AC 2012-3132: GENDER DIFFERENCES IN AN ENERGY CONSERVATION IDEA GENERATION TASK

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Gender Differences in an Energy Conservation Idea Generation Task

Abstract

Engineering student teams are often formed under the assumption that diversity will increase team innovativeness. Rather than approaching the problem from an outcome-oriented stance, as has much of the previous research, this study examined how gender differences may affect specific phases of the design process. Seventy-three first-year engineering students completed a brief idea generation task as part of a design practical exam. The students were asked to list ways to reduce energy consumption at a local public library. In their 411 solutions, students utilized five energy reduction strategies (reduce usage, increase efficiency, alternative energy, encourage conservation, and economics) and identified four energy conservation areas (lighting, heating/cooling, electronics/appliances, and general). The proportions of male and female student solutions (N = 370 and 41 respectively) utilizing each strategy and within each energy conservation area were compared using Fisher's exact test. Female students were significantly more likely to propose solutions that encouraged energy conservation. Further, mixed-gender teams demonstrated greater quantity and variety of pooled solutions than all-male teams. These results suggest that male and female engineering students approach design solutions somewhat differently. Gender diversity in student teams can potentially lead to a wider solution space and consideration of non-obvious ideas. Future research should examine how well the social dynamics of teams allow an equitable exchange and consideration of these diverse ideas.

Introduction

Innovation is a longstanding goal of engineering design. Engineers are expected to produce better, more efficient, and more affordable designs than those of previous generations. With imposing grand challenges and worldwide economical instability, innovative design is considered more critical than ever[1]. Hence, it is essential that creativity and innovativeness be taught to and nurtured in engineering students from the onset of their education.

Team design projects are commonly used to provide students early design experience and nurture their engineering creativity. During such projects, instructors often form design teams to increase demographic diversity (e.g. gender or race) because of the potential positive effects on team and social outcomes. While the perceived benefits of gender and racial diversity among work and project teams are well documented[2, 3, 4], the empirical results have been inconclusive, especially regarding engineering student teams. Some report that gender diversity has no effect on team innovativeness of first-year engineering project teams[5], while others found that less diverse teams performed better on course projects[6]. Further, recent meta-analyses of team performance in the workplace indicate that demographic diversity has no, or even a negative, effect on team performance[7, 8].

Studying team innovativeness outcomes is important, as innovation must result in viable, feasible, and desirable products[9], but a complex team issue such as diversity may affect certain stages of the design process more than others. The idea generation stage in particular may be affected by gender diversity since diverse teams are theorized to consider a greater number and variety of potential solutions to design problems[2, 3].

The purpose of this study is to investigate the idea generation stage of the design process in relation to gender diversity. Specifically, our research questions were:

- Do male and female engineering students identify different types of solutions during an idea generation task?
- And thereby, do gender-heterogeneous teams have the capacity to consider a more various set of solutions than gender-homogenous teams?

Previous Literature on Idea Generation and Gender Differences

Idea Generation

During the idea generation stage of the design process, engineers identify concepts which might present feasible design solutions. While breadth of solutions is not conclusively linked to better overall solutions, idea generation represents a significant portion of the design process. Both engineering students and professional engineers spend, on average, over 70% of their total design time identifying and developing potential solutions[10].

While much effort has gone into improving the idea generation process[11], it is still unclear how to determine quality outcomes of idea generation. Metrics created to assess the successfulness of idea generation techniques focus on variety, novelty, quantity, and quality[12], but successful design does not always require each of these four characteristics. For example, professional engineers often focus on tinkering with one good idea rather than choosing among many poorly developed ideas[10]. Still, engineering design teams may have a better chance of implementing a successful solution when they can select from, elaborate upon, and potentially merge elements of a large, varied solution space[13].

Gender Differences in Idea Generation

Few previous studies have addressed gender differences in engineering student design behavior. Kilgore and colleagues[14] found gender differences in problem scoping. In their study, 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 desire information about users and surroundings while male students were more likely to desire information about budget and costs. In a more recent study, female students exhibited a client-centered focus during a short design activity, while male students were more likely to discuss technical limitations and provide evaluations[15]. These findings suggest possible differences in the way engineering students frame design problems and suggest that male and female students may identify different solutions to similar problems. We found no studies, however, that directly investigated gender differences during idea generation.

Research Methods

Participants and Setting

The participants in this study were 73 first-year engineering students (65 male, 8 female) enrolled in a first-year engineering course at a large Midwestern university. In the course, taught during the spring 2011 semester, students were introduced to engineering professions, engineering design and problem-solving, and teamwork. These students comprised 19 teams of three or four within which they had worked for about three months. The eight female students were split among four teams of two females and two males.

Data Collection

Students were given ten minutes to identify inexpensive energy-saving solutions for a fictional local library with a limited budget. The individual output consisted of a handwritten exam sheet with space for ten solutions and an explanation of the most innovative solution they considered.

Data Analysis

After the handwritten data were transcribed and removed of personal identifiers, one of the authors coded the data to determine the general problem-solving approach followed in each response. After an initial round of coding and discussion among the authors, we identified four unique energy conservation areas and five unique solution strategies (Tables 1 and 2). Fifty-two of the responses (among a total of 463) were either too ambiguous or confusing and were eliminated from consideration.

During a second round of coding, one author determined the classification within each of these categories for each of the responses. The second author coded fifty of the remaining solutions to provide inter-rater reliability. The percent agreement was 90% and the Cohen's Kappa was .83, indicating a high degree of reliability. We used Fisher's exact test to determine significant differences in proportions of male and female student solutions that belonged within each category as well as the proportions of male and female students who indentified at least one solution in each category.

Table 1. Energy Conservation Areas Identified During Idea Generation

Conservation Area		Description
I.	Lighting	Changes to any component of the lighting system at the library (e.g. light bulbs, windows (added for light), dimmers, motion detectors)
II.	Heating/Cooling	Changes to any component of the temperature control system at the library (e.g. heating/AC unit, fans, insulation, windows (when replaced for insulation))
III.	Electronics and Appliances	Changes to any electronic device or appliance at the library (e.g. computers, televisions, book scanners, break room appliances, outlet availability)
IV.	General	These solutions pertained to no specific element of the library (e.g. alternative energy, policy changes, hours of operation)

Table 2. Energy Reduction Strategies Identified During Idea Generation

Strategy	Description
I. Reduce usage	To reduce the usage of any energy-consuming device(s). This could be using the devices less often, turning them to a lower power setting, offering fewer devices, or reducing the amount a device needs to be used without changing its efficiency. Solutions ranged from turning off half of the lights to using personal fans instead of AC.
II. Increase efficiency	To replace current energy-consuming devices with those that will be similarly effective but use less energy. Common examples include replacing incandescent light bulbs with energy-efficient bulbs such as CFL or LED bulbs and replacing the current electric heating unit with a natural gas heating unit.
III. Alternative energy	To supplement the energy consumption with production of alternative or renewable energy. Solutions ranged from windmills to piezoelectric flooring.
IV. Encourage conservation	To promote energy conservation at the library by persuading or convincing staff and patrons to limit energy usage and reduce energy waste. Example solutions are educational seminars and signs reminding people to turn off electronic devices when not in use.
V. Economics	To decrease operation cost or find new revenue to offset the cost of energy. Solutions included decreasing staff wages and charging for typically free services such as computers or book rental. Note: these solutions do not satisfy the design problem as stated.

Further, four all-male teams were randomly selected to compare to the four teams with two males and two females. Though the students generated ideas individually, we pooled their ideas, discarding redundant ideas, to create one set of ideas that might represent the outcome of an idea generation session for each team. In authentic team settings, team processes may inhibit idea sharing or lead to consideration of new ideas[14]. Thus, the actual results of a team idea generation session may be greater or less than the results of pooled individual ideas. Pooling ideas, however, represents our best guess of team output. We used variations on Shah and colleagues[12] ideation metrics to compare the idea generation outputs of all-male and mixed-gender teams.

Shah and colleagues[12] describe four metrics—quantity, quality, novelty, and variety—that collectively describe the overall effectiveness of the idea generation process. Since the goal of this study was to determine the breadth of team idea generation outcomes, we used only the *quantity* and *variety* metrics. *Quantity* is the number of unique ideas developed during the idea generation process. For the purposes of this study, an idea was considered unique if it utilized a different combination of energy conservation area (such as lighting or heating/cooling), energy reduction strategy, and specific implementation of the energy reduction strategy from all previous ideas in the set. For example, if a team considered installing motion-activated lighting near bookshelves and sound-activated lighting in group study areas, they only had one unique idea since both ideas had the same energy conservation area (lighting), energy reduction strategy (reduce usage), and specific implementation of energy reduction strategy (automatic shutoff to reduce waste).

Variety describes how well a team explores the idea space[12]. Ideas produced by the same team are organized into a genealogy tree with levels of increasing detail. Shah and colleagues'[12] levels include *physical principle*, *working principle*, *embodiment*, and *detail*. The set of ideas is awarded points based on the number of branches at each level, with greater point values awarded to higher-level, and thus more fundamentally different, branches (10, 6, 3, and 1 respectively for the levels listed above). The overall variety is calculated as the branch points divided by the total number of ideas. Thus a set of ideas that differs only in embodiment and details would receive a low score, while a set of ideas that uses all different physical principals would receive the highest possible score. Since Shah and colleagues' levels are not directly relevant to the student ideas in this study—they are not necessarily physical products—we defined a new set of levels based on increasing specificity of approach to the design problem (Table 3).

Table 3. Variety Levels

Level	Points Awarded per Branch
Energy conservation area (e.g. lights or heating/AC)	10
Energy reduction strategy (e.g. reduce usage)	6
Specific strategy (e.g. within reduce usage: use less frequently, use lower power setting, use less devices)	3

We did not assess *quality* or *novelty* since the focus of this study was breadth of idea generation. When evaluating *quantity* and *variety* based on gender distribution, we were not able to perform statistical analysis to compare the output of mixed-gender teams to that of all-male teams due to small sample size. We only provide descriptive statistics to demonstrate possible differences among these teams.

Results

Of the five energy reduction strategies, *reduce usage* was the most common (60.6% of all responses) and *economics* was the least common (2.7%). Females were more likely than males to suggest *encourage conservation*, *alternative energy*, and *reduce usage* and males were more likely to suggest *economics* and *increase efficiency*. A greater proportion of female responses were directed towards *encourage conservation* and *alternative energy* while a greater proportion of male responses were directed towards *reduce usage, economics, and increase efficiency*. The only statistically significant difference between male and female responses was in proportion of responses in the *encourage conservation* category. Similarly, there were no significant differences in the energy conservation areas identified by female and male students. Table 4 displays the number and proportions of female and male responses describing each of the energy reduction strategies and energy conservation areas. Table 5 displays the number and proportions of female and male students who identified at least one idea utilizing each energy reduction strategy and implemented within each energy conservation area.

Table 4. Proportion of Male and Female Student Responses in Each Category

Strategy/Energy Conservation Area	Female Responses (N=41)		Male Responses (N=370)	
	Number	Percentage	Number	Percentage
Reduce Usage	19	46.3%	226	61.1%
Increase Efficiency	9	22.0%	88	23.8%
Alternative Energy	8	19.5%	38	10.3%
Encourage Conservation*	**5**	**12.2%**	**7**	**1.9%**
Economics	0	0.0%	11	3.0%
Lighting	11	26.8%	115	31.1%
Heating/Cooling	9	22.0%	93	25.1%
Electronics and Appliances	5	12.2%	57	15.4%
General	16	39.0%	105	28.4%

* indicates statistically significant difference (α = .05)

Table 5. Number of Male and Female Students Responding in Each Category

Strategy/Energy Conservation Area	Females (N=8)		Males (N=65)	
	Number	Percentage	Number	Percentage
Reduce Usage	8	100.0%	60	92.3%
Increase Efficiency	4	50.0%	47	72.3%
Alternative Energy	5	62.5%	26	40.0%
Encourage Conservation	3	37.5%	7	10.8%
Economics	0	0.0%	7	10.8%
Lighting	7	87.5%	57	87.7%
Heating/Cooling	4	50.0%	46	70.8%
Electronics and Appliances	5	62.5%	36	55.4%
General	7	87.5%	52	80.0%

Note: table contains no statistically significant differences

The next level of analysis included an examination of the data at the team level rather than the individual level. This analysis helped determine if mixed-gender teams had the capacity to consider a more various set of solutions than gender-homogenous teams. In Table 6, we display average and standard deviation of the quantity and variety scores for all-male and mixed-gender teams. On average, mixed-gender teams demonstrated greater quantity and variety of ideas. Because there were only four samples of each type of team these results were not statistically tested.

Table 6. Mean Idea Variety and Quantity for Gender-Heterogeneous and All-Male Teams

Category	Mixed-Gender Teams	All-Male Teams
	Mean (SD)	Mean (SD)
Quantity	17.3 (3.77)	16.8 (3.10)
Variety	8.61 (1.50)	7.43 (1.46)

Discussion

While previous studies suggest that women are more affected by reduced usage of lights and heating and men are more willing to pay additional premiums for renewable energy[17, 18], these preferences were not apparent in their idea generation outcomes. Almost half of the female solutions focused on reducing usage of devices such as lights and heating/cooling, and female students were more, but not significantly more, likely to suggest renewable energy options. These results suggest that potential differences in perspective and personal experience by gender may not significantly affect the way engineering students approach idea generation phase of a design project.

We did observe some difference in the way male and female students approached the problem. Compared to male students, female students appeared to favor the *alternative energy* or *encourage conservation* approach. Male students, in turn, appeared to favor *reduced usage* and *increased efficiency*. However, the only statistically significant difference was in the proportion of female student solutions that were directed towards *encouraging conservation*. Moreover, though there were apparent percentage differences, members of both genders used each of the four valid approaches—female students did not use *economics*, which did not satisfy the design problem and was only included because of its large number of occurrences—focused on each of the four primary energy conservation areas, and most frequently suggested solutions in the *reduced usage* and *increased efficiency* categories.

Strikingly, the individual similarities in energy reduction strategy and conservation area resulted in possible differences to team solution *quantity* and *variety*. The results of team output were descriptive only, but in the small sample, Hence, it is possible that mixed-gender teams with good team processes will have more ideas upon which to draw, and thus a greater possibility of identifying a successful or innovative design solution.

Conclusions and Future Work

Overall, we found few significant differences in ideas generated. However, female students championed one approach—*encourage conservation*—that male students tended to ignore. A small number of male students, in turn, suggested a solution approach—*economics*—that no female student considered, though it represented an invalid solution to the given problem. These results do not suggest that female students are "better" at idea generation; in fact, male students, on average, considered 5.7 solutions compared to the female student average of 5.1. Instead, these results suggest that male and female students will identify only partially overlapping design solutions and thus mixed gender teams may be able to consider a broader range of design ideas during idea generation. The team-level analysis supports this assertion, as the four mixed-gender teams slightly outperformed the all-male teams. These results relied on small sample sizes, and pooled ideas rather than the output of an actual team idea generation exercise, and thus should be considered preliminary. In reality, social factors and individual differences have been observed to both hinder and improve team outcomes[16,19,20]. Future studies should be conducted to further explore if similar results will be observed for different design problems and team settings (e.g. team projects, joint idea generation), and with a larger number of diverse teams/individuals.

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