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The Relationship between Team Gender Diversity, Idea Variety, and Potential for Design Innovation*

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Design teams are commonly formed in engineering courses with the expectation that gender diversity will lead to more innovative solutions, but few studies have examined this relationship. In this study, we investigated whether the variety of ideas and the innovative qualities of team design solutions are related to team gender diversity. The research participants were 148 engineering students working in 37 teams. These teams were identified as gender balanced or all-male based on their gender composition. Their idea generation outcomes and final design solutions were evaluated using an established variety metric and a new innovation potential metric developed by the authors. The innovative potential, variety scores, and correlation between variety and innovation potential were compared with respect to team gender diversity. The results indicated that gender balanced teams were no more innovative than all-male teams, nor were there any significant differences in the variety of alternative solutions between the two groups. Gender balanced teams, however, did demonstrate a strong positive correlation between variety and innovation potential. Results suggest that diversity, defined by gender alone, may not increase the innovation potential of student design teams but may support innovation in the presence of other factors. Efforts should focus on helping teams better utilize their diversity to improve their ability to be innovative.

Keywords: design; gender diversity; idea variety; innovation potential

1. Introduction

Innovation is the process of creating, testing, developing, and disseminating novel products, processes, or systems that are technologically feasible, economically viable, and desirable to the users [1, 2]. Engineers foster innovation by assuming a variety of roles during all stages of the innovation process; hence, the success of an innovation process often depends on the contributions from, and the collaboration of, a diverse set of people [2–4]. Previous studies point to diversity as a means to cultivate innovative thinking and create a competitive advantage for companies [5–12]. When managed well, diverse teams are capable of producing creative solutions, considering a broad range of stakeholders, and applying comprehensive criteria and evidence to decision-making processes [5, 7, 13, 14]. As such, people who contribute to the diversity of workplaces are sought by employers and managers [4, 15].

Team diversity, however, can take many forms. Many studies utilize aggregate measures of team diversity by combining demographic and functional attributes [16, 17]. Others argue that specific diversity categories such as gender, age, and functional background should be considered separately since they can have different effects on team functioning and outcomes [18]. One oft cited attribute is gender diversity. Companies employing more women have demonstrated greater innovation than those with a less gender diverse employee base [7, 8, 11, 19, 20]. Few studies, however, have explored these findings at the team level [18], and whether they might translate to undergraduate engineering students.

Teamwork studies in engineering education have contributed a variety of relevant findings. Svihla [21], for example, found that process elements such as team cohesion, which is often associated with gender homogenous teams, and perspective-taking, which is often associated with mixed gender teams, contributed to innovative outcomes for senior design teams in biomedical engineering. Other studies have focused on whether gender diversity affects team design outcomes. Lau and colleagues noted that teams of engineering graduate students with more balanced gender compositions performed better on an innovative design project [22]. Conversely, two studies that examined design performance among undergraduate engineering teams with different gender compositions found that gender homogeneity improved design outcomes, although they did not focus on explicitly innovative design [23, 24]. Qualitative studies have also explored dynamics, culture, and functioning among engineering student teams with different gender compositions [25–30]. These studies indicate that team roles and contributions of female students

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may be minimized in mixed gender teams, and moreover, that the minimized roles may result from gender norms learned throughout one's undergraduate engineering career [26].

Collectively, this prior research on gender diversity in student engineering teams suggests, but does not substantiate, claims of potential differences in team innovative abilities based on gender composition. In this study, we build on the above prior work by examining the relationship between team gender diversity and innovation potential among teams of first-year engineering students. We investigated first-year teams to better understand the role of gender diversity in engineering teams before gender norms begin to solidify [26, 29]. Specifically, our research questions are:

- Do gender balanced teams achieve greater idea generation variety during a first-year engineering innovation project?
- Do gender balanced teams produce design solutions with greater potential for innovation?
- Does a relationship exist between idea generation variety and innovation potential in gender balanced or all-male teams?

2. Literature review

2.1 Definition of innovation

Innovation has been categorized as an individual characteristic or competency, a process, an outcome, and a product of a particular work environment or culture [2, 14, 31–34]. While each of these dimensions of innovation contribute unique understanding of the concept as a whole, the two dimensions most germane to this study are *process* (i.e., understanding the effect of team gender diversity on team functioning) and *outcome* (i.e., comparing effectiveness of teams with different gender compositions). As a process, innovation can be defined in terms of a series of stages from identifying a problem, new technology, or market need through adoption of the product, process, or system by a significant portion of the market or community [1, 35]. Figure 1 describes one example process.

As an outcome, an innovation often marks significant change [36]. Many suggest that to achieve such change an innovative outcome must demonstrate a combination of novelty and usefulness [37–39]. This view is limited because it does not consider social, business, and technical aspects that might hinder a potential innovation on its path to diffusion and change. Innovative companies such as IDEO [2] argue that innovative designs must also be feasible, viable, and desirable. In their argument, *feasibility* refers to whether the design can be created and function at a technical level, *viability* implies that the cost of the design is comparable with the current alternatives and competitors, and *desirability* requires that the design satisfactorily addresses an important user need. Similar qualities are also suggested by a variety of professional engineering innovators [34].

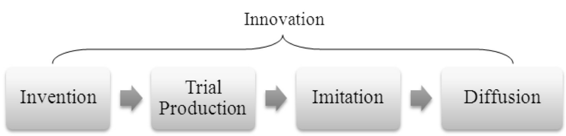

Fig. 1. Four components of innovation (Figure depicted based on Ford et al. [1]).

Our view of innovation encompasses each of these characteristics while acknowledging the role of novelty in supporting change. An innovative outcome, then, is a novel product, process, or system that is technologically feasible, economically viable, and desirable. Early in the innovation process, when project proposals are submitted, it is difficult to measure and quantify the feasibility, viability, desirably, and novelty of a design idea. Such uncertainty only grows when evaluating student designs, which are often less detailed than professional proposals. Thus, in this paper we use the term *innovation potential*, which refers to an idea's potential for innovation rather than actual innovativeness.

2.2 The role of idea generation variety in innovation

Idea generation variety captures the extent to which a designer or design team has identified the range of possible solutions to a particular design problem [38]. Many suggest that variety in ideas generated is necessary for quality design outcomes and innovation [38, 40, 41]. For example, teams that identify an array of possible solutions to a design problem are more likely to select a solution that has the potential to be innovative [41]. These teams are also able to identify more salient features of potential solutions [38], and thus are better equipped to modify or synthesize ideas for innovativeness [40]. While no conclusive link between idea generation variety and innovation has been identified, many researchers use idea generation outcomes as measures of innovativeness and engineering creativity [38, 42–44]. Furthermore, innovative companies champion ideation practices that result in a variety of solutions [2].

Despite the perceived importance of idea generation variety, novice designers typically do not identify a diverse array of ideas unless they are encouraged to consider the design problem or solution from a different perspective [45, 46]. Instead, they often experience design fixation and only consider a limited set of potential solutions [46], or even focus on a single idea [40]. Team gender diversity may be one factor that influences novice engineering students to consider a wider variety of ideas. At the team level, diversity is thought to be effective because of the broad range of perspectives and skills individuals bring to team settings [12, 17]. When team members demonstrate alternative views, their teammates are forced to confront these views and consider problems from multiple perspectives, which can inspire a greater number of potentially innovative ideas that are stronger than those developed individually or by less diverse teams [12, 47, 48].

2.3 Gender and conflict

The ability for gender diverse teams to incorporate a variety of perspectives into an engineering design process may be inhibited by increased team conflict. Examples in the literature indicate that female students are denied opportunities to participate in teams when they are outnumbered by male students [25, 49]. Male engineering students can also be more critical of their female peers [28, 50], leading to decreased opportunity and willingness to participate among female students in the team. For example, a case study conducted in an undergraduate engineering course revealed that female students tended to follow gender stereotyped roles in gender heterogeneous project teams when they otherwise would not have in all-female teams [27]. A more recent study reported similar findings with a sample of first-year students [30]. Thus, female students may not only be limited by male teammates in their opportunity to contribute to team projects, but may feel obligated to act in a particular way in their presence.

Conflict between female and male teammates can also be influenced by the specific design task. Gender-biased design tasks, or those that are perceived as such by members of a team, can highlight innate differences between male and female teammates and cause subgroups to form within a team [51, 52]. For example, Pearsall and colleagues [51] found that gender heterogeneous student teams were significantly less productive and creative on a gender-biased design task (an electric razor for men only), but were just as productive and creative on a gender-neutral design task (an alarm clock for men and women). It is important to note that the task need only be perceived as gender-biased by the design team to jeopardize team outcomes [51, 53].

As noted by De Dreu and West [13], limited participation diminishes a team's ability to utilize multiple perspectives. Thus any conflict or lack of communication within gender diverse teams is likely to decrease the innovative potential of those teams. The above literature suggests many potential sources of conflict within student engineering teams consisting of male and female students, especially those in which males outnumber females. It is unclear, however, the extent to which the decrease in productivity resulting from conflict neutralizes the positive effects of individual differences in perspectives and skills between male and female engineering students.

2.4 Individual differences in engineering student creativity, innovation, and design behavior

Much of the research promoting advantages for gender diverse teams suggests that these advantages result from differences between individual team members. Thus, differences between male and female engineering students may support the theory that gender diverse student teams would be more innovative than homogenous teams. While there appears to be no substantial overall differences in design-related ability or creativity [43, 54], gender differences in design behaviors have been shown in prior studies. Kilgore and colleagues [55] found that female engineering students were significantly more likely than male students to consider context-related issues during initial stages of design. Further, during information-gathering, female students were more likely to request information about users and surroundings while male students were more likely to ask for information about budget and costs [55]. Similarly, a more recent study found that female students exhibited a client-centered focus while male students were more likely to discuss technical limitations [56]. Another study demonstrated differences in the design concepts identified by male and female engineering students during an idea generation exercise [57].

It is important to emphasize that the gender differences reported in the studies discussed above do not suggest differences in design competency. Rather, women and men may emphasize and value different aspects of design or a given problem. These studies in combination suggest that teams comprised of male and female students may be able to consider a broader range of stakeholder needs and identify more comprehensive criteria, which could lead to more comprehensive idea generation, improved decision-making, and more innovative solutions.

2.5 Diversity in engineering student teams

In engineering education, a small number of studies have directly investigated whether gender diversity affects the outcomes of engineering design projects. Laeser, Moskal, Knecht, and Lasich's [23] study with first and second-year engineering students evaluated the quality of team design reports. In their study, engineering student teams were classified as either majority male, majority female, or mixed gender (equal number of male and female students), while omitting homogenous teams. Descriptive statistics demonstrated that among first-year teams, majority male and majority female teams outperformed gender-balanced teams on overall report scores and all individual sub-scores. Majority female teams, in particular, demonstrated strength identifying clients and their needs. With a similar population of introductory engineering students, Okudan and colleagues [24] found that all-male and all-female teams outperformed mixed gender teams and majority male teams. In another study, Lau, Beckman, and Agogino [22] examined the quality of design project reports and compared their results based on gender composition. In contrast to previous studies, Lau and colleagues focused on graduate engineering students. In this study, teams with more balanced gender distributions tended to receive better scores.

The findings of these studies suggest that gender diversity may influence team performance, but do not agree on a team composition that results in positive change. One possible explanation is that the graduate students in Lau and colleagues' study were better able to utilize their gender diversity due to experience or maturity, but none of these studies included enough teams for meaningful statistical comparison. Further, they did not focus explicitly on innovation outcomes.

3. Research design

3.1 Participants

A total of 238 students (82% male, 18% female) were enrolled in two sections of a first-year engineering design course. These students were all in their first semester of a dedicated first-year engineering program and had not yet selected specific engineering majors. During the third week of the semester, students were placed into permanent four-person teams based on schedule compatibility. In addition, the team assignments attempted to avoid isolating individual females or ethnic minorities in teams. Teams were the unit of analysis.

Among the 60 teams, 23 teams were not included in the study due to at least one the following reasons: (1) we did not have access to the team reports, (2) design solutions were insufficiently detailed to reasonably assess for innovative potential, (3) three-person teams and majority male or female teams were not considered for the analysis (for further justification see the *Data Sources* section). The final data analysis was based on 37 teams of four (totaling 24 females and 124 males). Twelve of these were gender balanced teams (two female and two male students) and 25 were all-male teams.

3.2 Classroom setting & team design project

This study took place in the context of a first-year engineering design course during the Fall 2010 semester. The class served as an introduction to engineering, covering engineering design, mathematical modeling, teamwork, and communication skills. It was required for all students in the engineering program. Throughout this course, students worked in teams both in and out of class. In-class activities were typically short thought exercises (e.g. think-pair-share), analysis tasks, or hands-on design problems. Outside of class students completed two model-eliciting activities in teams and weekly homework that often contained a team component. Students also completed a brief unit on diversity training. The course culminated in an eight-week design project, completed both in and out of class.

The goal of the design project was to propose a transportation system for the university campus. Students were given in-class presentations and information on the current campus transportation system and were expected to conduct their own research. The director of campus planning presented the need for a new system and provided information on the history of campus planning and the university's plans for the future. There were no restrictions to solutions students could propose. However, they were directed to address three stakeholder needs: (1) increase use of public transportation, (2) reduce consumption of non-renewable energy for public transportation, and (3) propose a futuristic and innovative solution. Students were not given a specific cost constraint but had information on the cost of maintaining the current system, which could help them identify a competitive budget for their project. While students did not receive specific instruction on systems design, key attributes of innovative design including feasibility, viability, and desirability were stressed throughout the course. The course also covered a design process with a focus on iteration and information gathering. While students were provided with various design models, the model in Fig. 2, compiled by a course instructor, guided their project deliverables.

3.3 Data sources

3.3.1 Gender demographics of design teams

Data on student gender were gathered using a self-report survey completed by the students. Teams were defined dichotomously, based on their gender

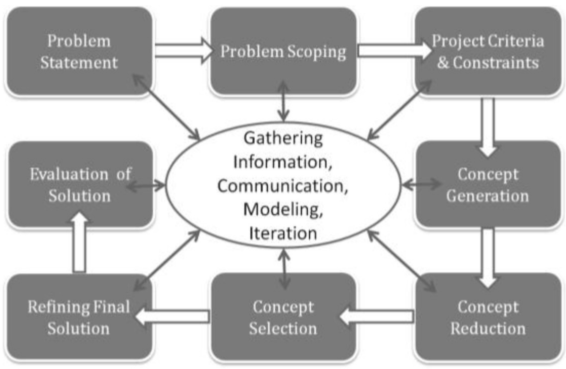

Fig. 2. Design Process Presented in First-Year Engineering Course [58].

diversity, as either all-male or gender-balanced. A *gender balanced team* consisted of two female and two male students. An *all-male team* consisted of four males. Teams with an unbalanced number of males or females (i.e., one female and three males or one female and two males) were not included in our analysis due to an insufficient number of teams at each available gender composition for meaningful statistical comparison. Thus, we used a binary comparison between all-male and evenly distributed teams rather than a more engrained examination of levels of diversity.

3.3.2 Design reports

Each team submitted a report detailing the steps of their design process and the resulting design proposal. These reports were the culmination of each team's design process and included information on their alternative and final solutions. The length of these reports ranged from five to twenty typed pages. Teams completed and received peer and instructor feedback on five milestones (portions of the design report) throughout the semester. The reports included the following content: executive summary, problem scoping, idea generation, concept reduction, and solution selection & detailing.

3.4 Data analysis

3.4.1 Calculation of variety

We calculated the variety scores of each team by adapting a metric commonly used to determine the variety of a set of engineering design ideas [38, 59] with the Function-Behavior-Structure schema [60]. In this variety metric, a set of design concepts, for example the output of a single idea generation session, is scored based on how well it covers the range of potential solutions. Evaluation occurs in three phases: (1) identification of unique concepts, (2) scoring of concepts, and (3) calculation of scores. Shah and colleagues [38] categorized concepts at four levels: *physical principle*, *working principle*, *embodiment*, and *detail*, each representing increasingly minor ways concepts can differ. Here, levels adapted from the Function-Behavior-Structure framework [60] emerged as more appropriate for students' transportation system designs. The *function* category identified the general design goal of the concept, for example, to encourage more people to walk. The *behavior* category described the method designers employed to achieve the function, for example, improving the convenience of walking. The *structure* category addressed the specific implementation that would lead to the function and behavior, for example, adding walking paths around campus.

Our metric diverges from Shah and colleagues' metric by calculating coverage of the potential solution space by the set of ideas instead of differences between ideas in the set. By evaluating coverage rather than difference we are valuing a team's ability to consider a broad range of ideas, not just variation. For example, Fig. 3 represents the idea generation outcomes for two design teams. Team 1 has only minimally covered the extent of the potential solution space (represented by the circle) by developing only two ideas (represented by letters A and B). Since ideas A and B differ from each other (represented by the distance between them), Team 1 would receive a strong variety score by Shah and colleagues' metric. Team 2 more comprehensively covered the solution space by identifying the same two ideas as Team 1 and four other closely related ideas. Compared to Team 1, Team 2 would receive a low variety score by Shah's metric, but should be better positioned to develop an innovative idea.

Using the aforementioned approach, we reviewed all design concepts from the *idea generation* section of team reports to identify the range of potential solutions and developed a system to differentiate the concepts. Teams considered a total of 70 unique concepts. Categories were designed such that each concept would have a unique code in each category. The final coding scheme contained three codes for

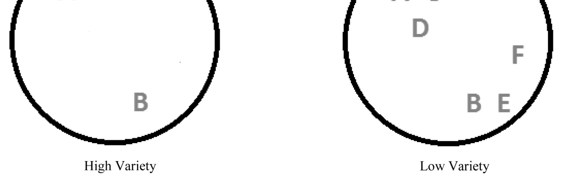

Fig. 3. A Comparison of Idea Generation Space Coverage by Two Hypothetical Teams based on Shah and colleagues' variety metric [38, 59].

Table 1. Design Solution Approaches by Level of Analysis

Function	Behavior	Structure Examples
Improve Bus System	1. Increase efficiency/sustainability	hydrogen, solar, hybrid buses
	2. Reduce traffic	optimize routes, stagger class times, create bus-only routes
	3. Increase convenience of buses	increase route frequency, bus tracking
	4. Improve riding experience	Wi-Fi, comfortable seats, safety features
Introduce Alternative Transportation	5. Provide Alternative Scheduled Service	subway, monorail, trolley
	6. Provide On-Demand Transportation	taxi service, gondolas, zip line
	7. Provide User Rentals	bike, small car, Segway
Encourage Pedestrians	8. Assist pedestrians	moving walkway, floating torus
	9. Increase convenience of walking	repave paths, add paths, tunnels, overhead walkways
	10. Decrease convenience of Motorized Transportation	prohibit parking, prohibit cars

function, 10 codes for behavior, and 70 codes for structure. Table 1 presents each code in the function and behavior categories, and example codes from the structure category to display the range of students' design concepts and better demonstrate the coding scheme.

During an axial coding phase, two researchers coded each design concept (N = 193) for function and behavior using the scheme depicted in Table 1. We calculated percent agreement and Cohen's kappa between raters to ensure inter-rater reliability. Inter-rater agreement after an initial round of coding was 96.9% for function and 85.5% for behavior. Kappa values were 0.95 and 0.83 respectively, indicating sufficient reliability of the coding scheme. Raters later reconciled disagreements and agreed upon codes for all concepts during a second meeting.

During the calculation phase, we considered the function, behavior, and structure of each concept a team identified in order to determine the overall variety of their set of concepts. Individual concepts increased a team's variety score based on how much they differed from previously considered concepts. Concepts that introduced a new function were awarded ten points; concepts that introduced a new behavior were awarded five points; and concepts that introduced a new structure were awarded one point. We elected to use this tiered scoring system because function-level differences are stronger than behavior- and structure-level differences, and behavior-level differences are stronger than structure-level differences. A team's unstandardized variety score is then the sum of the individual scores of each concept they reported. The unstandardized score is divided by 6.5 (one tenth the maximum possible score for a set of ten ideas, which was the maximum number of ideas reported by any team), in order to standardize variety to a 0-10 scale. Mathematically, the variety calculation can be expressed as:

$$\begin{aligned} Variety = (10 * (functions) + 5 * (behaviors \\ - functions) + 1 * (structures \\ - behaviors))/6.5 = (5 * (functions) \\ + 4 * (behaviors) + structures)/6.5 \end{aligned}$$

Table 2 demonstrates the variety calculation for a hypothetical set of design concepts. The team's unstandardized variety score was 26, the sum of points awarded for each individual concept, and their standardized score was 4.

3.4.2 Calculation of innovation potential

To evaluate the innovativeness of each solution, we employed a semi-structured innovation metric similar to those used by Dorst & Cross [61] and

Table 2. Example variety scoring

Design Concept	Points	Justification of the Points
Hybrid Bus	10	Introduced a new function (improve bus system), behavior (increase efficiency), and structure
Optimize bus routes	5	Introduced a new behavior (increase convenience) and structure within the "improve bus system" function. Did not introduce a new function
Monorail	10	Introduced a new function (alternative transportation), behavior (alternative scheduled service), and structure
Trolley	1	Introduced a new structure in existing function (alternative transportation) and behavior (alternative scheduled service)

Christiaans [62]. Such metrics allow expert raters to assess designs on a variety of general constructs using their own judgment rather than conforming to operationalized definitions of the constructs, thus reflecting a view of the constructs more consistent with those used in practice [63]. These semi-structured metrics have been used to evaluate creativity and other design aspects with high degrees of inter-rater reliability among both experts and novices [21, 62, 63]. The specific metric in this study assesses potential for innovation based on four factors: feasibility, viability, desirability, and novelty.

Two researchers rated the solutions during three 2-hour coding sessions. During these sessions, the raters had access to the original project reports and design summaries created by one of the authors. Student reports included visualizations, verbal descriptions, and performance data for their solutions. Most of the solution details were contained in the final section of the report, but raters also considered initial descriptions of the concept from the idea generation phase and other report sections that provided contextual information related to the solution.

After a review of the four evaluation categories and a coding protocol, the researchers independently rated each solution on each of the four categories on a 0–10 scale. Cohen's alphas for the initial ratings were 0.91 for feasibility, 0.82 for viability, 0.63 for desirability, and 0.80 for novelty, indicating high levels of inter-rater agreement for all constructs except desirability. In order to understand and reconcile the rating discrepancies, the researchers discussed the solution features and consulted the original reports and summaries. This process allowed the raters both to clarify how they scored each category and to consider one another's alternative perspectives, thereby strengthening their ability to agree on ratings for each solution. After each reconciliation, the researchers reached a consensus with respect to the ratings in each category for each student design. The final interpretation of each of the four categories is presented in Table 3.

Once individual category scores were determined, we used them to calculate each team's overall *potential for innovation*. The overall potential for innovation score for each team was based on a tiered system meant to model the path a design takes to diffusion and change (see Fig. 4). A solution must first be feasible before it is given serious consideration for implementation. A solution must be viable before it would be implemented. A solution must be desirable in order to be adopted by users once it is implemented. A solution must be novel in order to create change once it is adopted. Thus we set a threshold of five points in each category to represent a sufficient level of attainment, i.e., a solution with a feasibility score of five or better was feasible enough to be considered for implementation. Starting with feasibility and moving towards novelty (as described in Fig. 4), each design solution was evaluated for sufficiency. If it met the threshold in one category, it moved to the next category. A solution was given five points for each successive threshold it met. Once a solution did not meet a threshold, for example if it scored six in feasibility, seven in viability, and three in desirability, it could not move forward. Its innovation potential score was five times the number of thresholds it met plus the score in the category with the threshold it did not meet (13 in the previous example). Fig. 4 demonstrates the score ranges for each solution category (infeasible solutions ranged from zero to four points). Solutions deemed to have strong potential for innovation scored well in all four categories.

Table 3. Categories for Potential for Innovation Assessment

Category	Description
Feasibility	Evaluates whether a proposed solution can be implemented given current conditions. The primary considerations are whether the required technology exists and whether the solution fits into the current infrastructure. For example, neither teleportation devices nor water taxis are feasible solutions because, respectively, they do not exist and the university's campus would not support a system of waterways.
Viability	Evaluates whether a proposed solution can be easily introduced and maintained. The primary consideration here is with cost (both implementation and operation). Student designs often lacked reliable cost information, so researchers estimated viability levels based on number of vehicles, amount of construction required, worker salaries, expected maintenance, and newness or intricacy of technology.
Desirability	Evaluates whether target users will want to utilize the proposed solution. This category depends upon the specific design problem and the target users. In this particular problem, the key elements of desirability included transportation speed, frequency, safety, fun, and comfort.
Novelty	Evaluates how different a solution is to other existing designs. A high score would be awarded to solutions that do not exist anywhere, but we also considered how closely the solutions resembled the current system on campus and whether similar solutions are prevalent in other campus settings. By taking a local rather than historical view of novelty, we placed more emphasis on the specific context of the design problem—students were designing a solution for a specific location and group of stakeholders rather than a universal product to be marketed worldwide—and allowed student solutions to fill a greater range of scores.

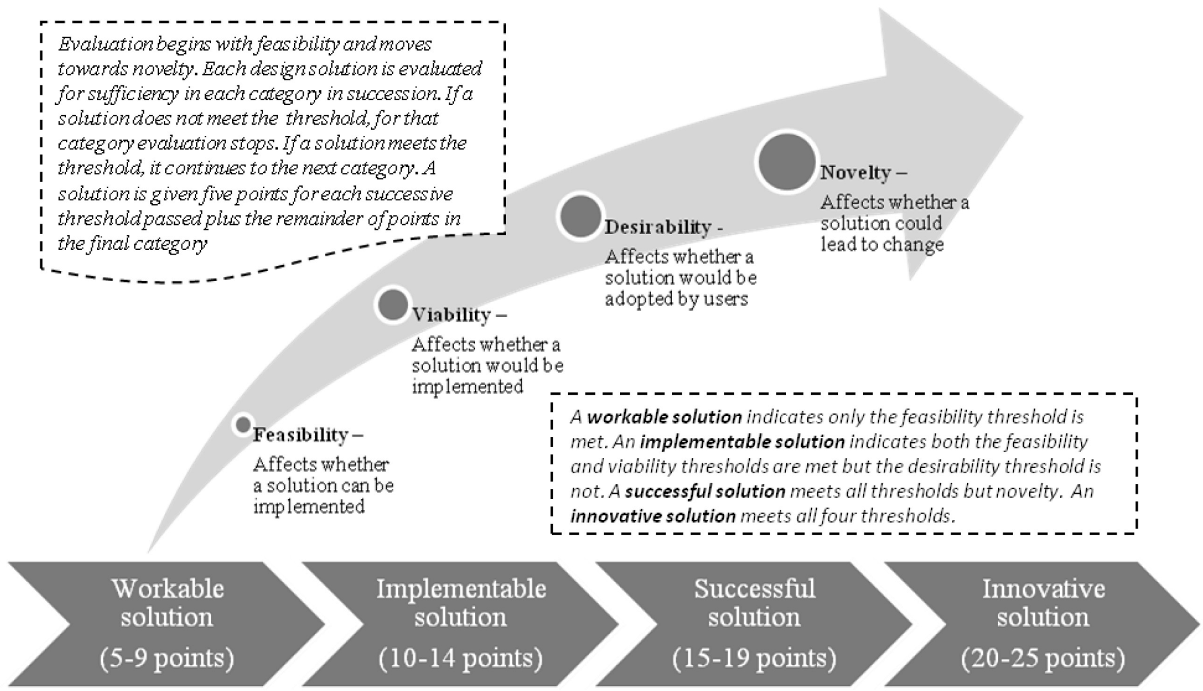

Fig. 4. Potential for Innovation Assessment.

3.4.3 Independent t-tests and correlation analysis

We compared variety, innovation potential, and individual category scores of all-male and gender balanced teams using independent samples t-tests. We also compared the Pearson's r correlation between variety and innovation potential for both gender balanced and all-male teams.

4. Results

4.1 The relationship between team gender diversity, idea variety, and innovation potential

We analyzed the idea generation variety scores to identify if gender balanced teams developed a greater variety of ideas than all-male teams. Variety scores were determined based on how well a team's set of design alternatives covered the potential design solution space. Though all-male teams had higher variety scores than gender heterogeneous teams, with a medium effect size, the results of the independent samples t-test indicated no statistically significant difference between the two groups (t (35) = 1.53, p = 0.13, d = 0.53). This finding challenges the view that gender diverse teams develop a larger set of ideas. Table 4 presents the descriptive statistics.

A comparison of the team innovation potential scores for both gender balanced and all-male teams is also presented in Table 4. The innovation scores were computed based on teams' final solutions and reflected these solutions' overall progress on the path to innovation. Gender balanced teams, on average, had higher innovation potential scores compared to all-male teams. These differences were not statistically significant and the effect size was negligible (t (35) = 0.52, p = 0.61, d = 0.18). This finding challenges the view that gender diverse teams develop more innovative design solutions.

Table 4. Comparison of Variety and Innovation Scores for Gender Balanced and All-Male Teams

	Variety Score			Innovation Potential Score		
	Gender Balanced (N = 12)	All-Male (N = 25)	All (N = 37)	Gender balanced (N = 12)	All-male (N = 25)	All (N = 37)
Mean (SD)	4.22 (1.34)	4.84 (1.05)	4.64 (1.17)	3.90 (2.70)	3.38 (2.98)	3.55 (2.86)
Min	2.46	2.31	2.31	0.4	0.4	0.4
Max	6.15	6.31	6.31	8.8	10	10

Table 5. Individual Innovation Potential Category Scores and Comparison of Means

	Gender Balanced Teams Mean (SD)	All-Male Teams Mean (SD)	*t*	*df*	*p*	*d*
Feasibility	6.17 (3.59)	5.12 (3.13)	0.91	35	0.37	0.32
Viability	4.33 (2.02)	3.96 (2.82)	0.41	35	0.68	0.15
Desirability	5.17 (2.55)	6.44 (2.18)	1.57	35	0.12	0.54
Novelty	4.75 (3.36)	6.56 (2.35)	1.90	35	0.07	0.65

Fig. 5. Variety vs. Innovation Potential for All-Male and Gender Balanced Teams.

4.2 The relationship between team gender diversity and categories of innovation potential

We analyzed the scores in individual categories of innovation potential to identify whether gender balanced teams outperformed all-male teams in any specific area of innovation. Gender balanced teams scored higher in feasibility and viability and lower in novelty and desirability, but none of these differences were statistically significant. Differences in desirability and novelty demonstrated moderate effect sizes. Table 5 presents the descriptive and inferential statistics.

4.3 The relationship between variety and innovative potential in gender balanced and all-male teams

We also examined the correlation between variety and innovation scores. In gender balanced teams, variety had a moderate positive correlation to innovation potential (r = 0.45, p = 0.14). In all-male teams, variety had a negligible correlation (r = 0.03, p = 0.94). Neither of these correlations was statistically significant, however the small sample size of gender balanced teams resulted in low statistical power of the significance test.

A plot of the variety and innovation potential scores (Fig. 5) demonstrated potential outliers, so we also tested for these using the DFFITS statistic [64]. If a single outlier (*DFFITS* = –1.34) is removed from the sample of gender diverse teams, the correlation between variety and innovation potential for gender balanced teams becomes large and statistically significant (r = 0.70, $p < 0.05$). We performed a similar outlier analysis for the all-male teams. Removal of a single outlier (*DFFITS* = 1.93) results in a small positive correlation between variety and innovation potential that is not statistically significant (r = 0.29, p = 0.35). These results suggest a general trend of idea generation variety increasing innovation potential for gender balanced teams, but one from which certain teams may deviate.

5. Discussion

5.1 Comparison of team outcomes

Our analysis revealed that gender balanced teams in a first-year engineering course, on average, did not consider a broader range of design alternatives or develop design proposals with more innovation potential than all-male teams. These findings challenge the belief that gender diversity will support idea generation breadth and innovative outcomes in team design projects. Two potential explanations for the results are that (1) individual differences between the male and female students were not sufficient to create an advantage for gender balanced teams and (2) the processes used by gender balanced teams limited opportunities to share and utilize divergent perspectives.

Although thorough investigation of team processes and individual differences is beyond the scope of this study, prior literature supports the latter explanation. Studies of first-year engineering students indicate significant differences in the way males and females approach and frame design problems [55, 56]. Studies also indicate that conflict and the actions of male students in first-year and other undergraduate teams may limit their female teammates' opportunities or willingness to contribute to team projects [26, 27, 30, 50]. It is unclear from this finding, however, the extent to which individual differences and team conflict affect team outcomes.

5.2 Variety and potential for innovation among gender balanced teams

A second key result of our study was that gender balanced teams that were able to identify a broad range of possible solutions were likely to develop final design proposals with strong potential for innovation. All-male teams demonstrated no such relationship. The logical interpretation of this finding is that gender balanced teams are better positioned to make use of a varied set of ideas during an innovation project than all-male teams. In concert with the previous findings, this result suggests that team process, especially thorough and effective decision-making, plays a key role in gender balanced teams' success. Gender balanced teams in which conflict occurs are unlikely to be successful at idea generation, and further, are less likely to achieve innovative outcomes with their final project. Gender balanced teams that include the perspectives of all team members are likely to develop an array of design alternatives and employ similar processes to further develop an innovative solution.

Since the correlation was moderate ($r = 0.45$), however, only a small portion of the variance (20%) in innovation potential was explained by idea generation variety for gender balanced teams. This finding suggests that factors other than idea generation variety, and the effective team process it suggests, play a strong role in the success of gender balanced teams. One factor could be individual skill and knowledge. Creativity and innovation research has highlighted a plethora of innovation-related competencies [14, 31, 32, 43, 65, 66]. Some team success may be attributed to individual members who are fluent in these skills. Further, the contributions of team members could have varied across the duration of the project. The gender balanced team that most deviated from the main trend demonstrated strong variety but weak innovation potential. This team may have had important contributions from all members early in the project to generate a variety of potential solutions, but may have experienced increased conflict and decreased participation or inclusion as they selected and modified their final solution. A final suggestion is that other forms of diversity may have played a role in team success. Gender represents an important way engineers can differ, but it is not comprehensive. Some research suggests that other forms of diversity, such as functional role or educational background, may also be key to variety of perspectives, team conflict, and team outcomes [16, 17, 67].

5.3 Variety and potential for innovation among all-male teams

One other interesting result is that there was no relationship between idea generation variety and innovation potential for all-male teams. This result is contrary to the literature that suggests high variety leads to improved innovative outcomes. Prior literature suggests that novice designers often spend their time modifying a single solution rather than considering a variety of alternatives [40, 68, 69]. Thus it is possible that students in all-male teams may have identified a single solution to pursue and carelessly identified approximately four more solutions to fulfill the requirement of at least five design alternatives. The success of these teams would then result from the quality of the initial solution and their ability to develop the solution into something that could be innovative. For example, the outlying all-male team developed an innovative solution by synthesizing their similar initial ideas into a single, coherent solution. Alternatively, lack of conflict may have been detrimental to some team's decision-making processes. One argument against homogenous teams is that they are more likely to experience team cohesion, which can limit their ability to consider many critical aspects of a problem [70]. Despite strong idea generation, some teams may have agreed upon a poor solution because no member noticed or voiced concern about a critical flaw.

6. Implications for teaching

6.1 Team formation

One implication of this study's findings is that first-year project teams should not be formed solely on the basis of gender composition if the instructor's primary focus is innovative project deliverables. Other factors such as team process [33] and multiple forms of diversity [67] are likely play a key role in innovativeness and overall team success. Some instructors might be inclined to avoid forming gender heterogeneous teams because of the established potential for conflict and exclusion, especially if a team contains only one female member [49, 71]. While we suggest avoiding situations that may be detrimental to long term learning, gender heterogeneity can have benefits such as effective utilization of a broad range of generated ideas and long-term teamwork skills, but care must be taken to ensure that diverse teams function well.

6.2 Facilitating effective teams

It may be that facilitation of teams, regardless of gender composition, has a stronger effect on both team innovativeness and individual learning, and thus should be considered more carefully than gender composition. While each team is unique, the results of this study in concert with previous work suggest different ways all-male and gender balanced teams commonly struggle. In all-male teams, team cohesion has the potential to cause teams to settle on a poor design alternative without considering more radical options that may also be more appropriate and successful. Encouraging teams that experience cohesion to not only identify, but seriously consider, a wider range of design alternatives can help these teams develop innovative solutions for the project as well as better prepare them for future engineering work.

In gender balanced teams, conflict may interfere with individual members working together productively, especially as the project continues and team norms begin to form. While this study does not allow us to identity the specific conflicts that occurred in the participant teams, prior research highlights some potential sources. These studies suggest that as undergraduates, and especially during the first year, male and female students are not always prepared to work together effectively [23, 25–28, 50]. The attitudes and actions of male engineering students towards female engineering students and the status quo of engineering culture can contribute to conflict, exclusion, and lack of participation. Team conflict may especially detract from creative output in the presence of a gender-biased task, such as designing a men's razor [51]. Designing projects to limit bias towards either gender is key, but it may be more important to help students understand why the project should not be biased and how both females and males are affected by the project's outcome. Moreover, conflict and exclusion could potentially be minimized as students come to understand how their actions towards teammates are perceived by those teammates, as well as the unique ways those teammates could contribute to the project given an open and supportive environment.

6.3 Encouraging innovation

In addition to factors related to gender diversity, limitations in students' ability to develop innovative solutions as well as the ability to utilize a variety of solutions are concerning. The average innovation potential score for all teams in this study was only 3.55 out of 10. It is possible that the way students define and approach innovation affects their abilities to develop innovative solutions. In problem tasks that emphasize futuristic or innovative design, students often emphasize novelty and ignore other critical aspects such as feasibility, viability, and desirability [72, 73]. In particular Cropley and Cropley [74] note a paradox between practicality and novelty for student design solutions. In this study, teams that identified novel and desirable solutions often did not ensure that they could be implemented, while the teams that identified feasible solutions often modeled their solutions closely to existing systems. This relationship is indicated by a large negative correlation between novelty and feasibility ($r = -0.73$, $p < 0.05$) and desirability and feasibility ($r = -0.75$, $p < 0.05$). Feasibility is a key engineering concern, but it must be considered in concert with other key attributes, such as whether the solution meets key user needs. A critical message for engineering innovation should be the importance of striking a balance between technical, business, human-centered, and creative thinking.

7. Directions for future research

The results of this study add to the body of knowledge on gender diversity, teamwork, and innovation in engineering education. They also suggest three paths for future research.

7.1 Team process

We found that gender balanced teams were no more innovative than all-male teams in a first-year engineering setting which suggests that team process (lack of conflict for gender balanced teams and lack of cohesion for all-male teams) perhaps played a role in team success. Further qualitative studies should investigate what conflict and cohesion look like in student engineering teams, how they are related to gender composition, and how they affect team outcomes. Mixed methods or quantitative studies could also gauge the specific relationship between gender-related conflict and innovativeness, or the ability to develop an innovative solution from a broad set of design alternatives.

7.2 Design context

Contextual factors in this study may affect its applicability to other learning environments. The limited amount of diversity training and the nature of the design project may have influenced the ways teams worked together. Future studies could explore the effect different types of design projects have on teams of different gender compositions. In particular, studies could investigate the effects of gender-biased or gender-neutral design scenarios on extended design projects. Future studies might also explore the types of diversity training that are most effective for supporting innovativeness among engineering students.

7.3 Participants

One limitation of this study is that we considered only all-male and gender balanced teams of first-year engineering students. Prior research suggests that the level of gender heterogeneity may affect team outcomes [22, 23], thus including majority female or majority male teams could add insight to how gender composition affects innovative outcomes. Repeating this study with more senior engineering students could also yield different results, for example, if more experienced students have better success working together. Finally, our study suggests that factors other than gender composition might affect team process and outcomes. Future studies should consider the effects and implications or other types of diversity, such as race and educational background.

8. Conclusions

Three key findings result from this study. First, gender balanced teams did not demonstrate greater innovation potential or idea generation variety than all-male teams in the first-year setting. Second, gender balanced teams were more likely to develop solutions with potential for innovation when they also developed a broad range of design alternatives. Third, variety was not linked to innovation potential for all-male teams.

These findings suggest a complex landscape for first-year engineering teams participating in innovation projects. Most importantly, they indicate that gender composition alone is not likely to affect the innovativeness of first-year teams. It may be that encouraging innovation, facilitating team process, and taking a more holistic view of team diversity during team formation play important roles. Still, care must be taken to understand how gender composition can affect team functioning and how potential problems can be mitigated if they arise.

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