STUDIES IN ENGINEERING EDUCATION

Exploring Patterns in Engineering Brainstorming Conversations by Combining Discourse Analysis and Statistical Methods

EMPIRICAL RESEARCH

AIMEE CHIEM

BEN LUTZ

*Author affiliations can be found in the back matter of this article

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ABSTRACT

Background: Group brainstorming is an essential aspect of engineering design, and the discussions that take place during these activities influence downstream outcomes. A better understanding of brainstorming discourse can improve the effectiveness of discussions and improve engineering solutions.

Purpose: This study explores the nature of conversations during engineering brainstorming activities and identifies themes and patterns in these discussions.

Methods: We used a convergent mixed methods approach that combines discourse and statistical analysis to better understand different elements of engineering brainstorming discussions. We analyzed transcripts from 13 brainstorming sessions involving 59 engineering students tasked with designing accessible playground equipment.

Results: Our analysis revealed three dominant themes in the brainstorming discourse: Active Engagement, Group Rapport, and Exploring the Problem. These themes represent the different ways that engineering teams generate ideas and the different kinds of conversations that take place across a given brainstorming session.

Conclusion: Our findings suggest that effective engineering brainstorming entails more than simply generating ideas; it also requires understanding social dynamics and exploring the boundaries and constraints of the problem itself. This study contributes to design research by highlighting key elements of engineering brainstorming discourse and offering insight into the complexities involved in creative activities like ideation. By accounting for these different aspects of conversation in brainstorming, engineering educators can encourage more productive discussions in ways that lead to more effective design solutions.

CORRESPONDING AUTHOR:

Ben Lutz

Mechanical Engineering, Cal Poly San Luis Obispo, California, US

blutz@calpoly.edu

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INTRODUCTION

Group brainstorming is an important part of the engineering design process and can have formative downstream impacts on the outcomes of the project (Chulvi et al., 2012; Kavadias & Sommer, 2009). Effective brainstorming allows engineers to fully explore the design space and develop novel solutions (Bonnardel & Didier, 2020). Understanding brainstorming in engineering is therefore important because of the ways it can influence the solutions that engineers ultimately converge on. Within conceptual design settings, engineers might engage in a wide range of brainstorming approaches. Some methods are structured, such as the SCAMPER technique (Özyaprak, 2016), where students utilize a specific framework to generate new ideas. Some involve a combination of solitary and collaborative work, as in the case of brainwriting (Linsey & Becker, 2010). Some might involve the use of sketching, as is the case with the 6-3-5 methods or C-Sketch techniques (Shah et al., 2001). Countless web-based tools also exist to enable collaboration asynchronously and in geographically dispersed groups (e.g., JamBoard) (Anderson et al., 2022). In all cases, however, these collaborative activities generally involve some kind of discussion or deliberation among team members, either in person or virtually. That is, most brainstorming approaches are supported or facilitated by discourse. By developing a better understanding of the ways brainstorming conversations contribute to ideation processes, we can better support students and professionals in ways that enable more creative, effective brainstorming outcomes. Examining engineering language and speech in these settings can help engineering teams develop more effective processes and ultimately products.

Discourse analysis is a research process that examines the role of language in constructing meaning and seeks to better understand the relationship between language and the contexts in which language is used (Gee, 2010; Johnstone & Andrus, 2024). Discourse plays an important role in brainstorming because it is through discussion and deliberation that team members can offer new ideas, build off them (Lutz et al., 2022; Osman et al., 2021), and engage in problem definition and scoping (Svihla et al., 2021). Engineers create ideas through the words they use. We argue that effective brainstorming discourse has the potential to help teams work more effectively, explore the design space more fully, and ultimately converge on the best design solutions. Therefore, it is valuable to study the conversations that happen during brainstorming to gain a deeper understanding of how it can produce more effective ideation outcomes.

The purpose of this paper is to develop a deeper understanding of the ways engineers talk to each other during brainstorming activities. The research is guided by the following questions:

1) What are the different kinds of discursive moves that students make during engineering brainstorming activities?
2) What patterns or themes emerge among these discursive moves?

To address these questions, we used a convergent mixed methods design that combined discourse analysis with statistical analysis. We collected transcript data from student discussions of an open-ended brainstorming prompt and moved back and forth between qualitative and quantitative methods to examine patterns and themes in student discussions. First, we developed a codebook focused on identifying the discursive move present in participant utterances. A discursive move refers to the intended purpose or function of a piece of dialogue in context. An utterance was defined as an uninterrupted turn taken within the transcript data. We applied our codebook and used frequency counts to explore correlations among occurrences of each discursive move. We used visual diagramming to uncover different “clusters” of codes and worked recursively through our transcript data to better understand what these clusters represented in terms of discourse patterns. This research represents a novel integration of qualitative and quantitative methods and offers new ways to visualize the results of discourse analysis and examine emergent themes and patterns. By developing a better understanding of the different kinds of speech and relationships among them, engineers can have a better grasp on how to frame brainstorming activities in ways that can yield more effective conversations among teams. This can be extended to engineering educators, and the same can be done for student teams as students learn better engineering practices for their future.

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LITERATURE REVIEW

Two major areas of literature are relevant to the present study. First, we focus on research in engineering brainstorming, as that provides a way to think about different brainstorming processes and outcomes as well as the relationship between the two. Literature on brainstorming also offers a range of frameworks or tools to examine the process and outcomes. Next, we turn to the literature on discourse analysis both within and beyond engineering-specific contexts. Discourse analysis helps us characterize the discussions that take place during brainstorming and to better understand how different patterns of talk form and relate to each other. The following sections provide an overview of these two areas and illuminate the gaps our present work seeks to address.

BRAINSTORMING IN ENGINEERING DESIGN

Brainstorming is a central activity in engineering design and can have a strong influence on the way engineers think about and solve problems. Brainstorming typically serves to generate multiple solutions to an engineering problem and in the process, explore the design space (i.e., the range of potential solutions) (Dym et al., 2005). While there has been significant focus on the outcomes of brainstorming (e.g., (Kavadias & Sommer, 2009; Shah et al., 2003)), less research in engineering has examined the process-oriented elements. However, some noteworthy studies are relevant to the research presented in this paper.

One strand of research in brainstorming has focused on factors such as team composition or diversity. Zhao and Hou (2010) suggest that factors such as team composition and alignment in interaction styles play important roles in modulating brainstorming effectiveness. Relatedly, Kavadias and Sommer (2009) demonstrate that diverse teams are more effective for cross-functional or interdisciplinary problems, but nominal teams (i.e., the combined results of several individuals) can outperform groups on specialized problems. The findings highlight the role of interpersonal factors in engineering brainstorming outcomes.

Another area of research has focused on the role of different design methods and their impact on brainstorming outcomes. Chulvi et al. (2012) found that traditional brainstorming (i.e., unstructured collaborative discussions) was effective in developing solutions but that more structured design tools such as functional analysis or the SCAMPER technique (acronym for Substitute, Combine, Adapt, Modify, Put to another use, Eliminate, Rearrange) encouraged greater exploration of the problem space and more divergent thinking. More recently, Murphy et al. (2023) compared differences in brainstorming outcomes from students who used individual, unstructured techniques to others who used design heuristics. They found that both approaches are important to use at different points, with individual being useful for systems-level ideation and heuristics being effective for component-level considerations. These studies demonstrate that the mode or structure of ideation processes can impact the outcome and offer insight into the affordances and drawbacks of different techniques.

While these studies provide insight into the impact of different factors such as team composition or activity structure, they overlook some of the in-depth communicative dynamics that support these brainstorming interactions. A focus on discourse and language in brainstorming can complement our understanding of the processes by examining how students talk to each other to achieve brainstorming goals. Discourse analysis can be valuable to understanding engineering brainstorming because of the central role of language and discussion during brainstorming activities (Chiem, 2023; Lutz et al., 2022; Cross, 2004).

DISCOURSE ANALYSIS IN ENGINEERING EDUCATION

To further situate the present study, we turn to research that uses discourse analysis (and related methods such as content analysis) in engineering education settings. Discourse analysis is a research methodology that focuses on language use in social contexts and seeks to examine how meaning is constructed through different forms of communication (Gee, 2010). Communication can be verbal or written, and discourse analysis has been used in a wide range of disciplines including engineering education (Case & Light, 2011). Data used for verbal discourse analysis are often forms of natural speech, such as a transcript of a classroom discussion or, in our case, a brainstorming session. Discourse analysis is helpful in explicating beliefs, values, motives, etc. that are embodied in language and can therefore illuminate the deeper meaning within a passage of text or speech and its relation to broader social contexts. Gee (2010) describes how discourse is used to convey different meanings of words, inform and construct identities, and signal membership in different groups. The ways that we speak and write are often dependent on local norms and assumptions, making discourse analysis useful for exploring the role of context in different forms of communication. It helps researchers understand how language shapes and is shaped by its context (Johnstone & Andrus, 2024).

One major area of research on discourse in engineering surrounds knowledge construction and collaboration. Kittleson and Southerland (2004) used discourse analysis to examine how engineering students construct knowledge in group activities. They used transcripts of lab sessions for senior design students to show how students negotiate and develop conceptual understanding through discourse. McNair et al. (2010) applied discourse and speech act analysis to written exchanges (i.e., emails and design memos) among internationally distributed teams working on an interdisciplinary engineering design project. They identified twelve discourse practices related to collaboration and trust within teams such as asking for/providing elaboration on an idea, offering/soliciting feedback, and acknowledging the contribution of other team members. Eggert et al. (2014) explored how initial teaming interactions provided support for design team success for first-year students. They used recordings of team design meetings to identify different "failure modes" of design teams or the dominant themes that seemed to result in suboptimal collaboration and performance. These studies highlight the importance of discourse in supporting effective engineering collaborations.

Another strand of research has used discourse to examine power, positioning, and inclusivity in different engineering education contexts. Savaria and Monteiro (2017) used critical discourse analysis to examine language in engineering syllabi to make recommendations for more inclusive language that might appeal to more diverse students. Gius et al. (2020) highlight some different ways that language is used to influence power and direct discussions during brainstorming interactions. They found that some participants used different kinds of speech to control the discussion and leveraged technical jargon to exert authority over the discussion. Discourse can thus be a primary way to mediate power dynamics in engineering education.

A third major area of research concerns issues of problem framing and perceptions of agency. Svihla et al. (2021) used sociolinguistic content analysis to examine students' sense of agency in framing engineering problems. They found that engineering teams with a greater sense of shared agency were more effective in navigating impasses related to problem framing. Chindanon and Koretsky (2023) build on this through their use of discourse analysis to investigate different kinds of interactions during collaborative, open-ended engineering tasks. They identified conceptual, social, and material aspects of collaborative discussion, and also analyzed speakers' intonation to highlight subtler, less verbally explicit modes of communication in engineering groups. These studies highlight the role of discourse in shaping boundaries and constraints of a problem space. For engineering education, discourse analysis is important as a research methodology because discourse lies at the heart of learning and development (Johri & Olds, 2011). Through engagement with texts and discussions with others, we learn new ideas and form new concepts. Given the centrality of brainstorming to engineering design, we believe that discourse analysis can be applied to brainstorming conversations to uncover important elements and identify the kinds of conversations that characterize and support ideation. By studying brainstorming discourse, engineering educators and design researchers can better understand the linguistic processes that characterize this critical aspect of engineering activity. Doing so can help us better understand the kinds of discursive practices that might lead to more effective brainstorming and ideation.

Discourse Analysis Frameworks Used in this Research

Research that has most directly informed the present work are studies by Mileva (2009) and Wieselmann et al. (2019, 2020, 2021), who have used discourse analysis directly in engineering design and brainstorming activities. Mileva (2009) used discourse analysis in electronic brainstorming (i.e., chat rooms) to explore the effects of anonymity on brainstorming. Notably, Mileva developed a codebook that described the different categories into which speakers' statements during ideation could fall. It included a coding scheme that captured different types

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of queries and solutions proposed, as well as supportive, opposing, or neutral statements that a person made. Wieselmann and colleagues (e.g., (Wieselmann et al., 2019, 2020, 2021)) employed discourse analysis to study student interactions during different STEM activities. They analyzed the discourse of K-12 students engaged in design-based activities to examine, for instance, power and positioning (Wieselmann et al., 2021) as well as gendered differences and patterns (Wieselmann et al., 2020). The research team developed a codebook that characterized different speech acts such as *explaining, suggesting, directing, dis/agreeing*, etc. to analyze different patterns in the ways teams engaged in engineering activities (including brainstorming). Work from both Mileva (2009) and Wieselmann and colleagues (2019, 2020, 2021) are instrumental to the work here, as they helped to form the basis for the codebook we developed for the present discourse analysis. We used codes developed by these researchers to form the basis of our initial deductive codebook that we applied to our brainstorming conversation data (Lutz et al., 2022).

METHODS

The purpose of this research is to explore engineering brainstorming conversations and to examine patterns or relationships within those discussions. We used discourse analysis techniques to characterize the different "discursive moves" made by participants during the brainstorming sessions. By discursive move, we mean the purpose or goal of a given piece of dialogue. We used transcripts of group brainstorming sessions to identify and count the various discursive moves made by our participants as they worked on a conceptual design prompt. We examined correlations among these discursive moves and used these correlations to identify patterns and themes that emerged from our data.

DATA COLLECTION

Participants were recruited from a large, public, predominantly undergraduate institution on the west coast. We used a combination of course- and department-level listservs within the College of Engineering. Interested students completed a screening survey that collected names, email addresses, and other demographic information such as year in school, engineering major, race/ethnicity, pronouns, international status, and transfer status. In total, we received 90 survey responses.

First, we stratified the sample according to year in school, as we wanted to create groups of students with similar design experiences. Pilot studies suggested that when students with vastly different experience levels (e.g., 1st year vs 4th year), those with less experience tended to be less engaged and contributed less to the discussion than when experience was controlled for. After collecting participants' availability, we created groups of between 2–6 students in which we sought maximum variation in terms of gender, race/ethnicity, and engineering major, in that order. In total, we conducted 13 brainstorming sessions that included 59 total students. The demographic breakdown of each group is shown below in Table 1. Groups 7–13 were conducted in person in the spring of 2019 and groups 1–6 were conducted using a videoconferencing platform during the spring of 2021. We do not disaggregate race/ethnicity any further to avoid potentially identifying participants.

Table 1 Participant demographics by gender and ethnicity (white or non-white).

*All student respondents used either he/him or she/her pronouns.

GROUP	YEAR IN SCHOOL	MEN (HE/HIM)	WOMEN (SHE/HER)	WHITE	NON-WHITE	*TOTAL PARTICIPANTS*
1	2–4	4	2	3	3	*6*
2	3–4	3	2	0	5	*5*
3	2–3	2	2	2	2	*4*
4	2–3	3	3	4	2	*6*
5	2–3	4	2	4	2	*6*
6	2	1	3	2	2	*4*
7	4–5	2	2	1	3	*4*
8	1–2	2	0	1	1	*2*
9	1	2	1	1	2	*3*

(Contd.)

GROUP	YEAR IN SCHOOL	MEN (HE/HIM)	WOMEN (SHE/HER)	WHITE	NON-WHITE	*TOTAL PARTICIPANTS*
10	1–2	2	3	2	3	*5*
11	1–4	2	4	3	3	*6*
12	4	1	2	2	1	*3*
13	2–4	3	2	4	1	*5*
Total		*31*	*28*	*29*	*30*	*59*

Students were given the following design prompt, which was inspired by previous research on engineering design and ideation (i.e., (Atman et al., 2005, 2007)). Each group was given 30 minutes to work on the following prompt:

> *Playgrounds and parks are integral components of a child's development and offer myriad opportunities for individuals to get some exercise through physical activities while also socializing and making friends through play. However, most traditional playground equipment is primarily designed for able-bodied children and offers less access to those with limited strength or mobility (e.g., monkey bars, and stairs to access high points). To address this issue, your task is to design a new or modified piece of playground equipment for children who use wheelchairs.*

Students were asked to work together to create as many solutions as possible, ignoring constraints related to practicality, feasibility, or other factors that might hinder creativity and ideation ability. They were also encouraged to avoid using outside resources such as the Internet for inspiration. In-person groups were offered pencil and paper and whiteboards to assist in ideation and virtual groups used features such as the Zoom whiteboard or chat if needed to convey their ideas. Audio files were transcribed by a professional service and scrubbed to remove any identifying information. The study was approved by the university's IRB process (protocol #2019-172).

DATA ANALYSIS

This research used both qualitative and quantitative techniques to analyze our data. First, we performed a qualitative discourse analysis using a combination of deductive and inductive codes that were both informed by prior research (i.e., (Lutz et al., (2022); Mileva, (2009); Wieselmann et al., (2019, 2021)) and that emerged from our local findings. Following the discourse analysis, we tabulated frequency counts of each code for each brainstorming session. We used this tabular data to perform a quantitative correlational analysis that sought to identify patterns in conversation or any emergent themes in the relationships among different codes. We then performed what we termed a "data synthesis," which entailed developing a visual representation/mapping of correlational relationships and identifying clusters that correspond to broader themes in the conversation. The research design is convergent mixed methods because it involved moving back and forth across qualitative and quantitative insights to converge on the final themes in our results. Specifically, the qualitative analysis provided the frequency counts, which were then used to inform our quantitative analysis. Following our quantitative statistical analysis, we engaged in a process of qualitative data visualization/mapping that was based on our statistical findings. In this way, we performed a convergent mixed methods research design with a data transformation approach (Creswell & Clark, 2017). We will elaborate on each aspect of the analysis in the following sections.

Discourse Analysis

Individual utterances served as the unit of analysis, and an utterance was considered as a single, uninterrupted sentence or series of sentences that was eventually broken by another speaker. That is, segments began and ended when speakers changed. Each unit was coded using a combination of deductive and inductive coding, which involved using codes established in prior research when possible and adapting or creating new ones to fit our unique research context and data collection approach. Specifically, we began with codes used by Wieselmann, (2019) and Wieselmann et al., (2021), who examined discourse in K-12 STEM engineering contexts, as well as Mileva, (2009), who examined discourse analysis in online brainstorming environments in a Design Thinking course.

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We began with these codes because they offered a useful starting point for analysis based on the correspondence between our research context and those in their prior research. However, our unique research context also facilitated the development of emergent codes that were not accounted for in prior research.

Each code in our codebook was designed to identify the function of the utterance, such as proposing a new or modified idea, facilitating discussion, asking for clarification, or other speech that is characteristic of brainstorming discourse. Each code then refers to a unique *discursive move* that signifies the intent of the speaker for a given utterance. By understanding the different kinds of moves that people can make, we can better understand how to guide those moves and frame activities to achieve more effective brainstorming conversations.

The codebook was iteratively revised to categorize all lines of meaningful dialogue in the transcripts, and the process can be seen in more detail in our previous work (i.e., (Chiem, 2023; Lutz et al., 2022)), but our final codebook is shown in Table 2. We achieved consensus among coders in two different ways that are both consistent with recommendations by Walther et al. (2013), who lay out concrete strategies for ensuring quality in qualitative research. and in process reliability specifically. First, two student researchers performed independent coding of the same selected transcript segments. Results were compared, and the research team established agreement by arguing to consensus. The second round of interrater reliability was conducted via expert review. Author 2 was given segments of coded transcripts that had been completed by the research team and these segments were examined for consistency, clarity, and completeness. All discrepancies were argued to consensus until a final codebook was developed and agreed upon by all researchers on the project. These strategies are consistent with recommendations for process reliability and communicative validation (Walther et al., 2013). Using discourse analysis was beneficial to our goal because it allowed us to categorize the different types of speech and quantify them for further analysis. Our final codebook is shown below in Table 2.

Table 2 Discourse analysis codebook identifying the different discursive moves made by participants during brainstorming.

CODE	DEFINITION
Ideation	Proposal of an idea/potential solution, including additions to and variations of a root idea
Facilitation	An effort to guide the focus of the discussion and the group (typically to move forward or invoke more ideas)
Acknowledgment	An indication of acknowledging someone's comment or responding to another member's query
Support	An indication of supporting and approving someone's idea
Clarification	A reiteration, elaboration, or prompting of elaboration on a previously stated idea, question, or prompt
Criticism	An indication of not supporting or rejecting someone's (or one's own) comment
User Consideration	Direct discussion of user's needs, desires, or limitations, whether it be during idea proposal or otherwise
Building Credibility	Efforts to boost an individual's reputation in the group through mention of previous experiences
Technical Talk	Invocation of engineering-specific terms to describe or elaborate on, usually used to "perform" engineering knowledge
Small Talk	Conversation about topics not directly related to the prompt, usually helps to build rapport within the team

Each utterance was assigned at least one code from Table 2, though in some cases participants might have been making multiple moves within a single utterance (e.g., asking for clarification while also offering support). An example of the coding process is shown below in Figure 1.

In line 53, the speaker offers the idea of adding a secondary braking mechanism to the wheelchair. This is therefore coded as *Ideation*, but it is also coded as *User Consideration* since the speaker mentions why that would be beneficial to the user. Each line that followed was coded using the same process, identifying the purpose of what the speaker was trying to say and coding it accordingly.

Line	Speaker	Text	Ideation	Facilitation	Acknowledgment	Support	Clarification	Criticism	User Consideration	Building Credibility	Technical Talk	Small Talk
53	S3	I know a lot of wheelchairs, they have their kind of brake kind of thing. But I think a secondary kind of thing would be probably a good idea to make sure it stays and there isn't a chance of it rolling off.	X						X			
54	S1	What are we thinking that would look like?					X					
55	S3	I mean, I don't know how feasible this would be, but if we have a gate kind of system, it'd just be then a tall box with that back wall or the front wall being able to move back and forth.	X									
56	S1	Oh, I see. I see. I see.			X							
57	S3	Hinges kind of here. It's just, once again, there's a question of reaching this. How will this stay up here? Will there have to be locks then over here? And that's a lot of steps for the kind of park. Yeah. Or we could do some kind of rope thing that would attach to each wheel on each side. But once again, that could get caught, and that could be a problem, too.					X					
58	S1	But similar design for adaptation is basically just a bigger plate so the wheelchair could sit on, essentially.					X					

Figure 1 Example of coding process using an excerpt from a transcript.

Statistical Analysis

Aggregate counts of the occurrence of each code were totaled for each transcript, resulting in the descriptive statistics shown below in Table 3, which contains the frequency counts of each code for each transcript. We focus on the overall frequency (as opposed to the relative proportion of statements). We chose this approach because it allowed us to also retain data regarding the overall number of ideation statements within each group. Because all data collection sessions were approximately the same length of time, the raw count of different codes offered a useful means of comparison across groups in terms of performance and engagement.

We used the frequency counts from each coded transcript to perform a correlational analysis and explore potential correlations among different discursive moves. This allowed us to explore different relationships between all different combinations of discursive moves. We used SPSS (Version 23) to calculate each correlational coefficient and each corresponding p-value. Correlations with p-values less than 0.05 were considered statistically significant. We did not apply corrections for multiple comparisons (e.g., Bonferroni correction) because of the exploratory nature of the research and the desire to mitigate type II errors. Because we are trying to explore patterns and relationships in discourse, and because we have qualitative data to triangulate and explain our statistical findings, the potential benefit of identifying significant relationships outweighed the potential to commit type I errors (Gelman et al., 2012). A correlational analysis is provided in Table 4 in the results section.

Table 3 Descriptive statistics showing code counts for each transcript and the mean, standard deviation, maximum, and minimum. The proportion of statements withing a given transcript is noted in parentheses. Note: The data for Group 6 is derived from incomplete data collection due to technical errors.

GROUP #	IDEATION	FACILITATION	ACKNOWLEDGMENT	SUPPORT	CLARIFICATION	CRITICISM	USER CONSIDERATION	BUILDING CREDIBILITY	TECHNICAL TALK	SMALL TALK	TOTAL CODED LINES
1	67 (20%)	14 (4%)	120 (36%)	47 (14%)	38 (11%)	8 (2%)	4 (1%)	1 (0.3%)	7 (2%)	29 (9%)	*335*
2	48 (20%)	16 (7%)	65 (27%)	39 (16%)	46 (19%)	2 (1%)	12 (5%)	0 (0%)	2 (0.8%)	13 (5%)	*243*
3	47 (20%)	15 (6%)	66 (28%)	20 (8%)	55 (23%)	5 (2%)	7 (3%)	3 (1%)	5 (2%)	14 (6%)	*237*
4	57 (15%)	12 (3%)	52 (14%)	19 (5%)	140 (38%)	24 (7%)	35 (9%)	2 (0.5%)	9 (2%)	19 (5%)	*369*
5	57 (15%)	19 (5%)	102 (28%)	53 (14%)	80 (22%)	10 (3%)	28 (8%)	5 (1%)	6 (2%)	8 (2%)	*368*
6	24 (26%)	9 (10%)	17 (18%)	7 (8%)	22 (24%)	1 (1%)	8 (9%)	0 (0%)	0 (0%)	5 (5%)	*93*
7	56 (31%)	8 (4%)	29 (16%)	16 (9%)	49 (28%)	1 (1%)	7 (4%)	0 (0%)	1 (0.6%)	11 (6%)	*178*
8	25 (17%)	8 (5%)	21 (14%)	4 (3%)	80 (55%)	3 (2%)	4 (3%)	0 (0%)	0 (0%)	1 (0.7%)	*146*
9	27 (15%)	8 (4%)	20 (11%)	8 (4%)	87 (49%)	3 (2%)	11 (6%)	0 (0%)	8 (4%)	7 (4%)	*179*
10	43 (23%)	10 (5%)	26 (14%)	18 (10%)	57 (30%)	10 (5%)	18 (10%)	0 (0%)	3 (2%)	3 (2%)	*188*
11	31 (23%)	4 (3%)	17 (13%)	16 (12%)	46 (35%)	2 (2%)	2 (2%)	1 (0.8%)	1 (0.8%)	12 (9%)	*132*
12	52 (19%)	19 (7%)	65 (24%)	35 (13%)	59 (22%)	7 (3%)	19 (7%)	1 (0%)	10 (4%)	7 (3%)	*274*
13	40 (14%)	18 (6%)	63 (22%)	26 (9%)	87 (31%)	9 (3%)	11 (4%)	0 (0%)	4 (1%)	23 (8%)	*281*
Mean	*44 (19%)*	*12 (5%)*	*51(22%)*	*24 (10%)*	*65 (28%)*	*7 (3%)*	*13 (5%)*	*1 (0.4%)*	*4 (2%)*	*12 (5%)*	*233*
Standard Deviation	*14.0*	*4.9*	*33.4*	*15.5*	*30.0*	*6.2*	*9.8*	*1.5*	*3.5*	*8.1*	*89.7*
Maximum	*67*	*19*	*120*	*53*	*140*	*24*	*35*	*5*	*10*	*29*	*369*
Minimum	*24*	*4*	*17*	*4*	*22*	*1*	*2*	*0*	*0*	*1*	*93*

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Data Synthesis

Our final approach to analysis represents a novel method that leveraged both quantitative statistical results and qualitative descriptive findings. We term this *data synthesis* because it involves moving back and forth from statistical results to qualitative transcripts to uncover salient patterns and higher-order themes within the discourse. To accomplish this, we first created a visual model similar to a concept map that provided a graphical representation of the statistically significant correlations among each discursive move. An example of this process is shown below in Figure 2, which illustrates the statistically significant correlations (p = 0.05) among four different discursive moves, in this case, acknowledgment, ideation, support, and facilitation.

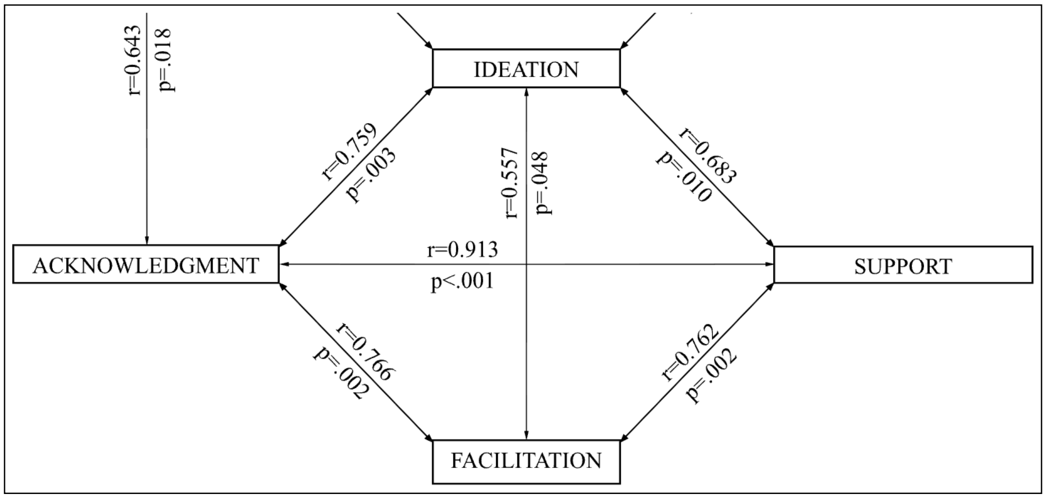

Figure 2 Visual model showing statistically significant correlations among discursive moves.

We continued this process for all statistically significant codes until it was organized in a format similar to a concept map. This process enabled us to identify different "clusters" of codes that were highly correlated with each other and to develop a visual model for the way discursive moves related to one another. Once different clusters were identified, we worked recursively through our transcript data to identify the broader themes represented by different correlational clusters. For instance, based on the cluster in Figure 2, we reviewed transcripts for instances in which ideation, acknowledgment, facilitation, and support were coded near each other and identified different, higher-order conversational structures that occurred within a brainstorming transcript. We provide an overview of each of these themes in the following section.

This research approach represents a novel methodology in that it incorporates both qualitative (i.e., discourse and thematic analysis) and quantitative (i.e., statistical correlations) methods to identify conversational themes within engineering brainstorming activities. The process of moving back and forth from qualitative to quantitative analysis helps triangulate and bolster findings from each portion of the analysis and provides a useful visual model to help designers better understand the way different discursive moves work together in practice during ideation.

Researcher Positionality

Our backgrounds, experiences, and identities are important to contextualize our findings and offer a better understanding of our interpretations. Author 1 is an Asian-American woman who identifies as straight. She was a Master's student at the time of data collection and currently works as a practicing engineer in mechanical and construction engineering. She has an interest in engineering design and creativity and engineering education research. She has experience with both statistical methods and qualitative coding, which informed the mixed-methods approach used in this study. Author 2 is a straight, White male and is an associate professor of mechanical engineering. He served as the advisor for the first Author's thesis. Author 2 has a background in engineering education research and has conducted several engineering design research projects using diverse methodological approaches. Together, our diverse backgrounds allowed us to approach the research from multiple viewpoints, including both as design instructors and students engaging in design. These differences also influenced our perceptions and analysis of group discussions during brainstorming sessions, and we worked to acknowledge these differences in our collective interpretation of our data.

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RESULTS

We used the descriptive statistics in Table 3 to conduct a correlational analysis among the different discursive moves. We then used these correlations to create a visual representation of statistically significant relationships. These relationships helped us identify clusters of discourse that represent larger themes within the brainstorming conversation. The results highlight how the use of mixed methods can offer unique insight into the nature of brainstorming discourse and the kinds of conversations present that work in advancing creative design processes.

CORRELATIONAL ANALYSIS

Table 4 provides the results of the correlational analysis and highlights those that are statistically significant with a p-value of 0.05 and 0.01. We identify significance at both p = 0.05 and p = 0.01 because although we did not apply a correction for multiple comparisons, p = 0.01 does indicate a stronger likelihood of statistical significance and is thus noteworthy in exploratory research.

Table 4 Correlation matrix showing correlation coefficients and p-values for all codes.

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

CORRELATIONS											
		IDEATION	FACILITATION	ACKNOWLEDGMENT	SUPPORT	CLARIFICATION	CRITICISM	USER CONSIDERATION	BUILDING CREDIBILITY	TECHNICAL TALK	SMALL TALK
Ideation	*Pearson Correlation*	—									
Facilitation	*Pearson Correlation*	.557*	—								
	Sig. (2-tailed)	0.048									
Acknowledgment	*Pearson Correlation*	.759**	.766**	—							
	Sig. (2-tailed)	0.003	0.002								
Support	*Pearson Correlation*	.683*	.762**	.913**	—						
	Sig. (2-tailed)	0.01	0.002	0							
Clarification	*Pearson Correlation*	0.206	0.135	0.017	−0.066	—					
	Sig. (2-tailed)	0.499	0.661	0.955	0.832						
Criticism	*Pearson Correlation*	.586*	0.369	0.357	0.273	.760**	—				
	Sig. (2-tailed)	0.035	0.215	0.231	0.367	0.003					
User Consideration	*Pearson Correlation*	0.477	0.434	0.235	0.313	.687**	.832**	—			
	Sig. (2-tailed)	0.099	0.138	0.439	0.298	0.009	0				
Building Credibility	*Pearson Correlation*	0.479	0.449	.573*	.559*	0.239	0.424	0.496	—		
	Sig. (2-tailed)	0.098	0.124	0.04	0.047	0.431	0.149	0.085			
Technical Talk	*Pearson Correlation*	.567*	0.516	0.506	0.432	0.493	.629*	.588*	0.393	—	
	Sig. (2-tailed)	0.043	0.071	0.078	0.14	0.087	0.021	0.035	0.184		
Small Talk	*Pearson Correlation*	.580*	0.314	.643*	0.473	0.07	0.299	−0.069	0.083	0.313	—
	Sig. (2-tailed)	0.038	0.296	0.018	0.103	0.821	0.321	0.824	0.788	0.298	

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Table 4 represents the relationships among each discursive move with each other. For instance, *Support* and *Ideation* correlate r = 0.683 (p = 0.01). This suggests that in our engineering brainstorming data, there is a potentially meaningful, statistically significant relationship between statements intended to present ideas and statements intended to offer support for an idea. However, examining these correlations individually or one by one might overlook higher-order themes or patterns.

DATA SYNTHESIS

Because we wanted to explore the themes that characterize brainstorming discourse, we synthesized the correlational data into a visual map that specifies statistically significant correlations at p = 0.05. Because we are interested in ideation processed and outcomes, we focused on statistically significant relationships in which *Ideation* was part of these relationships. This map visualizes the codes in terms of their correlations to other codes in the codebook, and the connections are mapped in the diagram in Figure 3, which also shows the respective correlation coefficient and p-value for each correlation.

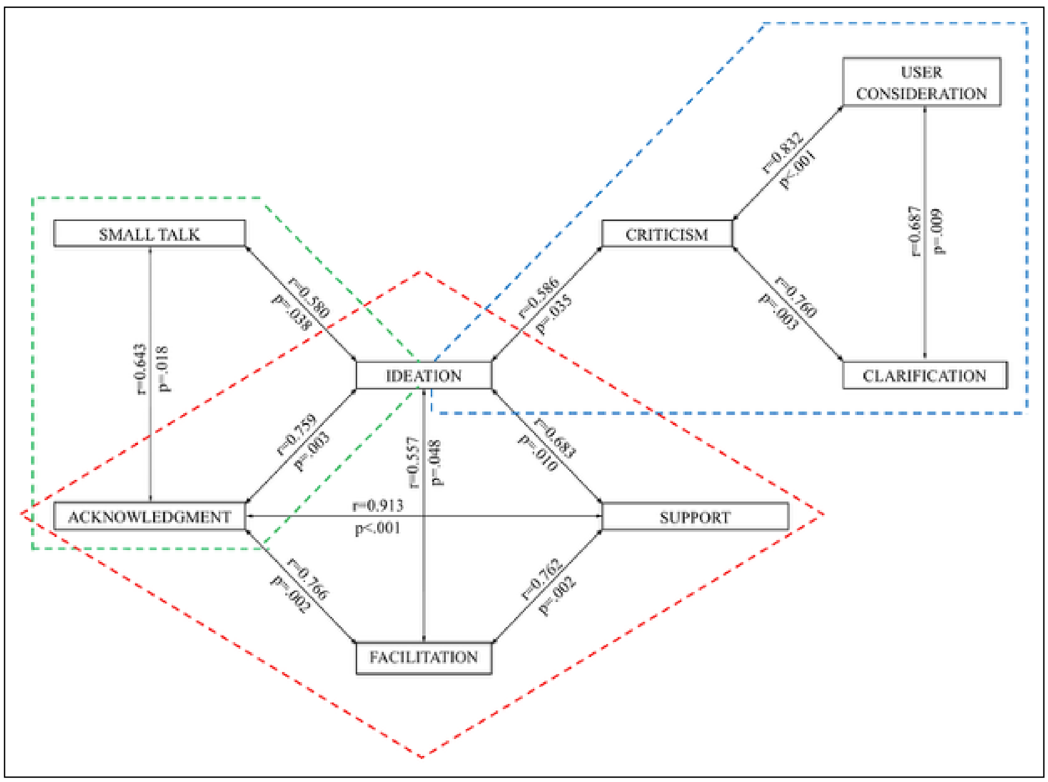

Figure 3 Diagram of correlational mapping surrounding ideation. Red refers to *Active Engagement*. Green refers to *Group Rapport*. Blue refers to *Exploring the Problem*.

Organized this way, we identified three clusters of correlations that represent higher-order themes in the conversation. Specifically, we observed notable relationships among the following groups of variables:

1. Ideation – Acknowledgment – Support – Facilitation
2. Acknowledgment – Small Talk – Ideation
3. Ideation – Criticism – User Consideration – Clarification

These clusters describe instances where these codes occur near each other in discourse and represent different components of the conversation that takes place within engineering brainstorming activities. One noteworthy observation here is that *Ideation* is part of all three clusters, suggesting that each one of these conversational elements has some contribution to the generation of new ideas during brainstorming.

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Table 5 offers an overview of the three emergent themes and their operational definition in the context of the study. The following sections provide a more in-depth description of each theme grounded in examples from our transcripts.

Table 5 Emergent themes from each code cluster and their operational definitions.

CODE CLUSTER	THEME	OPERATIONAL DEFINITION
Ideation – Acknowledgment – Support – Facilitation	Active Engagement	Conversation that surrounds heavy participation, through offering, guiding, or responding to ideas
Acknowledgment – Small Talk – Ideation	Group Rapport	Conversation that develops a level of comfort with groupmates
Ideation – Criticism – User Consideration – Clarification	Exploring the Problem	Conversation around the boundaries of the scenario to better address users' needs and define the problem

Theme 1: Active Engagement

The *Active Engagement* theme is most closely associated with what might be understood as traditional types of brainstorming conversation. That is, these are parts of the conversation intended to make progress in generating ideas, either through offering them or encouraging others to do so. This theme is characterized by dynamic collaboration and rapid sharing of ideas that are often accompanied by supportive statements. This theme of active engagement can be observed in the following transcript excerpt, which starts with S1 offering a new idea:

LINE	SPEAKER	TRANSCRIPT	CODE(S)
331	S1:	10-foot pole. Really cool. Also really unsanitary.	Support, Criticism
332	S2:	I don't think play structures, as a rule, are, though.	Clarification
333	S1:	Yeah.	Acknowledgment
334	S1:	What else?	Facilitation
335	S3:	Those mazes ... You know those wheel mazes? Where there's a ball in a wheel and you're spinning it, and you have to get it to go the way that-	Ideation
336	S1:	Come out. Yeah. Those are cool.	Support
337	S3:	We've got to exercise their minds and stuff. Right?	User Consideration
338	S1:	Yeah. And those will be good because they use all their hands and stuff.	Support
339	S4:	The balls that you can climb into and run around with. If we could have this standard wheelchair that was discussed earlier that has more degrees of freedom in the rotation on the bottom wheels, so then you could go in all directions like inside a ball.	Ideation
340	S3:	Yeah.	Acknowledgment
341	S2:	Wow.	Support

Group 5

During active engagement, when ideas are introduced, they are typically met with responses of affirmation or support (*Yeah. Those are cool*.). These discursive moves act as a form of positive feedback for the individual who offered an idea. They keep the conversation going and can create an environment where others in the group will engage and contribute to ideation. In other cases, individuals will keep the flow of ideas by guiding the group in a particular direction or engaging in facilitation (*What else?*). Prompting for more ideas tends to lead to new or additional ideation statements, and these statements help orient and focus brainstorming teammates.

Theme 2: Group Rapport

Our second conversational theme emerged from statistical relationships among *Acknowledgment, Small Talk*, and *Ideation*. These three discursive moves combine to contribute to interpersonal dynamics and help group members become more comfortable with one another. The following excerpt illustrates this process during brainstorming.

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LINE	SPEAKER	TRANSCRIPT	CODE(S)
137	S1:	Well do you know the guy at [Redacted University] who's like outfitted his skateboard and --	Small talk
138	S2:	Yeah.	Acknowledgment
139	S1:	I've seen him around town, he has a wheelchair, and he still skateboards.	Small talk
140	S2:	Yeah, he--	Acknowledgment
141	S3:	Pretty insane.	Acknowledgment
142	S2:	He's gnarly. He's, he's shown up on like, Sports Center and all that stuff. Yeah. That's pretty cool.	Small talk
143	S4:	I've never seen that. What do you mean like he outfitted it, is it electric?	Small talk
144	S2:	[inaudible]--	NA
145	S1:	Yeah.	Acknowledgment
146	S2:	Go ahead.	Facilitation
147	S1:	It's electric, and then he has some sort of mounts where like, he can put his wheel sideways on it, and so he's like looking this way and like, going like, this way as he's controlling it electrically but he's on his wheelchair on the skateboard.	Small talk
148	S2:	Like one of those boosted board things.	Small talk
149	S4:	Wow.	Acknowledgment
150	S2:	Yeah, it's super neat. Like super mesmerizing to watch how he's able to just balance himself, and you know, just lean back and forth, and he, he looks like he's gonna fall the whole time but he's actually like, totally fine.	Small talk

Group 1

The group begins this segment of conversation with some Small Talk. This discussion is a casual conversation among peers around a shared experience. While it does not necessarily result in new ideas or ideation statements, it does seem to offer inspiration for ideation statements shortly thereafter. The team then continues:

LINE	SPEAKER	TRANSCRIPT	CODE(S)
151	S4:	You can also have like a, a ramp that looks like it's a jump over something, but it's actually like the, the part where there would be the jump is like, clear so like, it's the feeling of getting air over something in a wheelchair.	Ideation
152	S2:	Oh yeah.	Acknowledgment
153	S3:	I like that.	Support
154	S2:	I don't know how I'd make this work with someone in a wheelchair but a foam pit is super cool.	Ideation
155	S3:	That is cool. Might get a little dirty but uh, yeah, very cool.	Support, Criticism
156	S2:	Yeah.	Acknowledgment
157	S5:	You already have a trampoline on here right? Oh yeah.	Clarification (requesting)
158	S2:	Yep, yeah I have no idea how that will work either but--	Clarification (offering)
159	S5:	Haha.	Acknowledgment
160	S2:	But I'm putting it down.	Clarification (offering)
161	S4:	I think some kinda, wheelchair bumper car attachment would also be fun.	Ideation
162	S2:	Oh yeah, oh my god.	Support

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Group 1

What is notable is that once the group begins presenting ideas, they appear to be comfortable with one another and share ideas openly. Speaker changes are rapid, and teammates appear supportive and encouraging. This could be especially important because individuals in the groups formed for this study did not previously know each other. The connections made with the small talk during these conversations seem to encourage a stronger group rapport. Ideas are met with support from others, and the degree of comfort with the group may encourage people to offer additional ideas to explore and expand on (*a foam pit is super cool*). The rapport established by the group in these conversations highlights the role of interpersonal relationships in developing creative solutions.

Theme 3: Exploring the Problem

Our final emergent theme is represented by statistical relationships among *Ideation, User Consideration, Clarification*, and *Criticism*. This theme describes conversations that are designed to help teammates better understand the problem and expand the potential solution space in efforts to continue developing solutions during brainstorming. Here, teammates used these different discursive moves to probe the problem and think more critically about the role of users in the solution. The theme is illustrated in the following passage, which begins with a combination of Ideation and User Consideration:

LINE	SPEAKER	TEXT	CODE(S)
24	S1:	What I've seen before is a swing that's kind of more similar to a car seat, so where you wheel up backwards to it. And then you push yourself into the seat, and it clips you in. Because someone else will have to be there to push them on the swing. So that way, they're secure. And then – I don't know – it's less difficult to secure the entire wheelchair in place if that makes sense.	Ideation, User consideration
25	S2:	That kind of makes sense. Yeah.	Acknowledgment
26	S3:	Yeah, I feel like the only worry is that then that means that you have to have someone else. But I guess if you're on a playground, you're mostly with a little kid. You probably [crosstalk] the whole field.	Criticism
27	S1:	I mean, I think for a swing, you have to have someone to push you.	Clarification (requesting)
28	S2:	Yeah, that's a two-person activity right there.	Clarification (offering)
29	S4:	Yeah. So I guess to stop, yeah, you will have that one person to stop you.	Clarification (requesting)
30	S2:	Yeah, so. Okay. I think I came up with another idea on the spot, which was, what if a slide, we make one, obviously, with less twists and turns and stuff. But then you create a track system so that the person with their wheelchair can just kind of slot right into the track, and then slide down the slide.	Ideation
31	S4:	Would they be sliding with the wheelchair on them?	Clarification (requesting)
32	S2:	Yeah, yeah. Kind of a roller coaster kind of model where they would be in the chair and then rolling-on-ish rail system [sic].	Clarification (offering)

Group 9

When speaker 1 offered an idea, they also grounded that idea in a sense of the user experience and what will be needed to enable a particular idea (*someone else will have to be there…*). The discussion of the user in line 24 opens up a wider discussion about how different stakeholders would interact with the design and opens up the idea to additional probing, clarification, and criticism through questions. The concern led to back-and-forth discussions about the issues with the idea, clarifying how it may work or what alternative solutions may allow it to work. Sharing everyone's thoughts this way ensured the group had a solid understanding of what factors to address when brainstorming new ideas, an important aspect of promoting successful design outcomes (Daly et al., 2017).

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SUMMARY OF FINDINGS

The purpose of this research was to characterize different kinds of discourse during engineering brainstorming and to explore themes and patterns within those conversations. We used several different methodological approaches to accomplish this goal. First, we used discourse analysis to generate frequency counts of each discursive move performed across 13 brainstorming transcripts. We used these frequency counts to examine correlations among these different discursive moves. From these correlations, we developed a visual representation that highlighted strong, statistically significant correlations. From this map, three clusters of discursive moves emerged, and these clusters represented higher-order conversational themes present in brainstorming sessions. These themes represent dominant forms of discussion present in engineering brainstorming activities and provide insight into the kinds of discursive moves that comprise brainstorming discourse.

DISCUSSION AND IMPLICATIONS

Our findings highlight the range of conversations that are present in an engineering brainstorming session. In addition to what might be traditional brainstorming activity (i.e., *Active Engagement*), other kinds of conversations occur that operate alongside generating ideas and that provide space and support for teams to collaborate. Therefore, while *Active Engagement* describes conventional discourse associated with developing solutions, conversations that establish *Group Rapport* and that help teams *Explore the Problem* appear to be central to brainstorming activities. In the following sections, we will discuss each theme and situate them in terms of how they contribute to and build upon our understanding of engineering brainstorming. We will also use these themes to make recommendations for engineering design teams and facilitators (e.g., instructors) to encourage effective, productive brainstorming discourse.

ACTIVE ENGAGEMENT IN BRAINSTORMING

Active engagement is the core mode of brainstorming discussion and is generally the space where teammates generate ideas most rapidly and productively. This theme emphasizes the relationships among facilitation, support, and acknowledgment that support ideation. That is, ideas are generated more effectively in an environment that is encouraging, that is affirming, and that has some attention to the direction or focus of the discussion. These findings align with research from Wieselmann et al. (2021), who illustrated the importance of clear instructions and facilitation in the outcomes of engineering design activities in K-12. While her findings emphasize the importance of a designated leader or facilitator, our research shows that this leader can change throughout a brainstorming session and that facilitation can be engaged by different group members at different times. To be sure, certain individuals tended to make more facilitation statements than others within a group, but our findings show how the role of facilitator need not be fixed for a team brainstorming session to be productive. These findings are echoed in research from Chindanon and Koretsky (2023), who found that different student team members adopted leadership or facilitation modes of discussion depending on the kinds of tasks they worked on and the information sources needed to complete those tasks. To encourage more equitable group interactions on brainstorming tasks, it might be important to frame different brainstorming sessions in ways that rely on diverse skills and knowledge sources. For instance, some brainstorming could be facilitated in ways that focus on technical elements of the problem, and others could be designed to explore broader contextual factors (e.g., environmental, economic, cultural, and political impacts). These different areas of focus will give different students opportunities to facilitate teamwork across different kinds of ideation activities and ensure more equitable, productive participation.

This theme is also marked by the prevalence of positive feedback from teammates. Team members offered acknowledgment and support when ideas were offered, and this seemed to encourage more idea generation. One of the earliest sets of brainstorming principles recommends withholding judgment to enhance creativity (Osborn, 1953), and psychological research has demonstrated the relationship between positive feedback and creativity, noting the importance of rewarding engagement as opposed to performance (Selart et al., 2008). Further, Lu et al. (2019) found that positive feedback during brainstorming promoted group creative performance and interpersonal engagement, while negative feedback tended to suppress creativity. Our findings appear to highlight the role of positive feedback on group brainstorming performance and offer some insight into how to more intentionally achieve states of active engagement during brainstorming.

GROUP RAPPORT IN BRAINSTORMING

Group Rapport describes the conversational processes involved in getting to know one another, taking breaks for small talk, and other modes of discourse designed to establish comfortable, positive interpersonal relationships. This theme is comprised of relationships among small talk, acknowledgment, and ideation. Our findings suggest that these kinds of casual conversations helped create an environment where participants felt open and confident sharing their ideas. The discursive practices observed in group rapport highlight the importance of establishing comfort for sharing ideas within a team and are supported by findings from McNair et al. (2010), who identify a range of discursive moves that can improve relational trust in virtual teams. Indeed, several of our codes overlap with theirs, and point to the importance of, for example, acknowledgment, feedback, and requests for help or clarity. However, about half of our data were collected in person and the other half via Zoom video conferencing, suggesting that these group rapport activities are important across common engineering brainstorming contexts.

This theme also aligns with existing research on psychological safety and team productivity. For example, You (2021) found that the psychological safety within a team was a moderator of team interactions, which ultimately predicted team creativity. Our study supports these findings by explicating the links among small talk, support, and idea generation in brainstorming conversations. Cole et al. (2022) found that engineering design teams with greater psychological safety generated fewer ideas than those with lower safety, but the overall quality of those ideas was higher than in groups with less safety. Our findings provide support for these results, as we do note a lower prevalence of ideas generated as teams are establishing group rapport. That is, the density of ideas is lower during clusters that highlight discourse establishing group rapport. However, the teams with greater rapport do appear more comfortable working together, which can help encourage a more thorough exploration of the design space and therefore higher-quality solutions. These opportunities for small talk appear to serve as a social lubricant that can ultimately benefit creative processes in the long run. This may be especially important in newly formed teams where there might not have been existing rapport or relationships in place.

Given the importance of rapport in supporting creative design, engineering educators and design facilitators could incorporate intentional activities to help build rapport within teams and establish a shared set of goals. Some activities could include icebreakers or intentional opportunities for socializing, but it could also be as simple as encouraging or modeling some degree of small talk and acknowledging the importance. Some of these rapport-building conversations could feel wasteful in an academic setting, where time could be better spent on generating a greater number of ideas (i.e., in *active engagement*), but our findings suggest that these conversations play a critical role in the creative process and we encourage design educators to incorporate space for them.

EXPLORING THE PROBLEM IN BRAINSTORMING

Our final theme is characterized by the interplay among ideation, user consideration, clarification, and criticism. Taken together, these discursive moves point to brainstorming conversations in which participants were actively working to better understand the parameters and constraints of the problem.

This theme is supported by prior research illustrating the importance of problem definition or scoping. For example, numerous engineering design texts and manuals stress the importance of problem definition and its impact on the final solution (e.g., (Ulrich, K. T., Eppinger, S. D., and Yang, M. C. 2020; Pahl et al., 2007)). Further, design researchers have documented the critical role of problem definition in design, noting different factors that impact how a problem is designed. Atman et al. (2007) note the differences between novice and expert designers in time spent defining the problem and show that activities that help engineers better understand the problem are consistent with expert-like design practices. Daly et al. (2017) note that effective problem-framing is vital to generating effective solutions. These findings are echoed in our own set of discursive moves related to user consideration, where participants used discussions with stakeholders to probe the problem space and generate new ideas. More recently, Svihla et al. (2021) showed how agency in problem-framing activities helped students navigate different impasses throughout design projects. For example, when students engage in problem-framing activities, they can develop more concrete approaches to navigating challenging decision-making situations and more effectively work through problems together. Our research tends to support these findings by demonstrating the importance of asking for clarification and offering criticism to better understand an engineering problem. However, the inclusion of *stakeholder considerations* in our thematic cluster extends this work and suggests that asking questions about who is impacted by a solution can help offer clarity on different engineering design tasks.

Focusing on problem definition and exploring the problem space can also have implications for developing more equitable or socially just solutions. Leydens and Lucena (2018), in their book *Engineering Justice*, articulate the importance of fully understanding the problem. They argue that engaging with diverse stakeholders is critical to effectively defining the problem, which resonates with this theme, which includes *User Consideration* as a key part of exploring the problem.

The presence of criticism in this theme is noteworthy because prior research on brainstorming has shown that negative feedback can suppress creative ideation in teams (Lu et al., 2019). While recommendations for brainstorming often emphasize withholding judgment, our findings suggest that a certain degree of constructive criticism may be beneficial for exploring the design space. Our findings align with Badke-Schaub et al. (2010), who found that teams with higher levels of cognitive conflict scored higher on creativity outcomes than those with higher levels of agreeableness. When participants raised concerns or asked critical questions, it prompted a deeper exploration of the problem space and helped them incorporate alternative perspectives.

For engineering educators and designers, this theme points to the importance of incorporating strategies for effectively framing and exploring design problems, rather than solely focusing on ideation techniques. Helping engineers consider user needs, ask clarifying questions, and engage in productive critiques can help cultivate more effective brainstorming conversations and ultimately more innovative solutions. Providing time and space for teams to more fully explore the problem, rather than rush to solutions, has the potential to result in more meaningful, equitable innovations.

LIMITATIONS AND FUTURE WORK

It is important to consider our findings in the context of relevant limitations, as these can point to areas of important work in the future. One limitation is that our analysis focused primarily on the quantity of ideas generated as measured by the number of ideation statements. Idea quantity is a common metric for brainstorming outcomes, but several others such as novelty, creativity, feasibility, or several others have been used in prior research. Future research should examine the ideation statements in greater depth to determine the quality of ideas as they relate to different brainstorming discussions. We also only focused on a single cluster at a time for analysis. Indeed, it might be the case that the sequence of clusters is important for understanding how a brainstorming discussion progresses over time. Future research should examine, for example, the conditions that precede and follow each cluster to better understand how these themes interact within a given brainstorming session.

Another limitation of the work is the controlled nature of the research setting and the differences in data collection modality (i.e., some were in-person and others were on Zoom). Participants here were relative strangers to each other and did not have any prior teamwork experience together. It is possible that if these teams had been composed of existing, intact teams (e.g., from a long-term class project), these discussions may have gone differently. For instance, teams with existing rapport and comfort might spend less time establishing rapport than the ones observed in this research. On the other hand, higher levels of rapport could have also led to more interpersonal conversations. It is also possible that the virtual nature of some of the brainstorming sessions influenced the degree to which students could effectively build rapport. While the effect of the modality of brainstorming is beyond the scope of the present work, we believe that exploring these differences could offer insight into how to mediate brainstorming in both virtual and in-person settings. Relatedly, teams with different levels of curricular experience (i.e., 1st year vs seniors) might perform differently in terms of the patterns and themes that surface within a brainstorming session. Future research should explore differences across relevant team demographics such as experience level or relative familiarity with each other.

Finally, this research was carried out on a single campus with students from the College of Engineering. The singular cultural context represented here might not generalize or transfer to other settings (e.g., engineering practice). Given the increasingly global nature of engineering work, future research should examine brainstorming discourse in a wide variety of cultural, professional, and educational settings.

CONCLUSION

The purpose of this study was to explore discourse during engineering brainstorming and to identify patterns and themes within that discourse. We used a novel mixed methods approach that included both discourse analysis and statistical methods to uncover emergent themes within these conversations. Our findings highlight the importance of Active Engagement, Group Rapport, and Exploring the Problem in engineering brainstorming conversations and offer insight into effective ideation discourse. These findings highlight that effective brainstorming involves more than the rapid generation of ideas. In addition to the ideation associated with Active Engagement, the role of Group Rapport underscores the role of collaboration and interpersonal interactions for creative activities. Additionally, Exploring the Problem emphasizes that a vital part of brainstorming involves deepening one's understanding of the challenge itself, including its parameters and constraints. These findings have implications in both engineering education and practice. For design educators, our findings highlight the need to teach skills that move beyond ideation techniques and include rapport-building and problem-exploring. This research demonstrates the value of applying our novel methodology to brainstorming conversations. By working back and forth with qualitative and quantitative data, we gain a richer understanding of the nuances of engineering communication and the cognitive and social processes that characterize creative problem-solving activities. Engineering brainstorming conversations are instrumental in shaping engineering design outcomes, and our research contributes to a better understanding of how to foster productive ideation and more innovative, impactful solutions.

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COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR AFFILIATIONS

Aimee Chiem
Cal Poly, San Luis Obispo, California, US
Ben Lutz orcid.org/0000-0003-2637-0942
Mechanical Engineering, Cal Poly San Luis Obispo, California, US

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