Exploring the Influence of Gender Composition and Activity Structure on Engineering Teams' Ideation Effectiveness

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Exploring the Relationship among Gender Composition, Activity Structure, and Brainstorming Novelty

Abstract

Ideation is a critical stage in the engineering design process and has substantial impacts on downstream decision making. As a result, a better understanding of the factors that positively contribute to ideation effectiveness is of key interest to stakeholders in engineering design education. While previous research has developed approaches for assessing the novelty of brainstorming outputs, less attention has been paid to the relevant factors that might influence that novelty. The purpose of the present work is to explore the ways that brainstorming activity structure and team gender composition might affect the novelty of brainstorming outputs. To address this purpose, we recorded both structured (using the 6-3-5 method) and unstructured brainstorming sessions, while varying the ratio of men to women in each team. We adapted Shah's (2003) novelty metric to assess the average novelty of design solutions generated in ideation.

We conducted quantitative analysis to explore differences across both gender composition and activity structure. Regarding activity structure, preliminary findings suggest that unstructured brainstorming sessions resulted in higher average novelty than structured sessions. Further, in terms of gender composition, gender balanced teams generated lower average novelty across both structured and unstructured sessions, and this difference was statistically significant for unstructured groups. Our preliminary findings suggest that both activity structure and gender composition of engineering teams might influence the novelty of brainstorming outcomes. Therefore, when forming engineering teams and conducting ideation sessions, faculty, project managers, and engineers should consider the ways in which they support ideation activities as well as how they form teams according to gender composition.

Introduction and Background

Developing competence with engineering design processes is an integral aspect of engineering education and helps prepare students for modern practice. Therefore, it is important that engineering educators have the knowledge and tools to effectively facilitate learning and performance as students engage in design activities. In this research, we focus on brainstorming and ideation processes and in particular the factors that might influence the novelty of brainstorming outputs (i.e., ideas and potential solutions). Specifically, we were interested in the potential influence of both activity structure and team gender composition on the outputs generated during brainstorming. We are interested in these aspects because they are factors that an instructor can, to some degree, influence in order to enhance learning, creative output, and interpersonal interactions. Our research explored the following question:

> *How do the gender composition and activity structure of a brainstorming exercise affect the novelty of engineering solutions generated?*

To explore this question, we conducted a pilot study to develop and inform practices in subsequent iterations of data collection. Six groups of six students (N = 36) participated in a 30-minute brainstorming activity during which they designed or modified playground equipment for children in wheelchairs. In each session, we varied the gender composition and structure of the brainstorming process. Using an existing framework (Shah, Smith, & Vargas-Hernandez, 2003), we developed an adapted measure of novelty to investigate the performance across brainstorming teams.

The current work-in-progress will address three major sections. First, we will provide an overview of the relevant literature surrounding engineering design processes, brainstorming, and issues related to gender and engineering team performance. Second, we present a discussion of the methods used to collect our data and the specific analytic approaches used to characterize novelty. Finally, we offer preliminary findings that examine the potential effects of gender and activity structure and make recommendations for future research and practice. By better understanding the factors that affect engineering design teams' novelty output, stakeholders in student success can intentionally design learning experiences to optimize creativity and cultivate inclusive teamwork spaces.

Engineering Design Process

The engineering design process is represented using a range of different metaphors, organizational diagrams, or flowcharts (Dym, Agogino, Eris, Frey, & Leifer, 2005; Pahl, Beitz, Feldhusen, & Grote, 2007; Shigley, 2011; Ulrich & Eppinger, 2008). And while these models vary based on their context or particular application or discipline, the authors generally conceptualize the design process in terms of three major phases: conceptual, embodiment, and detail. Notably, nearly all models of design describe some level of iteration within and across these phases.

The conceptual phase is characterized by the exploration of the design space and divergent approaches to solution development. Engineers work to define the problem and generate a wide range of potential solutions to that problem. We focus on conceptual design activities and brainstorming in particular for two main reasons. First, choices made during conceptual design can have substantial downstream impacts. That is to say, initial choices about the use of particular software, a specific component, or a piece of machinery can constrain the design space and limit the kinds of choices available to engineers. Researchers have noted the importance of effective ideation and demonstrated its influence on the success of the project (Nelson, Wilson, Rosen, & Yen, 2009).

Second, we are interested in conceptual design phases because it is during this period that team roles are formed and group norms are established (Butterfield & Pendegraft, 1996). Team interactions that are established early can set the tone for subsequent interactions and therefore design team effectiveness and success (Kolmos, Rump, Ingemarsson, Laloux, & Vinther, 2001; Liang & Lawrence, 2007; Roberts, 2012; Simmons, 2015; Yoon & Johnson, 2008). If ideation practices can be developed to enhance both creative capacity and equitable interactions in engineering teams, understanding such practices is of interest to a range of engineering education stakeholders.

Brainstorming and Ideation

Engineering teams frequently engage in brainstorming throughout the design process. In general, the main purpose of brainstorming is to generate the largest number of ideas in the least possible amount of time. While there are myriad recommendations and methods for conducting brainstorming, they all tend to operate under a relatively common set of principles. Rawlinson (2017) lays out four overarching recommendations that inform most brainstorming activities:

1. Suspend judgement: Evaluation of other participants' ideas should be avoided and put aside until later phases of design.
2. Free-wheel: Members should let go of their mental barriers and inhibitions and allow themselves to dream and drift around the problem they have at hand.
3. Emphasize Quantity: Participants should be encouraged to produce as many ideas as they can, regardless of their quality.
4. Cross-fertilize: If other people's ideas spark off new ideas in other participants, they should be picked up and further developed by the team.

Zhao & Hou (2010) conducted a review of literature to examine factors that influence the effectiveness of brainstorming. In particular, they found three major factors that can increase the effectiveness of team brainstorming activities. First, heterogeneity of the team led to increased effectiveness. They note this is an advantage because having a range of perspectives and backgrounds allows for more space to explore the problem and develop solutions. This finding would suggest that increasing diversity in brainstorming approaches is helpful for effectiveness of brainstorming activities. Second, processing mode of information, or the degree to which each individuals' ideas are able to shape and be shaped by others was found to increase effectiveness. This finding is important because it suggests that sharing information across a network of individuals is more effective than that same number of individuals engaging in their own solitary brainstorming. Finally, the authors found that brainstorming effectiveness hinged on the interactive modes of the team members. When a team engages in "social promotion" of its members, brainstorming is often more effective; when individuals perceive to be in competition with each other, the brainstorming will be less effective. This finding is relevant to our work in light of existing research around masculinity and competition (Secules, 2019). Given the relationships between masculinity and competition in engineering, we might expect male-dominant teams to be more competitive and therefore less effective in brainstorming. But while Zhao & Hou (2010) offer a useful means of understanding the factors relevant to brainstorming processes, they do not necessarily define "brainstorming effectiveness."

Understanding Output of Ideation Activities

To characterize brainstorming outputs, we turn to an existing framework that assesses the resulting novelty (Shah et al., 2003). The Shah Framework is a tool used to evaluate idea generated within a design group or session. The Shah (2003) framework has been revised and operationalized to meet a range of different goals, and researchers have offered updated or refined versions of the framework. For instance, Nelson et al. (2009) offer a refined metric for ideation effectiveness, noting limitations and inconsistencies in the scoring of variety. Additionally, Verhaegen, Vandevenne, Peeters, & Duflou (2013) refine metrics specifically pertaining to novelty. The authors introduce a hierarchical scheme for evaluating novelty and note improvements that allow for better comparisons across different brainstorming methods. Indeed, our current work focuses on novelty and also uses an adaptation (discussed below) of the original Shah et al. (2003) framework.

Gender Composition and Teamwork

Next, we turn to literature surrounding gender and teamwork in particular. While literature in engineering is relatively sparse, researchers in disciplines beyond engineering (e.g., social sciences and business) have demonstrated effects of team gender composition on performance and interactions in that team. Kathlene (1994) found that during public hearings with elected officials, men were more likely to interrupt women, take more turns talking, and use disproportionate amounts of time when talking. Hoogendoorn, Oosterbeek, & Van Praag (2013) observed student entrepreneurial business teams and found that gender balanced teams outperformed male-dominant teams in terms of both sales and profits. Conversely, Apesteguia, Azmat, & Iriberri (2012) found that for both undergraduates and MBA students involved in a business competition, all-female teams were outperformed by teams of any other gender composition, noting less aggressive pricing and other decision-making differences as potentially affecting outcomes. Such findings suggest that as the ratio of men-to-women shifts in a team, so does the overall disposition of the group as well as the decision-making processes. More specifically, female-dominant teams tend to be less aggressive and more egalitarian.

Though work is limited, engineering education researchers have also explored the effects of gender composition on teamwork and interpersonal interactions. For example, Laeser, Moskal, Knecht, & Lasich (2003) observed engineering student design project teams and investigated the ways gender composition influenced team interactions as well as project outcomes. They found that the gender composition of a team influenced the propensity for different kinds of teamwork functions. For example, members of majority-male teams were more likely to engage in *clarifying* functions and less likely engage in *standard setting* when compared to majority-female or balanced gender composition teams. Such findings are important because they suggest qualitative differences in the team interactions and dynamics as a result of the ratio of men to women.

More recently, Aeby, Fong, Isaac, Vukmirovic, & Tormey (2019) asked students to imagine themselves in hypothetical groups that were either predominantly male or predominantly female. They found that the gender composition of the hypothetical team influenced the challenges that students might anticipate when working with that group. In particular, participants anticipated more challenges when asked to imagine working on a predominantly female team, and those challenges were related to checking work and staying fully informed on the project. Notably, this effect was consistent across respondents of all genders, suggesting that both men and women will anticipate greater challenges when working on a female-dominant team. However, the teams were imaginary and so less is known about how these interactions might actually play out.

Our work will build on existing research in two primary ways. First, we will introduce an evaluation scheme for scoring novelty across structured and unstructured data sets. Where most existing research on novelty and brainstorming has leveraged sketches or images of a design, we will incorporate qualitative conversational data to represent and score solutions generated by participants. Second, this work will focus on specific engineering design activities that take place within a larger experience. Where existing research has explored gender composition in the context of larger projects, we will "zoom in" on a specific aspect of that experience in ways that will highlight some of the micro-level aspects of student experiences.

Methods

The goal of the present research is to pilot a particular method and conduct preliminary analysis of brainstorming transcript data according to gender composition and activity structure. To that end, we recruited mechanical engineering student teams to engage in different brainstorming sessions. The following sections describe the population of students, the data collection, and data reduction processes used to evaluate brainstorming output.

Sampling and Recruitment

We recruited students from the mechanical engineering department at a large, public, predominantly white, teaching-focused university in California. Students were recruited from mechanical engineering in particular for two key reasons. First, at the research site, mechanical engineering represents the largest department, serving over 1,200 students. Therefore, recruiting from the largest department offered the greatest potential to be able to stratify our brainstorming groups according to gender composition. Second, the supporting author is a professor of mechanical engineering and therefore had access to student listservs from which to recruit. We therefore used a combination of purposive and convenience sampling.

We implemented a screening survey to further refine our sample. We collected basic demographic information as well as preliminary information regarding their beliefs and perceptions related to conceptual design activities. Based on the survey, we were able to further control for grade level. In this case, we selected only 2nd and 3rd year students to mitigate effects related to design experience or expertise (e.g., a senior in a group of first-year students might interact differently than if that senior was grouped with other seniors).

In total, 174 students responded to our screening survey and 36 were selected for participation. We organized these 36 students into six groups of six and while varying the gender composition of the different teams. Table 1 provides an overview of the configuration of the six student teams according to both gender composition and activity structure.

Data Collection and Processing

Participants were organized into six groups of six that varied in terms of gender composition. There were two groups that were predominantly female, two that were predominantly male, and two that were balanced. Table 1 below offers an overview of how participants were organized for data collection.

Table 1: Overview of the data collection design for the current research.

Predominantly Female + Structured Ideation	Gender Balanced + Structured Ideation	Predominantly Male + Structured Ideation
Predominantly Female + Unstructured Ideation	Gender Balanced + Unstructured Ideation	Predominantly Male + Unstructured Ideation

Each group then performed either a structured or unstructured brainstorming task. Participants in the unstructured group were read a brief problem statement, debriefed on basic brainstorming principles, and given 30 minutes to generate as many solutions as possible. During the 30 minutes, participants were free to talk with each other, write on the whiteboard, share sketches, or whatever else helped them communicate their ideas.

Participants in the structured group performed the 6-3-5 technique in relative silence. Before beginning brainstorming, we read a description of the 6-3-5 process and answered any questions participants had. The 6-3-5 method is a brainwriting technique introduced in 1969 by Bernd Rohrbach as a way to help overcome creativity barriers associated with other forms of ideation or brainwriting. We chose the 6-3-5 approach for two primary reasons. First, a goal of the larger project was to explore the role of power within different brainstorming approaches, and we believed that the format of the 6-3-5 provided equitable opportunities for all members of the group to discuss their ideas. Second, the method is relatively simple and can be taught and executed in a short amount of time (~45 minutes). Playground equipment was selected for the design space because participants presumably have equal exposure to existing solutions, designs can be completed within five minutes, and to build on existing work in design research (e.g., (Atman et al., 2007))

During the 6-3-5 brainwriting, six individuals spend five minutes generating three potential solutions to a given design prompt. After five minutes, the group passes all their papers to the left and spends five minutes sketching three more potential solutions. It is considered a progressive method given that ideas are generated in a series of discrete progressive steps which are repeated a number of times and triggered through the interplay with others' sketches and ideas. The output of the 6-3-5 sessions was six sheets of paper, each containing approximately 18 potential solutions to the brainstorming prompt (i.e., pieces of playground equipment for children in wheelchairs).

Data Analysis

As noted, analysis was informed by Shah et al. (2003), in particular their approach to assess novelty of brainstorming output. However, given the context and goals of the current research, we made several modifications (described below) to make the framework suitable for the current research goals. The framework described by Shah et al. (2003) has been refined to address various purposes and research questions (e.g., (Nelson et al., 2009; Verhaegen et al., 2013)). Therefore, our methodology is in line with previous approaches in which the metric is refined to meet the needs of the present research context.

In order to score novelty in this research, we first identified the attributes that defined the potential design space. To do so, we inductively analyzed a portion of the structured (6-3-5) idea set and developed a list to describe the differences between potential solutions. We used this list of differences to distill a set of six attributes that would be used to score novelty. Based on the relevant aspects of the solutions in the data set as well as conventions from prior literature we developed six attributes to score the novelty of a given design, as shown in Table 2 below.

Table 2: Attribute Definitions & Examples

Attributes	Operational Definitions	Examples
Engagement	Ability to invoke affective, behavioral, and cognitive engagement through inputs and outputs	Completing a task, physical inputs, collaborating, thinking, games, physical activities, etc.
Immersion	Amount of sensory stimulation experienced by users	Sight, touch, taste, smell, hearing, adrenaline, etc.

Non-obviousness	Deviation from traditional playground experiences; expansion of the general design space	Wheelchair bumper cars that everyone can use
Versatility	An ideas ability to have its users create unique experiences while interacting with it	Role play, platforms for play, art/creation stations, etc.
Accessibility	Effort to maximize wheelchair accessibility and minimize differences in experiences between wheelchair and non-wheelchair users	Hand powered mechanisms, ADA amendments, etc.
Technical Complexity	Mechanical detail, foreign materials, mechanisms, and motions	Drive mechanisms, textured material, complex motions, etc.

Solutions were scored using the above attributes and were given a score of 1, 3, or 5 depending on the degree to which they satisfied each attribute. Scores were assigned to each idea for every attribute based on each attribute as determined by the research team. A score of 1 represents little to no novelty or distinction from typical playgrounds; a score of 3 represents uniqueness from typical playgrounds; a score of 5 represents new concepts or approaches to the design attribute. Thus, a particular design solution could have a maximum score of 30.

While the Shah et al. (2003) framework is suitable for sketches of designs, less research has applied the framework to verbal descriptions of ideas. Therefore, to analyze brainstorming data from the unstructured sessions, we developed an idea classification scheme to parse out and identify ideas and solutions that were articulated during unstructured brainstorming. To identify each idea in the unstructured set, researchers created conversation trees to map out the ideation process. An example of the process of breaking down the ideas is shown below in a screen capture in Table 3. In this case, the root idea is to leverage users' arms. The initial additive ideation suggests multiplying the power of user input and that they're feeling like superheroes, both which add to the idea, but do not significantly change direction. This is followed by a fighting robot game controlled by their arms, which shifts the focus of the conversation and acts as the new root idea for additive ideation.

Table 3: Overview of idea capture system through brainstorming dialogue.

Type	Discourse		
Root	Arms you could like push or pull, you could grab onto stuff, so I'm just trying to think, it doesn't necessarily have to be a playground thing, but any sport or activity that requires just arm movement.		
Additive		Yeah, is there anything that we could do that would make the power that they use with their arms, multiply that so that they're using their arms, but not that much power.	
Additive		They're feeling like super heroes.	
Branching		What if you had like, what if you had something where you know the fighting robot game where when you win it's head flies off?	
Additive			Rock 'em, sock them, yeah. If you had the big rock 'em, sock 'em robots, but then those were each controlled by, fake arms on the sides. So you could walk up to it and likepunch with the fake arms
Additive			I don't know how you'd reset the head. Maybe there's a crank on here that you'd...
Additive			Yeah, it's just got like a little pulley.
Additive			Or just a button that you press.

After the data were cleaned and ideas were separated, researchers assigned attribute descriptions to each idea using keywords. Based on the descriptions developed by the research team as well as the words used by participants, the team scored each individual solution according to the six attributes noted above. After the ideas were scored by independent judges, individual scores were aggregated and then averaged to get a final score. Scoring was consistent enough to prevent circumstances where one judge gives a 1 and another gives a 5; however, there were differences amongst 1s & 3s and 3s & 5s. When this occurred, they were averaged to 2s and 4s, respectively.

Trustworthiness and Credibility

In order to ensure the trustworthiness of the novelty scoring we implemented a number of strategies for consistency in our analysis. Throughout the research process, we engaged in several iterations to achieve high inter- and intra-rater reliability. First, researchers went through each attribute and compared the scores of each idea to compare scoring agreement amongst the team. This was done one attribute at a time to ensure consistent understanding of the operational definitions and scoring breakdowns. Researchers provided justifications for their scoring then argued to consensus. By looking at the biggest differences and closest similarities in scores, the team was able to better understand misalignment. Next, researchers compared their scores for similar ideas within their own scoring sheets to ensure consistency amongst trials. Agreement among researchers was generally high, and discrepancies were again argued to consensus.

It is also important to consider this research in the context of existing limitations. First, a primary limitation concerns sample size. The following results were obtained from six different brainstorming sessions with a range of variables changed each time. As a result, while we can run statistics and show relatively normal distributions, all of our findings and resultant claims are tentative and require further explanation. Second, while this work-in-progress was focused on gender composition, we did not address other dimensions of diversity which might have arguably influenced our results. Existing research has provided support and rationale for the focus on gender, but we recommend that future research in this direction consider other dimensions of diversity (e.g., race, ethnicity, age, ability).

Results

The goal of this research was to better understand potentially relevant factors that affect the output of brainstorming activity. In this case, we were interested in the ways that activity structure and gender composition might affect the overall novelty of the design solutions generated during brainstorming. To present our results, we first offer an overview of the novelty measurement scheme and provide examples of how it was applied to both structured and unstructured brainstorming sessions. Next, we offer descriptive statistics and support our rationale for particular novelty scores. Finally, we offer statistical comparisons according to activity structure and gender composition. Given the preliminary and exploratory nature of the present research, we treat each variable separately and examine each in turn. We present our results in terms of overall novelty and average novelty score and we draw comparisons across structured and unstructured brainstorming as well as comparisons across gender compositions of the teams. All statistics were calculated using Data Analysis tools in MS Excel.

Descriptive statistics

First, in order to provide a better understanding of our overall data, we performed descriptive statistical analysis. Shown below in Table 4 are the descriptive statistics for average novelty scores by brainstorming group. Here, N represents the number of ideas generated in a given brainstorming session and mean represents the total novelty score of each design divided by the total number of designs generated. The groups are denoted by the gender composition and structure (i.e., PM-S = Predominantly Male-Structured) We also present skewness and kurtosis to demonstrate the suitability of the dataset for subsequent statistical analysis. Based on the values shown in Table 4, we used standard statistical tests without violating assumptions of normality.

Table 4: Overview of descriptive statistics for novelty output for each brainstorming session.

Group	**N**	**M**	**(SD)**	**Kurtosis**	**Skewness**
PM-S	86	12.6	(3.68)	0.91	0.742
PF-S	106	12.5	(2.94)	-0.046	0.56
Bal-S	98	13.9	(3.05)	-0.445	0.042
PM-US	82	14.8	(3.87)	0.571	0.648
PF-US	70	14.8	(4.35)	-0.779	0.41
Bal-US	64	12.3	(3.67)	1.20	1.14

Comparison across activity structure

Next, we were interested in the ways the structure of the brainstorming session might affect the average novelty of designs generated. We conducted an independent samples t-test to compare brainstorming novelty across structured (i.e., 6-3-5 method) and unstructured brainstorming. Table 5 is an overview of the t-test results. Important to note here is that the groups are not separated by gender composition, only activity structure. Given the preliminary nature of the work, small sample sizes prevented further disaggregation at this step.

Table 5: Comparison in novelty of brainstorming output across activity structure

	Activity Structure							
	Unstructured			Structured (6-3-5)				
	M	SD	n	M	SD	n	t	df
Novelty	14.02	4.12	216	12.5	3.29	188	4.06*	399

*p < .05

There was a significant difference in average novelty between unstructured brainstorming (M = 14.02, SD = 4.12) and unstructured (M = 12.5, SD = 3.29) conditions; t (399) = 4.06, p = .0000291. Such results suggest that unstructured brainstorming sessions result in greater average novelty per design solution.

Comparison across gender composition

Our last component of preliminary analysis concerns questions related to the gender composition of an engineering team and the novelty of brainstorming output. To explore outcomes across gender composition, we performed two different ANOVAs, one which combined all results based on gender composition and one that focused only on the unstructured dataset.

Our first ANOVA concerns the aggregated datasets that combine scores for both structured and unstructured brainstorming sessions. We conducted a one-way between-subjects ANOVA to compare the effect of gender composition on average solution novelty within a brainstorming session. To explore potential differences related to gender composition, we looked across groups that were either predominantly female, predominantly male, or gender balanced. Table 6 presents results from our ANOVA.

Table 6: Results from one-way ANOVA looking across gender composition for all brainstorming sessions.

Source	***df***	***SS***	***MS***	***F***	***p***
Between groups	2	14.07	7.038	.5168	.5968
Within groups	503	6850	13.62		
Total	505	6865			

When analyzing the aggregated data, the results indicate that there was not a significant effect of gender composition on average novelty of solutions during brainstorming at $p < 0.05$. [$F(2, 503) = 0.517$, $p = 0.587$]

However, we were also interested in exploring differences within a given brainstorming structure. We conducted another one-way between-subjects ANOVA considering only the unstructured brainstorming data. Table 7 offers an overview of the ANOVA results from the unstructured brainstorming sessions.

Table 7: Results from one-way ANOVA looking across gender composition during unstructured brainstorming sessions.

Source	***df***	***SS***	***MS***	***F***	***p***
Between groups	2	286	142.9	9.04	.00017
Within groups	213	3369	15.82		
Total	215	3655			

Examining just the unstructured sessions, results indicate that there was a significant effect of gender composition on average novelty of solutions at $p < .05$. [$F(2, 213) = 9.04$, $p = 0.00017$]. Post hoc comparisons using the Tukey HSD test indicated that the mean score for the predominantly male ($M = 14.77$, $SD = 3.87$) and predominantly female ($M = 14.79$, $SD = 4.35$) groups were significantly different than the gender balanced ($M = 12.25$, $SD = 3.67$) groups. However, the predominantly male and predominantly female groups did not significantly differ from each other.

Discussion, Implications, and Future Work

The present work-in-progress offers an exploration into some potentially relevant factors associated with novelty resulting from brainstorming sessions. We conducted six brainstorming sessions while varying both the structure of the session and the gender composition of the team. While the present research is a work-in-progress, the present findings point to critical questions surrounding brainstorming and ideation in engineering contexts and have some useful implications for future research.

Influence of Structure on Novelty

First, our findings suggest that the structure of an ideation session can affect the average novelty of the solutions generated. In particular, the use of unstructured brainstorming approaches resulted in higher average novelty. One explanation for such results might be that the unstructured contexts affords dialogue in ways that more easily promote building and sharing of novel ideas. That is, if a novel idea was shared with the group during an unstructured session, as modifications to that solution were discussed, the novelty of the initial solution was persevered and increased by the various modifications suggested.

In contrast, in the 6-3-5 brainstorming, the process of building off one another's ideas is altered and potentially limited by the format and medium used to generate ideas (i.e., paper and pencil). While the 6-3-5 method does encourage members to build off of and use each other's solutions to generate new ones, the process is different from the dialogue generated during unstructured sessions. For example, during the 6-3-5, it was rare that participants asked for clarifications of others' sketches. Moreover, it was also unlikely that an individual used their time to make more than one modification to an existing idea.

At the same time, unstructured sessions generated fewer overall solutions than the 6-3-5 brainstorming groups. Such findings have useful implications for engineering instructors as well as designers in industry. More specifically, it seems useful to consider the relationship between the goals of a given brainstorming session and the techniques used to facilitate it. If the goal of a design team is to generate a higher quantity of solutions (as might be the case in early phases of design work), then a structured session might be more desirable. On the other hand, if the goal is to generate novel or innovative solutions, then an unstructured brainstorming session might meet those needs. Nonetheless, we suggest that future research explore the ways in which different or additional structures might affect brainstorming novelty—in particular attending to the point in the design phase such brainstorming occurs.

Gender Composition and Brainstorming Novelty

Second, while our findings related to gender composition are preliminary and tentative, they do raise important questions about the ways in which the ratio of men to women can influence brainstorming outcomes. The present findings suggest that during unstructured brainstorming, the gender composition of the team had a significant effect on the average novelty of the session. Specifically, both predominantly male and predominantly female teams generated, on average, more novel solutions than gender balanced teams.

This finding is interesting because it suggests that novelty is less about the contributions of the individual team members and more about the way the gender ratio influences the activity. That is, if women were, on average, more creative than men, then we might expect to see average novelty increase as the proportion of women to men increased in the team. However, we see that when a team is primarily composed of one gender or another, they generate more novel solutions than a team that is gender balanced. One interpretation of this might be that the creation of a majority for either group leads to individuals in that group feeling more comfortable and therefore more willing to share ideas. In a balanced group, the lack of a clear majority might prevent such effects. At the same time, the creation of a majority might negatively influence the performance or interactions of those in the minority. Further research is needed to more deeply explore the role of gender composition and brainstorming outputs.

Scoring and Characterizing Brainstorming Discourse

Finally, the present research developed a technique to capture and score ideas that were generated only through conversation during brainstorming. While the 6-3-5 method lends itself to relatively straightforward scoring of sketches, less research has explored the content of the dialogue that takes place during unstructured activity. During data analysis, we developed a method for capturing spoken ideas and scoring them in ways that allowed for a meaningful comparison with data in the form of sketches (i.e., the output of structured brainstorming). Given the richness of dialogue that takes place during brainstorming, it would behoove future researchers to explore ways to improve upon our scoring method outlined above. In particular, future work should explicate the specific processes and approaches used to break up individual ideas, determine their contents, and consistently evaluate resulting novelty.

Conclusion

Our work explored the influence of brainstorming structure and gender composition on the novelty of engineering design teams. Students were grouped according to various gender compositions and asked to generate solutions related to playground equipment for children in wheelchairs. Brainstorming sessions were either unstructured and free-flowing or structured according to the 6-3-5 method. We analyzed sketched ideas (6-3-5 method) and brainstorming discourse across three gender compositions and scored the novelty of each solution generated. We found that gender composition had an influence on group novelty in unstructured brainstorming, but not in structured. Such findings suggest the influence on novelty stems from differences in interactions between gender compositions, not differences between gender.

As noted, this work-in-progress is part of a larger research effort exploring the micro-interactions that take place during engineering brainstorming activities. Future work will use a mixed methods approach to triangulate factors that influence group novelty. Qualitatively coding the micro-interactions of engineering discourse (process-based approach) and comparing it to the novelty scores of their respective ideation sessions (outcome-based approach) may shed light on what influences a group's novelty. Further, another component of the data collection entailed focus groups after each ideation session, during which we explored group-level experiences and perceptions of effectiveness. We will incorporate this student perception data to better understand not only relevant brainstorming factors, but also how students respond to these different factors. Furthermore, we hope to leverage personality data from a University database on students' personal strengths in addition to our gender data points. Overall, the findings from the current work-in-progress highlight a number of areas primed for subsequent research and exploration. In developing brainstorming and ideation approaches, it is our hope to develop a cohesive set of recommendations for faculty who want to promote positive design outcomes and facilitate equitable teaming interactions.

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