

WIP: Predicting Psychological Safety by Individual and Team-Level Factors across Engineering Project Life Span Using Multilevel Models of Change

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Monitoring perceived psychological safety in engineering project teams helps instructors better manage student teams to lead to students' positive learning experiences and outcomes, especially for teams with minoritized and culturally diverse students. Teams with diverse backgrounds are found to experience reduced cohesiveness and more interpersonal and task conflict as people are less likely to work well with self-identified out-group members. Meanwhile, teams with diversified members have the potential to benefit from a richer pool of resources and experiences to produce more creative and higher-quality outcomes. Thus, diverse team composition could carry both positive and negative influences towards student perceived psychological safety across the team life span. Using multilevel models of change, we investigate how the diversity at individual and team levels influences psychological safety across time for 1463 first-year engineering students in 390 teams conducting team projects. Future work will explore how students' demographic and academic ability and the team composition affect perceived psychological safety to better inform engineering student team management for the instructors.

Keywords—teamwork, team dynamics, diversity, multilevel modeling, longitudinal study

I. INTRODUCTION AND LITERATURE REVIEW

Psychological safety refers to a consensus reached by team members that the team is safe for interpersonal risk-taking [1]. As team psychological safety develops from team members' shared beliefs, psychological safety should converge in a team and facilitate overall learning behavior within a team. Moreover, research reveals that team psychological safety is a team dynamic that significantly minimizes team members' concerns of embarrassment [1], stimulates team learning behavior, and provides team members with more confidence to take risks [2]. A high level of psychological safety will create a safe learning environment for students to explore and engage in team projects, which solidifies the root of success in team-based learning for students and facilitates healthy teamwork behavior and productive teamwork effectiveness. Unfortunately, the study of psychological safety has been scarce in the educational field and primarily focused on teamwork outcomes such as leadership effectiveness and work type [3], social support and groupware usage [4],

organizational learning [5], and team member behavior effectiveness [6].

Based on Harrison & Klein's diversity taxonomy [7], diversity at the individual level could be conceptualized as separation because individuals would possess different positions, values, or opinions that might hurt the team dynamic, which lead to more conflict and less trust and social integration ultimately to perceive lower psychological safety drawing from social categorization theory [8, 9]. Diversity of racial/ethnicity, gender, internationality, and academic standing at the team level might be conceptualized as separation because people from different backgrounds and experiences could enrich the resources pool to benefit the team based on the unique perspectives and contribution to increase psychological safety scores based on theories of information processing or the law of requisite variety [10]. Lastly, diversity of GPA might be considered as disparity as the most academically competent students might hold the social power to dominate the teamwork process and dynamics to lower psychological safety scores for the rest of the team members based on sociological theories of stratification [11] and relative deprivation [12].

Though Beigpourian (2020) explored how students' demographic diversity is associated with individual and team psychological safety, he stopped short of disaggregating the effect of diversity across individual and team levels, nor did he examine the developmental pattern of psychological safety. Building on his work, the overarching **research question** of this study is: How is team psychological safety as perceived by students associated with team compositional diversity at the individual and team level over the life of the team project? It is hypothesized that (H1) with more interaction, psychological safety level would increase over time because students get used to the team norms and cooperation pattern; (H2) at the individual level, students with lower GPA or identified as minoritized in gender, race/ethnicity, or internationality, compared to the reference population (White male domestic first-year students) would be associated with lower psychological safety; (H3) at the team level, students in a team with lower team averaged GPA or higher degree of diversity in gender, race/ethnicity, internationality, academic

standing, and GPA would indicate a lower level of psychological safety.

II. METHODS

A. Participants

The data was collected from the second mandatory introduction to engineering course in large R1 Midwestern public predominantly White institution in the Spring 2020 semester, granted by the institutional IRB. The initial sample included 1777 students in 460 teams across 16 sessions. Within the 16-week course, demographic and GPA information was gathered from students at week 2, including gender, race/ethnicity, internationality, and GPA in the previous semester. Academic Standing (first-year, sophomore, junior, and senior) was uploaded from course rosters. Though students were assigned into teams formed by a web-based tool called CATME Team-Maker [13] in week 3, their major team project was introduced in week 10 and continued until the end of the semester. Surveys including psychological safety were administered to students in weeks 12, 14, and 16, respectively across the team project life span.

B. Analytic Strategy

Multilevel models of change were used to test our overarching research question of whether the diversity of gender, race, internationality, academic standing, and GPA at individual and team levels are correlated with student perceived team psychological safety and its change rate. To disentangle the effects of diversity across levels, variables were generated to match their measurement at the appropriate level, as described above. The structure of the data is that time (survey order, denoted with a t subscript) is nested within individuals (team members, denoted with an i subscript) nested in teams (denoted with a j subscript). Models were built using the “lme4” package with the restricted maximum likelihood estimator (REML) method in R version 4.0.5 [14, 15]. The models were constructed in four stages starting from the unconditional model, to add Level 1, 2, and 3 variables into the models step-by-step. Due page limitations, only the unconditional model and the full model will be presented here.

The first model was the unconditional model that was used to examine the proportion of variance distribution explaining psychological safety across levels: within-person, between-person, and between-team variability by calculating the Intraclass Correlation Coefficients (ICC) for each level, the equation for the ICC for level 1 (time) shown as an example below:

$$ICC (Level 1) = \frac{\sigma_{time(t)}^2}{\sigma_{time(t)}^2 + \sigma_{individual(i)}^2 + \sigma_{team(j)}^2}$$

By building models by adding variables associated with different levels, the percent reduction in error (PRE) could be calculated to quantify the effect size estimation at each level. For example, to calculate the percent reduction in error at level 1 from the unconditional model to a conditional model:

Percent Reduction in Error (PRE)

$$= \frac{\sigma_{time \text{ in Unconditional Model}}^2 - \sigma_{time \text{ in Conditional Model}}^2}{\sigma_{time \text{ in Unconditional Model}}^2}$$

See Raudenbush and Bryk [16] and Snijders and Bosker [17] for further details.

The final model was specified as:

$$Psychological\ Safety_{tij} = \pi_{0ij} + \pi_{1ij}(Time_{tij}) + e_{tij}$$

where Psychological Safety_{tij}, or the level of psychological safety for student i in team j at survey round t , was modeled as a function of the following: π_{0ij} , indicating the estimated level of psychological safety for student i in team j ; π_{1ij} , the estimated change rate of psychological safety across survey periods for student i in team j ; and e_{tij} , a series of time-specific residuals. In turn, the level 2, or individual level coefficients were modeled as:

$$\begin{aligned} \pi_{0ij} = & \beta_{00j} + \beta_{01j}(G_{Female}) + \beta_{02j}(G_{Other}) + \\ & \beta_{03j}(R_{Asian}) + \beta_{04j}(R_{Black}) + \beta_{05j}(R_{Hispanic}) + \\ & \beta_{06j}(R_{Other}) + \beta_{07j}(INTL) + \beta_{08j}(AS) + \\ & \beta_{09j}(GPA_{WTC}) + r_{0ij} \end{aligned}$$

$$\begin{aligned} \pi_{1ij} = & \beta_{10j} + \beta_{11j}(G_{Female}) + \beta_{12j}(G_{Other}) + \\ & \beta_{13j}(R_{Asian}) + \beta_{14j}(R_{Black}) + \beta_{15j}(R_{Hispanic}) + \\ & \beta_{16j}(R_{Other}) + \beta_{17j}(INTL) + \beta_{18j}(AS) + \\ & \beta_{19j}(GPA_{WTC}) + r_{1ij} \end{aligned}$$

Where β_{00j} is the estimated level of psychological safety for team j ; β_{01j} to β_{09j} are the team-specific estimated main effects of being female, other gender, Asian, Black, Hispanic, other racial, international, non-first-year students, and within team-centered GPA at the individual level on psychological safety scores, and r_{0ij} is the individual student-specific error term for the intercept. β_{10j} is the estimated average person-level effect of the rate of change in psychological safety for team j . β_{11j} to β_{19j} are the team-specific estimated interaction effects between time (conceptualized as the rate of change) and the following corresponding variables: female, other gender, Asian, Black, Hispanic, other racial, international, non-first-year students, and within team-centered GPA at the individual level on psychological safety scores, and r_{1ij} is the individual student-specific error term for the effect of time on psychological safety. Finally, the individual-specific coefficients were modeled as:

$$\begin{aligned} \beta_{00j} = & \gamma_{000} + \gamma_{001}(Gender_{Div}) + \gamma_{002}(Race_{Div}) \\ & + \gamma_{003}(INTL_{Div}) + \gamma_{004}(AS_{Div}) \\ & + \gamma_{005}(GPA_{TeamAvg}) + \gamma_{006}(GPA_{Div}) \\ & + \mu_{00j} \end{aligned}$$

$$\begin{aligned} \beta_{10j} = & \gamma_{100} + \gamma_{101}(Gender_{Div}) + \gamma_{102}(Race_{Div}) \\ & + \gamma_{103}(INTL_{Div}) + \gamma_{104}(AS_{Div}) \\ & + \gamma_{105}(GPA_{TeamAvg}) + \gamma_{106}(GPA_{Div}) \\ & + \mu_{10j} \end{aligned}$$

$$\beta_{01j} \dots \beta_{09j} = \gamma_{0x0} \text{ \& } \beta_{11j} \dots \beta_{19j} = \gamma_{1x0}, \\ \text{where } x = 1 \dots 9 \text{ respectively;}$$

where γ_{000} is the estimated level of psychological safety across all surveys for all students in all teams; γ_{001} to γ_{006} are the main effects on psychological safety for team-level variables, specified as gender, racial, internationality, academic standing diversity, and the team averaged GPA and GPA diversity as disparity; and μ_{00j} is team-specific error term on the intercept of psychological safety. Moreover, γ_{100} is the sample-average estimated main effect of the rate of change in psychological safety; γ_{101} to γ_{106} are the sample-average estimated interaction effects of time (conceptualized as the rate of change) with team-level variables, specified as gender, racial, internationality, academic standing diversity, and the team averaged GPA and GPA diversity as disparity on psychological safety, and μ_{10j} is the team-specific error term on the change rate of psychological safety. Lastly, for model parsimony, individual-level variables were designed as fixed effects only, so the interpretations of $\gamma_{01j} \dots \gamma_{09j}$ should follow those described in the previous paragraphs for $\beta_{01j} \dots \beta_{09j}$. Therefore, the reference condition for the whole model would be a team comprised of members who are all male, White, domestic, in their first year, with the sample average GPA as the entire cohort.

III. DISCUSSION AND CONCLUSIONS

Outcomes in the context of a team are inherently multilevel, and our work in progress seeks additional evidence of the impact of diversity at the individual and team level on students' academic experiences, especially in team dynamics such as psychological safety. The implementation of the multilevel models of change sets an example for scholars and researchers to further investigate student attributes not only with variables of interest but also including patterns of change over time. In addition, using multilevel models of change allowed us to partition the variance of the focal independent variables into time-specific, individual-specific, and team levels so that the main and interaction effects of dependent variables could be studied more clearly. Furthermore, this work also reminds researchers to pay attention to aligning attributes of interest with appropriate levels of measurement. Combining with the call for the theory-driven conceptualization of diversity, we encourage scholars to use established diversity indices (e.g. Blau's index for diversity as separation and coefficient of variance for diversity as disparity) beyond individual levels to study the effect of diversity.

This work has the potential to identify negative team experiences, which are more likely to affect women and internationally and racially minoritized students. This will provide evidence of which teams instructors should pay more attention to and even intervene as needed to improve the experience of those students in team projects. Regardless of the findings, it might still be beneficial to assign students to a more racially diversified team to encourage teamwork skill

development and inspire positive teaming experiences. Lastly, it is suggested for instructors to collect team dynamics information from students to better monitor team health.

IV. LIMITATIONS AND FUTURE RESEARCH

Similar to many other quantitative studies, the sample range is always a limitation as only one cohort's data collected in a particular course in a single semester from a single university was used in this work. The expansion of the data could increase the predictive power and validity of this model. Further, the location of the sample and sample composition potentially means that results are biased to represent the experiences of the majority population – White, male, domestic first-year students with the average GPA across the cohort, and thus may not be generalizable to other universities. Furthermore, because this data was collected in Spring 2020 (the team project was introduced virtually and psychological safety data was collected afterward), there existed lots of potentially valuable confounding variables to investigate, such as the socioeconomic status (SES) of the students (working on getting the data). SES might approximate the resources at home and technology competency as the equipment and technology access played a huge role in the learning experiences and quality; it might also reflect on the available learning time at the chaos time [18, 19]. In addition, many other essential team dynamic indicators are worth closer investigation, such as team conflict, task interdependence, trust, team cohesiveness, and satisfaction by following the method presented in this work. Lastly, further investigation of the relationship among the team composition diversity, team dynamics, teamwork outcomes, and the development patterns will significantly advance the teamwork literature in education fields and propose important implications and suggestions for team assignment, management, and training.

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