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TEAM DIVERSITY AND CONTRIBUTION EQUITY IN ENGINEERING DESIGN EDUCATION: EXPLORING COLLABORATIVE DYNAMICS

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ABSTRACT

Collaboration is highly emphasized in engineering design education. While it offers various advantages in fostering learning and professional development, it is imperative to acknowledge the adverse factors that can disrupt collaborative efforts. By far, one of the most frequently cited challenges in student teamwork is perceived contribution inequity, which often leads to frustration during collaboration and strains peer relationships. Much work has been done to investigate effective team collaboration. Still, few studies have empirically delved into perceived contribution fairness or contribution equity from the lens of team diversity in engineering design. This study aims to investigate the complex relationship between team diversity (in terms of differences in gender composition and self-perceptions about one's ability and interests) and contribution equity in student teams. Data were collected from 26 teams in a sophomore-level engineering design course across two semesters. Findings suggest that gender-diverse teams demonstrated a higher tendency for contribution fairness, whereas teams with greater homogeneity in design interests and teamwork preferences were more likely to contribute fairly. These results highlight the importance of a strategic approach to team formation, considering diversity dimensions to promote equitable collaboration in engineering design education.

Keywords: team collaboration, team diversity, contribution fairness, contribution equity, engineering design education, student teamwork

1. INTRODUCTION

In the rapidly evolving field of engineering, collaborative teamwork is essential for driving innovation and solving complex challenges. Engineering education places strong emphasis on teamwork as a fundamental competency, preparing students to tackle real-world problems through effective group collaboration [1–3]. Teamwork in engineering design contexts—such as coursework training [4] and hackathon-like competitions [5]—is defined as the ability to coordinate efforts, set goals, plan tasks, and achieve design objectives within a team setting [6]. Effective collaboration relies on clear communication, mutual trust, and shared support, enabling teams to leverage diverse skills, experiences, and perspectives to develop more innovative and credible solutions [7–9].

One of the key factors influencing team effectiveness is team composition or diversity, which significantly impacts team performance—the extent to which a team successfully accomplishes its goals [10,11]. Team diversity is broadly defined as the range of differentiating characteristics among members that influence how they perceive and interact with one another [12–14]. Prior research categorizes diversity into surface-level and deep-level dimensions [15–17]. Surface-level diversity includes visible attributes such as age, gender, race, ethnicity, and physical abilities [15,16], whereas deep-level diversity encompasses less immediately apparent attributes, such as cognitive abilities, personality traits, values, beliefs, and interests [17]. While diverse teams benefit from broader perspectives and enriched decision-making, unmanaged differences can also lead to team conflicts and imbalances in participation.

Despite extensive research on team diversity's impact on performance, *contribution equity—the fair distribution of effort and responsibilities within diverse teams—remains an understudied aspect, particularly in engineering design education [18,19]*. High team performance does not necessarily

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equate to equitable contributions, which are crucial for fostering a sense of fairness, motivation, and overall team cohesion. This study builds upon existing research on team diversity and performance, specifically exploring *how diversity in gender composition and self-perceived abilities and interests influences contribution equity in an introductory engineering design course.* Understanding this relationship is vital for both academic research and practical applications in education, as it can inform strategies for structuring student teams to promote both inclusivity and fair participation. By addressing this gap, the study contributes valuable insights into optimizing team dynamics in collaborative engineering design settings.

2. BACKGROUND

This section introduces Social Exchange Theory (SET) as the theoretical framework for understanding the importance of contribution equity in teamwork. It then provides a brief review of the existing work on contribution fairness in team settings.

Before delving into these discussions, it is important to clarify key terminology used in the literature to describe inequitable contribution in teamwork. The terms social loafing and free-riders are commonly used in educational environments to describe situations where some team members contribute less than their fair share while still benefiting from the group's collective efforts [20–22]. In contrast, the term diligent isolates refer to individuals who take on a disproportional workload, often preventing their teammates from participating fully [20]. Another key concept, individual accountability, highlights each team member's responsibility for ensuring the group meets its collective goals [23]. These concepts are widely discussed in the literature on teamwork and equity. While this study reviews relevant research on these topics, it does not intend to claim a comprehensive review of all research work in the field.

2.1 Social Exchange Theory

This study draws upon Social Exchange Theory (SET), which explores the dynamics of social interactions within groups and emphasizes the exchange of resources, efforts, and perceived rewards between individuals [24,25]. According to SET, reciprocity, equity theory, and perceived fairness play a fundamental role in shaping group dynamics. Reciprocity refers to the tendency of individuals to match the contributions of others, creating a sense of interdependence within a team. Equity theory suggests that individuals evaluate fairness by comparing their own input-to-reward ratio with those of their teammates, seeking a balanced distribution of efforts and benefits. Meanwhile, perceived fairness captures the subjective evaluation of exchanges, with individuals assessing not only the actual outcomes but also the fairness of the process itself. Together, these concepts shed light on the intricate dynamics of human relationships, guiding decisions and behaviours in the complex web of social interactions.

When applied to teamwork, SET explains why contribution inequity often leads to dissatisfaction and conflict, particularly in diverse teams. Research has shown that unequal participation, whether due to social loafing, free-riding, or diligent isolation, disrupts reciprocity and triggers perceptions of unfairness [20–22,26,27]. This in turn weakens trust, cooperation, and overall team cohesion. When contribution imbalances persist, frustration among more engaged team members can erode motivation, reducing both collaboration quality and overall team performance. If left unaddressed, these dynamics can ultimately undermine the benefits of teamwork in engineering design projects [28,29]. Thus, understanding the relationship between team diversity and contribution equity is crucial for promoting fair and effective collaboration in educational and professional contexts.

2.2 Existing work on contribution equity

Over the past four decades, a substantial body of research has explored ways to reduce or prevent social loafing in teamwork by investigating variables such as group size [30], task visibility [31,32], performance evaluation [32], intergroup competition [33], meaningful tasks [31,34,35], and reward systems [36]. This section discusses the prevalence and consequences of inequitable contribution in team settings, as well as the role of diversity in promoting contribution equity.

Prevalence and consequences of inequitable contribution

Research has consistently highlighted the widespread issue of inequitable contributions in team-based work. Tekle and Sado [21] investigated the prevalence of social loafing among 277 second- and third-year undergraduate students at Madda Walabu University in Ethiopia. Using a five-point Likert scale, participants rated statements regarding group contributions. Their findings revealed that 53.2% of respondents agreed or strongly agreed that some members contributed less than expected, while 44.6% reported that certain group members did not do their fair share of the work. Similarly, a study by Chang, Brickman, and Tanner [37] found that most teams they examined reported experiencing social loafing.

Understanding the impact of unfair contribution on team dynamics and individual perceptions is crucial. Tekle and Sado [21] further examined the consequences of social loafing, finding that respondents most frequently agreed that group tasks took longer to complete (59.5%), teams lacked unity (56.8%), and overall group performance declined (61.1%) due to inequitable contributions. Aggarwal and O'Brien [22] also found that social loafing significantly affected individuals' satisfaction with their group experiences and their perception of grade fairness. In their study of 430 university students, participants recalled past group projects and rated their experiences using a seven-point Likert scale. The findings revealed a strong negative correlation between social loafing and satisfaction with team members' contributions, as well as a positive relationship between contribution equity and perceptions of grade fairness. In other words, students who felt that contributions were fairly distributed were more likely to believe that their grades accurately reflected their efforts.

Importance of diversity in teamwork

Beyond addressing inequitable contributions, research has also examined the role of diversity in teamwork. Smith-Doerr et al. [38] conducted an extensive literature review on the impact of diversity in scientific teams, differentiating between demographic diversity (e.g., gender and racial/ethnic composition) and intellectual diversity (e.g., cognitive approaches and disciplinary backgrounds). Their findings emphasized that the benefits of diversity depend not just on representation but on interactional integration, where all members contribute meaningfully. Without meaningful contribution, diverse teams may struggle due to hierarchical structures, uneven distribution of resources, or disparities in authority and skills. Similarly, Wang [23] found that when team members perceive equal status in terms of abilities and resources, they are more likely to contribute fairly, engage in meaningful peer interactions, and foster an open and inclusive team atmosphere.

Despite these insights, *few studies have empirically examined the relationship between team diversity and contribution equity at the group level*. This study aims to fill that gap by exploring *how team diversity influences contribution fairness in engineering design teams*. Specifically, we investigate *diversity in terms of gender composition and self-perceptions about ability and interests—including creative self-efficacy (CSE), engineering design self-efficacy (EDSE), design interest, and teamwork preference*. Given existing research on both team diversity and social exchange dynamics, we hypothesize that there is a significant relationship between team diversity in certain dimensions and contribution equity.

3. MATERIALS AND METHODS

This section introduces the study context, specific aims, participants, and data collection.

3.1 Study context

The primary goal of this paper is to investigate the intricate nexus between team diversity and contribution equity within design teams. Grounded in the framework and literature review outlined above, this study examines surface-level and deep-level team diversity. On the surface level, we delve into the gender composition of teams, discerning between homogenous and heterogeneous teams, with a specific focus on the role of women in engineering, which is a significant factor in the diversity discourse. At the deep level, we concentrate on the variations within teams concerning team members' self-perceived ability and interests, including creative self-efficacy - CSE, engineering design self-efficacy - EDSE, design interest, and teamwork preference. Drawing upon the theoretical foundation presented in Section 2, we recognize that reciprocity, equity theory, and perceived fairness are fundamental concepts that shape human interactions. Considering this, our research embarks on an exploration of diversity and contribution equity, using perception data as our primary lens of analysis. We deliberately choose this approach, emphasizing the subjective nature of perception data over more objective metrics. We believe that this approach allows for a more nuanced understanding of the complex interplay between diversity and contribution equity within design teams. More specifically, this study aims to understand:

How does a team's contribution equity relate to its diversity in terms of (1) gender, (2) creative self-efficacy (CSE), (3) engineering design self-efficacy (EDSE), (4) teamwork preferences, (5) and interests in engineering design?

To answer these questions, the data were collected from two semesters of a second-year engineering design course at Miami University involving 12 teams in the first semester and 14 teams in the second semester. Half of the course covered computer-aided design (CAD), and the other half taught the early-stage engineering design process. Individuals were required to finish a team design project by applying what they learned from both components. Individuals were pre-assigned to teams with a size of 4~5 members per team. To foster learning from peers, the instructor mixed individuals into teams roughly based on their gender and skills (e.g., graphical modeling, writing, presentation). Such information was collected from a background survey before each semester started, even though not all individuals completed the survey. At the beginning of the project, all teams were assigned the same design theme (i.e., Design for workplace safety and efficiency: Design a robot that collaborates with people) with some basic requirements. Teams were free to choose a specific problem under this theme for their design projects - see Figure 1 for some example projects. Then, every one or two weeks, the teams were required to submit an assignment to report their progress by following the design processes defined by Ulrich, Eppinger, and Yang [39]. The team project started by identifying an opportunity and working to model and analyze a final design concept. No physical fabrication or testing was involved. Surveys about the team projects were used to collect data needed for this study. Please see Section 3.3 for details.

In addition to the main research question above, we also examined the relationships between the mean levels of the five diversity factors and contribution equity. This analysis aimed to ascertain whether team contribution equity could potentially be improved simply by assembling a team composed of talented and highly motivated individuals, thereby emphasizing the intrinsic qualities of team members even before considering the impact of team diversity.

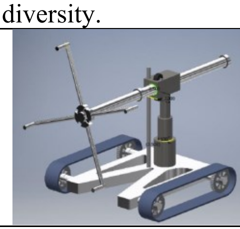	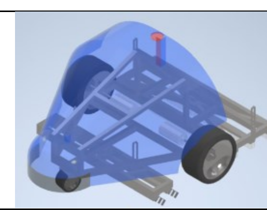
i). An autonomous pneumatic tire installer that helps increase efficiency and reduce worker injuries from the continuous lifting of tires and installing them in an automobile manufacturing plant.	ii). An automated turf-field maintenance device that helps replace manual brushing routine, which is a long and tedious maintenance process.

FIGURE 1: EXAMPLE TEAM PROJECTS

3.2 Participants

A total of 109 students from the same course, spanning two semesters, participated in the study after providing informed consent. The sample included 13 women and 96 men. Students were organized into 26 teams: 16 all-male teams, 7 teams with one female member, and 3 teams with two female members.

3.3 Data Collection

Data were collected in two ways with surveys: self-evaluation and peer evaluation. For continuous improvement, the course structure was changed in the second semester. Therefore, the data collection was different across the two semesters. In the first semester, the first half of the semester was about CAD modeling, and at week 8 design lectures and the team projects started. Both peer evaluation and self-evaluation were collected online at the end of the semester upon the teams finishing their final presentation and report. In the second semester, the team project started in the first week and CAD modeling and the design process were alternated bi-weekly to give students more time to incubate their design ideas. Three online peer evaluations were conducted in Weeks 5, 10, and 15, respectively. A self-evaluation was done in Week 15. Students were instructed to provide objective and honest evaluations. Figure 2 depicts the timeline of the projects and data collection.

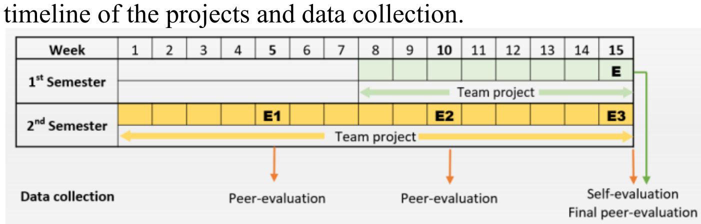

FIGURE 2: TIMELINE OF THE TEAM PROJECTS AND THE DATA COLLECTION

Self-evaluation

The self-evaluation survey was created on Qualtrics, and a submission was requested by the end of each semester. The assignment was graded based only on submission status instead of the actual responses to the survey. The response rate was 98%. The survey asked a series of questions to obtain information related to student creative self-efficacy (CSE), engineering design self-efficacy (EDSE), teamwork preferences, and interests in engineering design.

Creative self-efficacy was measured by a three-item creative self-efficacy (CSE) scale, which asks participants to rate the extent to which they agree/disagree with three statements (e.g., "I have confidence in my ability to solve problems creatively.") on a seven-point scale. It has been used in several published works in the past [40–42].

The engineering design self-efficacy (EDSE) measure was proposed by Carberry and his colleagues [43], which is a 9-item statement based on the major steps in engineering design. The originally proposed measures evaluate confidence, anxiety, motivation, and success on all the steps related to engineering design [43]. This research is more interested in engineering design confidence, and therefore, only the instrument regarding confidence to perform the 9 tasks in engineering design (e.g., identify a design need, research a design need, develop design solutions, select the best possible design) were analysed, using an approach similar to that of Ref [42].

A five-point scale from 1 (very low) to 5 (very high) was used to query students' enthusiasm about engineering design and their preference for teamwork in general, not specifically tied to this class. Other information collected is beyond the scope of this paper; therefore, it is omitted here.

Peer-evaluation

Peer evaluations were conducted with slight variations due to changes in the course structure, but the core questions regarding individual members' contributions remained consistent. In the first semester, a single peer evaluation was administered through Qualtrics at the end of the semester. Students were instructed to distribute 100 points among all team members, including themselves, to reflect their perceived contribution levels. Additionally, they were required to provide justifications for the assigned percentages. All responses were confidential and accessible only to the instructor. The response rate for this evaluation was 100%. In the second semester, peer evaluations were conducted three times throughout the semester (Weeks 5, 10, and 15). These evaluations were completed online via the Teammates platform[2]. Students assessed both their own contributions and those of their teammates while also providing written justifications. Additionally, they were asked to comment on team dynamics and share feedback for each teammate. While the feedback directed at specific teammates was visible to the respective recipients, all other responses were accessible only to the instructor. The average completion rate across the three evaluations was 97%.

4. RESULTS

This section describes the data processing and analysis methods, followed by a detailed presentation of the results.

4.1 Data analysis

4.1.1 Data processing

To examine the relationships between team diversity and contribution equity, quantitative data of individuals were processed into means (μ) and standard deviations (σ) at team levels. Therefore, the sample of 109 participants across 26 teams resulted in 26 data points. The data processing for each measure is described below.

Contribution equity. Team contribution equity was measured by individual members' contribution variations from the peer evaluations. Similar to the work in [20], the variation of a team was represented by the standard deviation (σ) of its members' contributions. The higher the standard deviation, the less the contribution equity. In the context of undergraduate

[2] https://teammatesv4.appspot.com

engineering design classes, teams that collaborate well are expected to have better contribution equity (i.e., lower σ).

In this study, each team member's contribution was determined by averaging the ratings they received from their teammates across all peer evaluations. In the first semester, the average perceived contribution for a team member was either 20 or 25, depending on team size (i.e., average = 100/team size, with teams consisting of either 4 or 5 members), since the total contribution sum per team was set to 100. In the second semester, the average contribution value was 100 due to the internal calculation method used by the Teammates platform, which required ratings to sum to team size × 100/equal share. To ensure consistency across both semesters, each individual's perceived contribution score from the first semester was multiplied by their respective team size (4 or 5) to align the scales. For example, if a team member in a five-person team received an average contribution rating of 22 in the first semester, this score was adjusted to 22 × 5 = 110 to match the second-semester scale. Similarly, a member in a four-person team with an average rating of 26 was adjusted to 26 × 4 = 104. This conversion ensured that all contribution ratings were comparable across both semesters.

Finally, the standard deviation (σ) of perceived contributions within each team was calculated to represent team contribution equity as the outcome variable.

Diversity factors. As mentioned in Section 3.1, the diversity of teams in this study concerned gender, creative self-efficacy (CSE), engineering design self-efficacy (EDSE), teamwork preferences, and interests in engineering design. Due to the disparity of gender ratios, the teams were either all men or only had one or two women. Therefore, gender diversity was considered as a categorical variable. Teams were separated into two categories: gender homogenous (all men teams) and gender heterogenous (men and women mixed in a team).

Other factors (CSE, EDSE, teamwork preference, and design interests) were considered as numerical variables. Standard deviations (σ) of each were derived to represent the diversity level of a team with regard to a specific factor. The larger the σ, the more diverse a team is in terms of its associated factor.

CSE of an individual team member was calculated as an average across the three seven-point Likert scale items. Similarly, EDSE of an individual team member was calculated as an average of the ratings (0-100) on all 9 engineering design tasks of that individual. Teamwork preferences and design interests were both measured with one five-point Likert scale item, respectively, and their ratings were used directly.

Furthermore, the team mean score of each factor was also calculated. These team mean scores will be used to explore whether team contribution variations could be explained by the team's collective levels of CSE, EDSE, teamwork preferences, and design interests.

4.1.2 Correlation check of all the diversity factors and contribution equity

This study is interested in the impact of team diversity on contribution equity, in terms of gender, CSE, EDSE, teamwork preference, and design interest. Due to multiple potential predictors, multiple linear regression is selected as the data analysis method. As suggested by Ref [44], the correlation of each variable pair should be computed before the regression analysis, and the ones that have a higher correlation with the response variables should be selected as predictors in the regression model while avoiding multicollinearity between predictor variables. Table 1 summarizes the correlations between all measures, with green indicating significance at the .05 level and with blue indicating significance at the .001 level.

TABLE 1: CORRELATIONS OF ALL THE DIVERSITY FACTORS AND CONTRIBUTION EQUITY

	Contribution σ	CSE σ	EDSE σ	Teamwork σ	Design σ	CSE μ	EDSE μ	Teamwork μ	Design μ
CSE σ	-0.12								
EDSE σ	0.28	-0.22							
Teamwork σ	**0.44**	0.00	-0.11						
Design σ	**0.42**	-0.10	**0.49**	0.11					
CSE μ	-0.10	-0.69	-0.05	0.18	-0.22				
EDSE μ	-0.42	0.01	-0.61	0.09	-0.33	**0.47**			
Teamwork μ	-0.42	0.00	-0.21	-0.54	-0.31	0.19	**0.44**		
Design μ	-0.35	-0.15	-0.41	-0.29	-0.66	0.28	**0.47**	**0.57**	
Women%	-0.49	0.16	-0.17	-0.39	-0.13	-0.16	0.16	**0.40**	**0.43**

The highlighted correlations are significant, with green color indicating $p<0.05$, and blue color indicating $p<0.001$. The significant positive correlations are bolded.

In terms of diversity (variations within a team), only three factors are significantly correlated with contribution σ, namely teamwork σ (r=0.44, $p<0.05$), design σ (r=0.42, $p<0.05$), and women% (r=-0.49, $p<0.05$). In addition, EDSE μ (r=-0.42, $p<0.05$) and teamwork μ (r=-0.42, $p<0.05$) each have significant negative correlations with contribution σ. From the correlation table, teamwork μ is also significantly correlated with teamwork σ (r=-0.54, $p<0.001$) and EDSE μ (r=0.44, $p<0.05$). We suspect that teamwork μ should be removed from the predictors to avoid the multicollinearity issue, but we will further confirm this through the model comparisons in the next section.

4.1.3 Model selection

The factors that are significantly correlated with contribution σ were all considered as potential predictors, including teamwork σ, design σ, EDSE μ, teamwork μ, and women%, as shown in Table 2 above. The categorical variable gender was also added (homogenous vs. heterogenous) to let the model comparisons suggest which variable about gender composition is a better predictor (women% vs. gender). To select predictors, we used criterion-based methods with R olsrr package [45]. It started with building distinct models through different combinations of the potential predictors to predict contribution σ. Based on the well-defined objective criterion (i.e., having the largest R-square value and the smallest AIC- Akaike Information Criterion or BIC- Bayesian Information Criterion), an optimal model with four predictors: gender, design σ, teamwork σ, and EDSE μ was selected. Note that the model comparisons further confirmed that even though women% and teamwork μ are significantly correlated with contribution σ, they should be removed from the model to avoid the multicollinearity issue with other predictors.

Next, a multiple linear regression analysis was performed to examine the influence of the four predictors on contribution σ. The regression model showed that gender heterogeneous, design σ, teamwork σ, and EDSE μ explained 56% of the variance from contribution σ. ANOVA test found that this value was significantly different from zero, F=6.73, p=0.001, R^2=0.56. More details of the model results are summarized in Table 2.

TABLE 2: SUMMARY OF THE OPTIMAL MODEL ("**", p<0.01)

	DF	Sum of Squares	Mean Square	F	Prob>F	R^2	AIC 182
Model	4	1147.01	286.75	6.73	0.001 **	0.56	
Error	21	895.39	42.64				BIC
Total	25	2042.40					185

4.2 Results

The optimal model, as shown in Equation (1), tested whether gender, design σ, teamwork σ, and EDSE μ each affect contribution σ. The model parameter estimates and their confidence intervals are summarized in Table 3.

$$Contribution\ \sigma\ = 34.11 - 3.29 * Heterogenous + 6.95 * Teamwork\ \sigma + 6.01 * Design\ \sigma - 0.43 * EDSE\ \mu \quad (1)$$

TABLE 3: PARAMETER ESTIMATES ("*", p<0.05, "#" p<0.1)

	Estimate	Std Error	t Ratio	Prob>|t|	Lower and Upper 95% CI	
Intercept	34.11	23.60	1.45	0.163	-14.97	83.19
Gender[Hete-rogeneous]	-3.29	1.46	-2.25	0.036 *	-6.33	-0.25
Teamwork σ	6.95	3.36	2.07	0.051 #	-0.03	13.93
Design σ	6.06	3.49	1.73	0.098 #	-1.21	13.32
EDSE μ	-0.43	0.27	-1.58	0.128	-0.98	0.13

Result 1: Gender diversity on teams significantly affects contribution equity. The obtained t-statistic in Table 4 shows the effect of gender composition on a team's contribution equity is significantly different than zero (t=-2.25, p=0.036<0.05). More specifically, a gender heterogeneous team is more likely to have significantly smaller contribution variations (n=10, mean=3.84, se=0.87), i.e., closer to contribution equity, than a gender homogenous team (n=16, mean=13.91, se=2.37), as visualized in Figure 3.

Result 2: Team diversity in terms of their interests in teamwork and engineering design might affect contribution equity. The t-statistics in Table 4 indicate that both teamwork σ and design σ have a marginal effect on contribution σ (teamwork σ: t=2.07, p=0.051<0.1; design σ: t=1.73, p=0.098<0.1). The positive t-values at 0.1 significant level show a promising trend that the more diverse a team is, in terms of individuals' teamwork preferences and design interests, the bigger the contribution variations. In other words, when the team members are more alike with each other about their teamwork preferences and design interests, the team members will be more likely to contribute fairly.

FIGURE 3: MEAN CONTRIBUTION σ IS SIGNIFICANTLY HIGHER IN GENDER HOMOGENOUS TEAMS THAN IN GENDER HETEROGENOUS TEAMS. THE GREEN DIAMONDS INDICATE 95% INTERVALS OF MEANS, AND THE BLUE LINES SHOW STANDARD ERRORS (se).

Result 3: No significance of the team average level in terms of Engineering Design Self Efficacy (EDSE) was found on contribution equity. Even though EDSE μ is significantly correlated with contribution σ as shown in Table 2, the t-statistics of its regression coefficient do not show that it is a significant factor that predicts contribution σ in Table 3 (t=-1.58, p=0.128>0.1). That means even if all members of a team have higher EDSE, it does not mean that they are more likely to contribute their effort fairly.

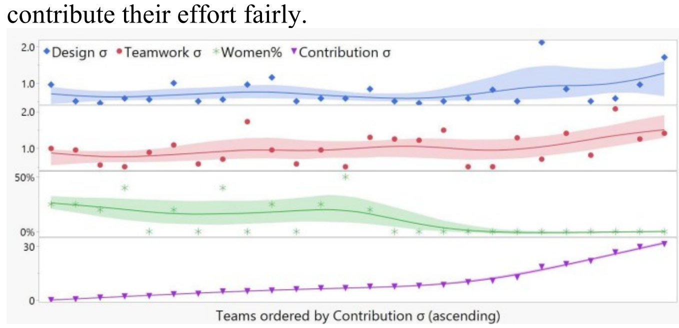

FIGURE 4: DESIGN σ, TEAMWORK σ, WOMEN%, AND CONTRIBUTION σ OF ALL TEAMS, SORTED IN AN ASCENDING ORDER BY CONTRIBUTION σ.

Overall, the relationships between the significant factor (result 1), marginally significant factors (result 2), and contribution σ are plotted in Figure 4 below to show the visual trend. Note that the categorical variable about gender (homogenous vs. heterogenous) is used in the regression model due to that woman % only has four values: 0%, 25%, and 50%, and it does not make sense to use it as a numerical variable in the analysis. However, to show the trend visually, gender is represented as women % in the figure. The fitted lines show the trend of each factor when contribution σ gets larger. It is obvious that the smaller the women%, the larger the contribution σ. The relationships between teamwork σ, design σ, and contribution σ are less clear, even though there is a trend that the more aligned teams in terms of teamwork preferences and design interests are more likely to contribute fairly.

5. DISCUSSION

The main goal of this study was to examine the relationship between team diversity and contribution equity in the context of engineering design projects. The concept of diversity in this research encompassed gender differences (surface-level diversity) and variations in self-perceived abilities and interests (deep-level diversity), including creative self-efficacy (CSE), engineering design self-efficacy (EDSE), teamwork preferences, and design interests. Our main findings were as follows:

- Members in a gender heterogeneous team were significantly more likely to contribute fairly than those in a gender homogenous team.
- When the team members were more alike with each other in terms of their teamwork preferences and design interests, they were more likely to contribute fairly.
- The average level of a team EDSE did not significantly affect its members' contribution equity propensity.

Gender diversity and contribution equity. The most remarkable finding of this study pertains to the impact of gender diversity on contribution equity within engineering design teams. As visually depicted in Figure 3, the contribution variations within gender homogenous teams were more than doubled compared to their gender diverse counterparts. The result that members in gender heterogeneous teams were significantly more likely to contribute fairly than those in gender homogeneous teams underscores the importance of gender diversity in promoting equitable collaboration.

This finding aligns with existing literature that suggests diverse teams, including those with gender diversity, tend to exhibit a broader range of perspectives, which can lead to improved problem-solving and innovation. Women are often reported to contribute more to group work than men [46], and teams with more women experience better performance due to the relationship-building and increased interpersonal communication that occurs [47]. It is plausible that the higher likelihood of contribution equity in more gender diverse teams might be attributed to women providing a mechanism for fostering cohesion among team members, similar to the mechanisms discussed in [38,48].

However, it is important to note that the study conducted by Cole et al. [49] found that there was no difference in psychological safety or the comfort level of team members when it came to sharing their opinions among members with and without gender diversity.

One limitation of our study is the relatively low representation of women students in engineering classes, which led to limited gender diversity in the teams. This limitation is reflective of the current landscape in engineering disciplines. Nevertheless, our findings still hold ecological validity. Future research in this area could further investigate the specific mechanisms through which gender diversity impacts contribution equity. It may also be valuable to explore how various forms of gender diversity, such as representation of underrepresented genders, influence team dynamics and work distribution differently.

Interest similarity (teamwork preference and design interest) and contribution equity. Another noteworthy finding highlights the influence of deep-level diversity, encompassing self-perceived abilities, interests, and teamwork preferences, on contribution equity within engineering design teams. The results indicated when team members shared similarities (less diverse) in their teamwork preferences and design interests, they were more likely to contribute fairly. This finding emphasizes the importance of compatibility in team dynamics and how shared interests can foster more equitable participation. Conversely, it implicitly suggests that not all manifestations of diversity contribute harmoniously to team dynamics. Thus, the concept of diversity emerges as a multifaceted construct, necessitating a nuanced approach to the constitution of teams.

Our findings are consistent with prior research emphasizing the importance of shared goals and mutual understanding in achieving effective team performance [50]. In particular, Mocko and Linnerud [51,52] examined student motivations in capstone design projects and found that common motivations among team members were linked to improved performance. This aligns with our interpretation that similarity in design interests and teamwork preferences may reflect a broader alignment in motivational factors, which in turn contributes to greater equity in team contributions. These insights reinforce the notion that it is not merely diversity itself, but the alignment—or misalignment—of key individual attributes that shapes team effectiveness.

It is important to note the potential interplay of multiple factors within this complex dynamic. For instance, Nolte et al. [53] observed an increase in individuals' self-efficacy resulting from participation in team design activities alongside individual reflection. Similarly, Hilton et al. [54] established a positive correlation between EDSE and active engagement in maker spaces. Our findings further illuminate that the homogeneity of teamwork interests and design interests is an influential factor in contribution equity. We speculate that the similarity of group work interests and design interests is a pivotal factor dictating the degree of individual contributions. Teams might exhibit a greater capacity to navigate disparities in self-perceived ability levels, particularly when members share a collective enthusiasm for collaborative work in design. Nevertheless, Gunay et al. [55] reinforces the importance of engineering design projects possessing multidisciplinary appeal and gender neutrality to enhance individuals' commitment to a project.

These diversity measures rely on individuals' self-perceptions, which may be influenced by intentional or unintentional biases [46]. For example, Madrazo et al. [56] have found that female individuals tend to undervalue their performance, consistently ranking themselves lower than their male peers. Although self-perception on some measures showed no significance in our study, underlying biases may still influence group dynamics. Future research with a larger and more diverse cohort is needed to further explore these biases and their impact on teamwork.

Average self-perceived ability and contribution equity. Contrary to common expectations, the average level of a team's EDSE did not significantly affect its members' tendency to contribute fairly. This suggests that while self-efficacy is a principal factor in individual performance and confidence in design tasks, it may not be as crucial in shaping the overall distribution of work within a team context. Furthermore, the effect of collective CSE on team contribution equity was inconclusive, primarily due to its exclusion as a predictor in our regression model, given its high correlation with EDSE. This preliminary insight highlights the critical notion that merely assembling a team of highly capable individuals, such as each possessing strong EDSE, does not inherently guarantee more balanced participation within the team.

Our finding echoes prior studies [50], recognizing the complexity of team composition and dynamics and illustrating that building an effective team extends far beyond a mere aggregation of individual talents. While aggregating a team of highly capable individuals may play a role in performance and problem-solving, it does not appear to be a primary factor in promoting participation equity within teams. In other words, factors such as alignment in teamwork preferences and design interests, gender diversity, may overshadow the influence of collective EDSE in shaping contribution equity. Realizing that contribution equity relies on multifaceted interactions and interdependencies among team members is vital for organizations and team leaders seeking to optimize teamwork.

Diversity should not be regarded as a singular measure. Not only are there many different types of diversity, these different types also have unique relationships to contribution equity in teams. This is important to consider when forming teams and attempting to gain the most benefit from teamwork. Teams cannot be made diverse in every way and expect to have similar benefits. To take advantage of the benefits of diversity in collaboration, a more nuanced approach to building diversity in teams which considers the many ways teams can be diverse must be taken. Ultimately, more effectively functioning teams will help individuals develop stronger relationships with their peers and prepare them for future professional work.

Limitations and future work. While the study offers valuable insights into the relationship between team diversity and contribution equity in engineering design projects, several limitations should be considered when interpreting the findings. First, the study has a relatively small sample size, primarily consisting of individuals from one engineering class at a single university. This limited representation may not capture the full spectrum of experiences and dynamics found in diverse engineering education settings. Consequently, the findings may not be fully generalizable to broader engineering programs or institutions.

Moreover, we acknowledge that we had a relatively low representation of women students in engineering classes, resulting in limited gender diversity within the teams. As gender diversity was a central focus of the study, this limitation may have influenced the results and might not fully reflect the potential benefits of gender diversity in engineering teams. Even though individuals’ contributions were all obtained from peer evaluations, the second semester had more data collection points than the first semester (i.e., three peer evaluations spread out the semester instead of one at the end). Future research should consider multiple peer evaluations to more accurately assess individual contributions.

Another limitation is the study primarily relies on survey measures to assess self-perceived abilities and interests. These measures may not fully capture the intricacies of student experiences in engineering design teams and may not account for subtle or contextual factors influencing contribution equity. For example, peer evaluations may not perfectly reflect actual contributions, as they can be influenced by factors such as communication frequency, visibility of work, or differing team schedules. Future work may incorporate additional data sources, such as task logs or instructor observations, to triangulate peer-reported contributions and improve accuracy. Joo [46] discussed the limitations in having individuals answer questions about a past experience as this may lead to inaccurate recall. Additionally, individuals may misrepresent their contributions, whether intentionally or unintentionally, to portray themselves in a more positive manner. A comparable phenomenon was theorized in the research of Tekle and Sado [21] as data were gathered from interviews and individuals may have been reluctant to share perceived sensitive topics with the interviewer which likely led to instances of conflict being underreported in the study. Finally, while we claim ecological validity, the specific context and characteristics of the study participants may limit the generalizability of the findings to other engineering education programs or diverse settings.

In light of these limitations, it is essential for future research to address these constraints and conduct more extensive investigations to refine and expand upon the insights presented in this study. Additionally, researchers should consider employing mixed-method approaches that combine self-perception measures with qualitative data to provide a more comprehensive understanding of the complex dynamics within engineering design teams.

Implications. The findings presented in this study offer profound implications for engineering education programs, shaping the way teams are composed and fostering a more inclusive and equitable learning environment. Engineering programs should actively promote gender diversity within student teams. The significant impact of gender diversity on contribution equity highlights the need to encourage participation from all genders in team design projects. Initiatives encouraging women and other underrepresented genders to pursue engineering education can enhance collaboration, problem-solving, and innovation within teams.

In addition to ensuring gender diversity, engineering educators should prioritize compatibility and shared interests as they form teams. Encouraging students to explore and articulate their interests can lead to the formation of more cohesive teams, fostering equitable participation and collaborative engagement. Engineering programs often emphasize individual capabilities, but this study suggests that collective self-efficacy, particularly in engineering design tasks, does not guarantee participation equity. Instead of solely focusing on individual abilities, programs should also prioritize developing students' teamwork skills to enhance their interests in design, which is crucial in fostering contribution equity within teams.

Recognizing the complexity of team composition and dynamics, engineering educators should prioritize the development of collaborative skills. Curricula should incorporate activities that enhance teamwork, communication, and conflict-resolution abilities. By fostering these skills, programs can prepare students not only for academic success but also for effective collaboration in future professional life.

Incorporating these implications into engineering education programs can not only optimize teamwork dynamics within student projects but also equip future engineers with essential skills for diverse and collaborative work environments. By promoting gender diversity, fostering compatibility, emphasizing teamwork skills, embracing diverse teams, addressing biases, and nurturing collaborative skills, engineering programs can play a pivotal role in shaping the next generation of engineers who thrive in diverse and inclusive workplaces.

6. CONCLUSION

In this paper, we examined the relationships between team diversity and contribution equity in engineering design projects from multiple aspects. Based on the findings, we concluded that diversity of teams is important to contribution equity but needs to be considered carefully based on the situation. The more diverse the teams were in terms of gender; the more likely contribution equity was to occur. At the same time, the less diverse the teams were in teamwork preferences and design interests, the more likely contribution equity was to occur. The average perceived abilities of a team did not emerge as an important factor in affecting team contribution equity. As social loafing and dislike of group work are prevalent despite group work being a necessity in the workforce today, an understanding of these relationships is important to improving the quality of team collaboration. With greater knowledge of factors related to increased contribution equity, groups can be better formed and have more effective teamwork. Recognizing that different types of diversity have different effects on contribution equity is instrumental for instructors and project managers to build efficient teams and thus enhance the team members' experience and work productivity.

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