent topic involved discussions on the creativity of the ideas. Starting at Time Point 2 (Idea Generation), students were told by the instructors not to hold back from generating any ideas that came to mind in order to inspire more creativity during the process. Some participants listed team members generating creative ideas as positive interactions (f = 62) for building psychological safety, while some participants complained about not having a certain quantity of creative ideas, which they recorded as a negative interaction (f = 10). For example, a participant from Team 28 commented that "We came up with many unique and good ideas." Another participant from Team 49 discussed that "We have a tough time being creative…"

These results show that even though participants list creativity as a factor many times (f=62) for positive interaction, topics about non-creative ideas are rarely being contributed to negative interactions. Indeed, prior research has demonstrated that a relationship between creative and psychological safety exists

[15, 31], Furthermore, previous research indicates that psychological safety is one of the important predictors for creativity [15]. This is because psychological safety could affect how vulnerable people feel when they express their opinions [21], and when they are not feeling vulnerable, they share creative ideas [14]. Even though previous research has demonstrated a relationship between creativity and psychological safety [31], whether the relationship is bidirectional is unknown, since most of the research indicates a higher psychological safety could increase creativity, but little evidence has substantiated that as creativity increases, there is a build in the psychological safety construct. Therefore, although some of the responses in this study indicated such a phenomenon, based on the frequency of the answers (f = 72) and a lack of the prior research to provide support, we cannot make the assertion that as creativity varies, there is a significant impact on the dynamic of psychological safety.

4.2.7 Other

The seventh discussion topic was named as "other" since these topics did not involve any of the other topics. The frequency counts for discussions that involved positive interaction (f = 21) was less than that for discussions that involved negative interaction (f = 41). When discussing positive interaction, some of the answers included were specific and based on the specific situation. For example, a participant from Team 36 commented that, "I asked to put an 'x' over the rearview mirror and was told that was ok." Some other answers in this category were relatively general. For instance, a participant from Team 65 pointed out that, "Everything today was positive and beneficial." When discussing negative interaction, a participant from Team 39 expressed that, "We second-guessed a lot." Other examples included discussions about some participants showing negative emotions during group activities, or some of the team members working on tasks without fully understanding the requirements.

4.2.8 Cohesiveness

The final, least frequently discussed topic was the cohesiveness in the group (f = 38). There were some participants who talked about having good or poor connections with their teammates when discussing positive and negative interactions. For instance, a participant from Team 26 commented, “We are able to laugh and get closer to each other.” Another participant from Team 15 answered “Isolation.” This topic was rarely discussed in comparison to other topics. In fact, prior research demonstrates that group cohesiveness is distinct from psychological safety, since team cohesiveness could reduce the likelihood of interpersonal risk-taking [53], as team psychological safety focuses on whether individuals consider themselves safe for risk-taking [14]. Therefore, it is less likely that the factor of cohesiveness has a strong and direct relationship with psychological safety.

Chapter 5 : Conclusion, Limitations, and Future Work

The aim of this thesis was to understand the longitudinal reliability of the psychological safety construct in engineering student teams. In addition, we tried to seek insights on what factors could impact the building or waning of the psychological safety in the 68 teams. The main findings from the study were as follows:

- Psychological safety takes time to develop and manifest accurately since psychological safety is a collective phenomenon that commences as individual feelings [48]. At the beginning, when teams first formed, the perception of groups had not yet shaped, thus it was hard to look at the psychological safety at this time point, as psychological safety manifests at the team level [14]. Therefore, when tracking psychological safety longitudinally, it was determined to know the time point that the team construct had stabilized in order for further analysis. In our sample, this period occurred at Time Point 2 when activities of idea generation occurred.
- Decreases in interrater agreement and interrater reliability could be caused by not working together on a same task. Because when team members are working on different assignments separately, it might weaken the shared mental model of a team [34].
- Early evidence suggests that work coordination and communication are two of the most likely factors that relate to the climate of psychological safety. This result also implies that having good general communication, being respectful to other's ideas, and listening to others are likely to build psychological safety in engineering teams over time. On the other hand, not working efficiently, not having everyone in the team contribute the same amount or participate actively, not being able to finish tasks as a group, procrastinating to do tasks until the last minute, and being absent or late to meetings are likely to be correlated with the decline of psychological safety. Also, having the spirit of cooperation and having appreciation towards other team members' characteristics could possibly increase psychological safety. On the other hand, having conflict in a group could either possibly help build or cause psychological safety to wane over time. These findings start to help us

identify the factors that could affect psychological safety in engineering design courses, and provide insight on how to further investigate *what types* of interventions might be helpful in engineering design.

Even though the study was exploratory in nature, the results indicated and answered some difficult fundamental questions on how to improve engineering education on team performance, such as *when* to intervene the team interactions for better performance, *what* type of intervention could possibly be pivotal, *how* to intervene the team successfully. However, the current study only begins to cast light on fundamental study of the construct of psychological safety by providing information on possible relationships. More direct relationships and correlations among factors also need further investigation.

Although the current study presents evidence towards the reliability and applicability of the psychological safety in engineering teams and indicates possible factors that have impacts on the climate of psychological safety, there are limitations to this work and some suggestions for future work.

1. First, the data collected for this study was all from the same university. Also, the participants involved in this study were all aged between 18-19, and all of the study data was collected from a first-year engineering design course. Thus, the results from the current study might only be applicable to this population. Therefore, for future studies, it could focus towards a larger scale by conducting the experiments at a variety of universities, and a variety of classes to a variety of ages of students to increase the level of generalization of the results.
2. In additions, some patterns started to appear in the study which were that different factors were mentioned most at different time points. Thus, further study could focus on what types of factors become more or less important during the progress of team construction to gain deeper insights on the dynamics of teamwork over project trajectory.
3. Furthermore, it might be the nature of students that prevents them from honestly and actively answering the questions about negative interactions that happened in their teams, which blocks the study from gaining more understanding of the decline of psychological safety. Future work could

examine the factors that cause psychological safety to wane in a more persuasive way to obtain more feedback instead of having lots of students answer “Not Applicable.”

4. Finally, this study suggests that psychological safety does contain the likelihood to have relationships with factors such as communication, coordination, etcetera, however, the current study does not involve investigating the role of psychological safety in team performance. Therefore, future work could consider examining the impact of psychological safety through team outcomes over engineering design courses.

Taken together, the new findings take us a step closer to understanding ways to improve education in the engineering design class, and support students to obtain better experience and outcomes in group works.

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Appendix A

Levels of Abstraction	Themes	Descriptions	Examples
Composition	Personal Traits	The participant discusses topics with reference to personality of other team members.	"Everyone is friendly to one another." "Definitely favoritism of their own idea and lacked an open mind to other ideas if it was not theirs."
	Not Explicitly Stated	The participant discusses topics with reference to characteristics other than openness and friendliness.	"They are all smarter than me." "Our team is a little shy."
Communication	Being Respectful to Other's Idea	The participant discusses topics with reference to if teammates respect each other and everyone's idea is being considered.	"Everyone in the group was very respectful to each other when discussing our individual research." "Not everyone in the team is respectful to other's ideas."
	Listening to each other	The participant discusses topics with reference to if team members would listen to other teammates without interrupting.	"Taking turns talking and everyone listened" "Part of the team does not listen to others carefully."
	Not Explicitly Stated	The participant discusses topics with reference to how team members communicate without mentioning the two subthemes above.	"Everyone on the team communicated well and played a role in deciding what topic we are going to focus upon." "Team in general was unresponsive."
	Efficiency	The participant discusses topics with reference to whether the team work is efficient.	"We worked fast and efficiently." "Not everyone working efficiently."
	Time Management	The participant discusses topics with reference to how team manages their time.	"We were able to complete the project in time." "We should use our time more wisely."

Coordination	Absence/ Punctuality	The participant discusses topics with references to attendance or whether team members on time for occasions.	"Missing a group member unfortunately." "One member was late."
	Work Contribution/Participation	The participant discusses ideas with reference to if everyone in the stay active and put in efforts equally.	"Everyone in the team almost had the equal amount of work." "Some of the teammates' contributions were nonexistent towards the end."
	Task Completion	The participant's response indicates the completion of tasks as a group.	"The rest of the team worked well to finish the project." "That we need to do a better job on completing work."
	Not Explicitly Stated	The participant discusses ideas with reference to work flow but without mentioning any of the above subthemes.	"We are able to progress through tasks given without difficulty." "We weren't organized enough."
Creativity	Creativity	The participant's response indicates the quality of quantity of ideas generated in a team.	"We came up with many unique and good ideas." "Sometimes it's hard for us to think deeply."
Cooperation	Cooperation	The participant's response indicates the action of working as a team.	"We all collaborated in way that successfully helped the design process of our project." "We were doing our own thing not collaborating."
Conflict	Consensus Decision	The participant's response indicates the incompatibility of the perspectives.	"We came to a consensus on what we should do." "It seems we had a split decision on ideas which lead to a battle of which idea was the most effective."

Cohesiveness	Cohesiveness	The participant's response indicates the extend that team members stick together for a common goal.	"Team bonding with goldfish and water." "Isolation."
Other	No Theme	The participant's response indicates factors other than personal traits, communication process, and work coordination/flow.	"When one of the teammate arrived late, we accepted him with open arms and continued working on the project as a team." "We disagreed heavily with design selection."
Not Applicable	No Theme	The participant's response indicates that there is no activity that can be applied.	"None"

ACADEMIC VITA

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- Revised 5 reports with an average of 70 pages each and improved normalization to assist the project teams to build digestible reports

Microsoft Corporation
Data Analyst Intern *May 2017-July 2017*

- Created a geographic heat map for analysis for McDonald's, used Power Business Intelligence and concluded the most takeout orders are near the two popular universities in Beijing in order to optimize marketing strategies
- Managed heartbeat messages and information from the data warehouse to analyze point of sale system daily success rate from McDonald's in the Greater China area so that the clients could monitor the performance of the system in the future
- Updated data visualization points of sale system analysis on EDH Management Portal in order for clients to gain a better understanding of recent customer behavior

AWARDS & CERTIFICATION

- Awarded $4000 scholarship from Penn State University Harold and Inge Marcus Industrial and Manufacturing Engineering Department
- Certified Six Sigma green belt