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Using Discourse Analysis to Investigate Conversations during Engineering Brainstorming Activities

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Abstract

Brainstorming is a crucial component of the engineering design process and the activities and conversations that take place during conceptual ideation can have significant downstream impacts on the design process and influence the outcomes of the overall project. While researchers have focused on the outcomes of brainstorming and the ideas that student teams generate, the role of discourse and conversation during these activities remains relatively underexplored. The purpose of this paper is to provide a codebook that can be used to analyze the discourse of engineering teams during conceptual brainstorming activities. The use of discourse analysis can offer a deeper understanding of how engineering students interact with one another, and the ways different kinds of discourse can lead to different ideation outcomes. We recruited mechanical engineering students from a large public university to participate in brainstorming sessions typical of preliminary or conceptual design phases. Each group was given the same task of collaborating for 45 minutes to create as many ideas as possible for wheelchair-accessible playground equipment and experiences. We combined existing research with emergent findings from our own data to develop a codebook that characterizes the range of "discursive moves" that engineering students use during collaborative brainstorming. Our codebook identified 11 different kinds of utterances that occurred during conceptual brainstorming activities. These codes capture instances in which students offered new ideas, as well as the ways students reacted to, built upon, and more generally engaged with these ideas. Further, when applicable, these 11 "discursive moves" were broken down using subcodes to identify the specific nature of a given comment or utterance. Our findings offer a useful framework for characterizing discourse during engineering brainstorming activities. We can use these codes to count the number and kind of utterances made by each student during brainstorming and explore relationships between the nature of the dialogue on one hand and ideation effectiveness on the other. Analysis is ongoing and is currently being used to explore differences across teams of varying gender compositions. The frequency of these code occurrences can also be compared to other factors within ideation to gain a greater understanding of how intergroup interactions affect various aspects of engineering design. With this, educators will be able to better support both creativity and equity within their classrooms and promote effective design skills through student interactions.

Introduction and Background

Brainstorming is a critical component of engineering design activities, and its outcomes often have significant influence on the solutions engineers ultimately converge on. As a result, there is substantial interest in engineering education and design communities to better understand the processes involved in brainstorming, the outcomes it produces, and the ways different approaches or techniques might improve the effectiveness of these processes (Dennis, Minas, & Bhagwatwar, 2013; Mileva, 2009; Shah, Smith, & Vargas-Hernandez, 2003; Wood & Jensen, 2012). But although significant focus has been put on developing techniques to enhance creativity and examining brainstorming output, relatively less work has examined the function of language and discourse during engineering brainstorming activities. It is important to be able to characterize speech and different discursive patterns because brainstorming is often a verbal activity in which team members talk with each other to propose ideas, build off of existing ones, and explore the design space. And while some research has explored how students talk to each other during STEM activities, research specifically examining engineering brainstorming discourse is limited. The purpose of this paper is to provide a codebook with which to conduct discourse analysis of engineering brainstorming activities in ways that can illuminate patterns between, for instance, speech patterns, idea quality/quantity, and exploration of the design space. In the following section, we briefly review some relevant literature that helped us develop our codebook and present an example of our coding process. We then provide our final codebook along with some examples and justification for how we applied these codes. Finally, we describe our future research plans and discuss some of the implications and contributions of this work.

Brainstorming is a critical engineering design activity that can have substantial impacts on the solutions and ideas that engineers pursue and design. Outcomes that occur from initial brainstorming activities are thus important for understanding and improving design choices, decisions, and constraints. Researchers both inside and beyond engineering have sought to examine different outcomes, processes, and relevant factors associated with brainstorming effectiveness. To examine brainstorming outcomes, Shah Shah et al. (2003) developed a metric to evaluate ideation effectiveness in terms of novelty, variety, quality, and quantity. This framework has been applied to numerous subsequent studies to provide a means to interpret brainstorming output from engineering design processes. The framework has also evolved and been applied in several different contexts (Cuellar, Trageser, Cruz-Lozano, & Lutz, 2020; Gius, Osman, Nevrly, & Lutz, 2020; Verhaegen, Vandevenne, Peeters, & Duflou, 2013). For example, Cuellar et al. (2020) adapted this framework to conduct preliminary statistical analyses to explore relationships among different categories of the Shah (2003) framework and the structure and composition of student brainstorming teams. They found that structured brainstorming resulted in greater quantity of solutions than unstructured sessions, but that unstructured sessions tended to produce more novel ideas, on average. Characterizing and evaluating brainstorming outcomes is therefore important for understanding how different interactions and discursive patterns might be related to those outcomes.

In addition to evaluating outcomes, researchers have also focused on the processes involved in brainstorming and worked to identify practices and recommendations for improving outcomes. Zhao & Hou (2010) noted the importance of team diversity as well as interpersonal dynamics and communication in influencing brainstorming effectiveness. Gius et al. (2020) explored the ways engineering students talked to each other in ways that might exert power or influence during brainstorming sessions. Their findings highlight how students engage in different kinds of speech that influences or constrains the subsequent speech of others in the group. In particular, they highlight the ways in which individuals affirm, reject, redirect, and use technical talk to maintain control of a line of reasoning or aspect of the design space. The findings help to provide a language to recognize and be mindful of the interactions within a brainstorming group.

To better understand the ways different interactions might affect brainstorming and engagement in STEM activities more generally, researchers have turned to discourse analysis. For example, Mileva (2009) used discourse analysis in electronic brainstorming environments (i.e., chat rooms) to explore the effects of anonymity. While she found that anonymous groups participated and cooperated at higher levels than identified groups, the main relevance of the work to this research is the codebook used in the research. Specifically, the coding scheme provided by Mileva (2009) offers a substantial number of codes that apply directly to our present research. She identifies codes such as "proposed solution" and "supportive remark" that were applied and adapted in the present work. Another line of research that incorporates discourse analysis for STEM student interactions is from Wieselmann and colleagues (e.g., (Wieselmann, Dare, Ring-Whalen, & Roehrig, 2020; Wieselmann, Dare, Roehrig, & Ring-Whalen, 2019; Wieselmann, Keratithamkul, Dare, Ring-Whalen, & Roehrig, 2021)). They used discourse analysis to examine small group student interactions during different STEM activities. Wieselmann and colleagues explore a number of different issues related to student speech including, for example, power and positioning (Wieselmann et al., 2021) as well as gendered differences and patterns (Wieselmann et al., 2020). Similar to Mileva, this strand of research has been instrumental in shaping our own thinking and codebook development for the present work. These two complementary lines of research form the basis from which our own analysis was developed and operationalized.

Discourse analysis (DA) has also been used in engineering education settings to examine different issues related to equity and humanistic dimensions of engineering. For example, Savaria and Monteiro conducted a DA on course syllabi and to use that analysis to make recommendations for increasing women's engagement in STEM (Savaria & Monteiro, 2017) (Savaria & Monteiro, 2017). More recently DA was used to explore engineers' conceptions of human dimensions of engineering (Castillo-Sepúlveda & Pasmanik, 2021). While the use and specific DA techniques are different across these two examples, they both demonstrate how DA can be a useful tool for exploring issues of equity in STEM contexts. The longer-term goal of this larger project is to develop techniques that can both enhance creative processes and increase equity in engineering interactions and activities. As a result, we believe DA is well-suited to help us address our broader research and practice goals.

The purpose of this paper is to present a codebook that can be used for discourse analysis of student brainstorming during conceptual design activities. To address this goal, we combined research from existing studies on brainstorming, discourse analysis, and student interactions in STEM contexts. We synthesized these three areas of scholarship to address our broader research goals and developed a codebook that highlights eleven "discursive moves," or different types of speech that students engaged in as they worked to generate new ideas and solutions to a design prompt.

Methods

Sample and Data Collection

We recruited mechanical engineering undergraduates from [blinded for review]. Mechanical engineering often focuses on the development of consumer products and systems, thus making effective ideation practices crucial for these students. We formed five groups of varying gender compositions–two predominantly male, two predominantly female, and one of balanced gender composition–with approximately five students per group. In total, we recruited 24 students across 5 teams. To control for expertise and experience in brainstorming as well as mechanical engineering knowledge in general, we also formed groups of students who were all within 1 year of each other in terms of academic process (e.g., 1st and 2nd year only, 2nd and 3rd year only). Participants met in the author's personal Zoom room and data was collected via audio recording of Zoom meetings. Each group was given the same task of collaborating for 45 minutes to create as many ideas as possible for a wheelchair-accessible playground. The prompt was inspired by prior research in design processes and activities (e.g., Atman et al., 2007; Cardella, Atman, & Adams, 2006)). Participants were read a design prompt, given an opportunity to ask questions and were instructed to begin the activity. Brainstorming and focus group sessions were audio recorded and transcribed and scrubbed of identifying information prior to analysis.

Data Analysis

These transcriptions were split into individual utterances as shown in Table 1 below so that each utterance is considered a single unit of analysis. Based on a combination of existing frameworks such as those noted above (Weiselmann (2019) and Mileva (2009)) along with our own emergent and local findings, we developed a codebook to identify the different types of speech acts students engage in during a conceptual brainstorming session. Codes were iteratively developed and refined as we applied them to our transcripts. Codes were assigned to each utterance based on each operational definition (provided below). For example, the following Table illustrates a brief exchange between five different students in a virtual brainstorming session.

Table 1: Excerpt from Transcript ID #1-6421

Line	Speaker	Text	Ideation	Affirmation	Support	Hedging
52	1:	It's kind of out there, but, but you could do some sort of like VR playground experience, where there's like interactive--	X			X
53	2:	VR, yeah. I like it.			X	
54	1:	Yeah.		X		
55	3:	Sounds cool.			X	
56	4:	That’s cool.			X	
57	5:	I like that.			X	

The first line is a student proposing a new idea (a VR playground) but also offering a qualification that seems to communicate a lack of confidence or assuredness about the quality of the idea (“*It’s kind of out there, but…”*). This utterance was therefore dual coded as both *Ideation* and *Hedging* according to our codebook. Next, Speaker 2 offers *Support* for the idea (“*yeah. I like it.*), Speaker 1 *Affirms* that Speaker 3 was heard, and Speakers 3, 4, and 5 also offer their *Support* for the idea. Segments were coded in this manner using an MS Excel spreadsheet to keep track of speakers and different categories of discursive moves. Most often, segments were assigned a single code based on the core message or purpose of the particular utterances, but in certain instances that contained richer student dialogue, we permitted the application of multiple codes to accurately capture the multiple core meanings potential present. We iteratively applied this type of analysis to five different brainstorming transcripts and used both a combination of existing codebooks along with emergent findings specific to the present research to develop a final codebook.

It is important to note that there are some limitations involved with the research that we conducted. First, our sample size was somewhat small, consisting of five brainstorming groups. However, despite this small number of groups, each group consisted of 5-6 students, yielding a total of 24 participants and over 1,000 utterances (units of analysis). Second, these brainstorming sessions were all hosted online. Prior research has shown that there is richer dialogue during in-person brainstorming (Cuellar et al., 2020; Osman, Cuellar, Chiem, Bethel, & Lutz, 2021). Participants could use a shared “whiteboard” on Zoom, but these tools do not have the same affordances as a physical whiteboard or other shared sketching space. Nonetheless, as virtual interactions (e.g., zoom meetings) become more prevalent in both academia and workplace environments, it seems important to understand how dialogue occurs in such settings.

Results

Table 2 below provides our codebook developed to examine student discourse in brainstorming interactions. These eleven speech acts or “discursive moves” can provide a way of characterizing group interactions and patterns of communication during engineering brainstorming activities.

Table 2: Codebook used for discourse analysis of conceptual brainstorming

Code	**Operational Definition**	**Example**
Ideation	Proposal of an idea/potential solution, including additions to and variations of a root idea	“First thing I thought was swings.”
Facilitating	An effort to guide the focus of the discussion and the group (typically to move forward or invoke more ideas)	“How do you guys want to do this?”
Affirmation	An indication of acknowledging someone's comment or responding to another member’s query	“Oh yeah, I see.”
Support	An indication of supporting and approving someone’s idea	“Ooh that’d be really, really cool.”
Clarification	Reiterating, elaborating, or prompting elaboration on a previously stated idea, question, or prompt	“I think you could do that with some heavy weights and stuff.”
Criticism	An indication of not supporting or rejecting someone's (or one’s own) comment	“Just can’t get too crazy with [an idea].”
Hedging	Adding a disclaimer to acknowledge the unsureness of a statement	“This is more outlandish, but…”
User Consideration	Direct discussion of user’s needs, desires, or limitations, whether it be during idea proposal or otherwise	“If we’re making things safer for [users], I feel like a wheelchair could…”
Citing Experience	Efforts to boost an individual's reputation in the group through mention of previous experiences	“I’m familiar with this topic from before.”
Technical	Engineering-specific technical language	“I wonder if you could have a

Talk	that tends to be primarily found in science/engineering textbooks	platform that's hydraulically assisted."
Small Talk	Conversation about topics not directly related to the prompt, usually helping to build rapport within the team	"How's everybody doing?"

As noted, this codebook is built based on codes outlined in previous work done by Wieselmann (2019), Mileva (2009), and Gius et al. (2020), as well as the concepts and interaction emergent within the present study. It builds on the connections made about discourse and group brainstorming in these works but also observes them in new contexts. In the following section we provide a few more examples of student discourse, code applications, and justification for those applications.

Table 3 captures an exchange between three students trying to determine how to work with the design prompt and imagine a user or stakeholder.

Table 3: Excerpt from Transcript ID #2-6421

Line	Speaker	Text	Ideation	Affirmation	Support	User Consideration
18	1:	And then...Wheelchair users, do they, do they want to do pull ups? Because I remember there's like pull up bars, but I always had to like jump with it, even though I was not in a wheelchair, but would they want that?	X			X
19	3:	Yeah, I feel like some people are into that fitness lifestyle.		X		
20	2:	Yeah, so having like better heights for those. That's a good idea.			X	

Here, Speaker 1 offers an idea in a way that shows *User Consideration* by expressing that they are wondering whether the user would want to utilize their idea ("*do they want to do pull ups?*"). When students asked or speculated about the relevant aspects of a user experience or interactions with their solutions or ideas, we coded these utterances as *User Consideration*. At the same time, this student is proposing a new idea and so the segment is therefore double coded as *Ideation* to account for the fact that they are also proposing a new idea. Our codebook then allows us to identify occurrences of *Support* from groupmates, similar to previous work. In the next line, another student *Affirms* the speaker by echoing back some of what the first speaker was discussing ("*that fitness lifestyle"*). Exchanges such as these helped keep conversations moving during brainstorming in this study.

The next exchange in Table 4 shows three students in the process of pursuing a new area of the design space and beginning to follow a particular solution set.

Table 4: Excerpt from Transcript ID #2-6121

Line	Speaker	Text	Ideation	Facilitation	Affirmation	Support
84	1	Okay awesome. Do you guys [sic] want to keep working on the swing set or do you want to like move on to another one?		X		
85	2	I'm down to go on, move on.				X
86	1:	Okay cool. We've got our seesaw, our tube thing.			X	
87	3::	You could have a basketball court.	X			
88	1:	Ooo that'd be really, really cool. Yeah I like that. So do you guys want to focus on the basketball court for a little bit?		X		X

In line 84, Speaker 1 engages in facilitation and asks the group if they are ready to change directions in their brainstorming. Line 85 represents support for the proposal to move on. In line 86, Speaker 1 begins the utterance by acknowledging a previous statement, hence the *Affirmation* code, and continues to guide the group by reviewing ideas that they have generated thus far. Line 87 then offers a new idea, so we coded this line as *Ideation*. Then, in line 88, Speaker 2 attempts to provide some direction to the group, yielding another *Facilitation* code. Further, Speaker 1's comment offers *Support* for Speaker 2's idea and so this utterance was double coded to capture the dual function of the particular speech act. Such kinds of facilitation can be helpful to keep group conversation moving and productive during periods of inactivity.

Discussion, Implications, and Future Work

The codebook developed here offers a means to observe and characterize student discourse during conceptual brainstorming. With the final codebook we have established, and the analytic process outlined above, we will be able to observe the frequency at which different types of speech are performed. This coding method results in frequency counts that can be analyzed in a number of different ways. For example, the data can be used descriptively to produce an overall portrait of the nature of a given brainstorming session (e.g., examining overall or relative levels of criticism vs. support). The data could also be sorted according to speaker ID to better understand each group member's contribution to the brainstorming activity, both in terms of number of turns taken and the kind of speech that occurred when they participated. Further, the data can also be scrutinized at different units of analysis, including sequences of discourse and student exchanges to better understand how particular patterns might emerge and how ideas and conversations might evolve. The following sections outline some of these analytic plans and approaches in more detail and offers some recommendations for future research in this area.

As part of the present research project, we will use this codebook in two primary ways. First, applying this codebook allows researchers to count the number and percentage of different kinds of utterances within a brainstorming session. This kind of descriptive analysis can give educators and design teams themselves a better sense of the *kind* of brainstorming session they were engaged in. For example, this codebook can provide insight into how affirming or how critical a particular group might have been during brainstorming. By counting the number of unique utterances in this way, the frequency counts for a given brainstorming session can provide a more holistic understanding of how team members talked to each other. Second, we will examine correlations among different discursive moves to explore patterns and relationships relevant to brainstorming discourse and outcomes. This codebook helps relate idea generation to other discursive moves that students make during ideation. For instance, the occurrence of the *Ideation* code can be quantified for each brainstorming group and compared to the frequency count of another code such as *Support*. This kind of correlational analysis can allow us to observe any correlations between forms of interaction in brainstorming groups and the number of ideas that are generated. We are currently performing different ANOVAs to explore potentially relevant factors associated with brainstorming effectiveness (e.g., number and novelty of ideation statements). We hope that these analyses will be able to inform engineering design education choices in terms of the kind of instruction and support students might receive when they engage in brainstorming activities.

However, our process of data handling and processing also affords us to examine the nature of discursive moves enacted *over time* within a brainstorming session and in response to previous utterances. That is, we can not only count the number of discursive moves made in a session but examine how those moves proceeded in sequence. Prior research in discourse analysis has used concepts such as "chaining, arching, and embedding" to organize interpersonal interactions concerning students asking questions in a classroom (Mishler, 1975). Researchers have broken discourse into specific different levels of analysis to analyze *sequences* of discourse, and these techniques seem promising here. Future work might consider an entire exchange about a single idea as a unit of analysis to examine how discourse might improve or interfere with exploration of a given design space or topic area. We plan to examine the ways different discursive patterns or sequences might emerge and how particular kinds of statements might affect overall brainstorming effectiveness. For instance, what kinds of statements tend to follow affirmations, and how does a sequence of utterances influence subsequent sequences and ultimately, ideation outcomes? Further, how might different discursive moves encourage or stifle a deep exploration of a given design space? Examining this interactive element of brainstorming discourse can help us understand the nature and flow of conversations and how that flow affects results and outcomes.

Further, these ideation sessions were each also followed by a 30-minute semi-structured focus group. These will be used in the future to triangulate our findings and better understand student experiences with their group's brainstorming approach. By reviewing students' personal thoughts on their ideation performance during the brainstorming session, we will be able to better understand the connections we make from our coding and analyses and modify our codebook accordingly to enhance credibility and trustworthiness. For example, we can use the reflective account provided by students to corroborate themes or patterns that were revealed through our discourse analysis. By combining multiple data forms and perspectives, we can enhance the robustness of our codebook and better understand how and why certain discursive patterns result in certain brainstorming outcomes.

Finally, it is useful to consider the practical elements of this codebook to engineering educators. We argue that this codebook provides a language to identify different kinds of speech and understand how they contribute to or detract from team success and equity in their process. Educators can use this codebook to instruct students about how to engage in productive kinds of talk as well as which kinds to avoid and at which points. For instance, when an initial idea is offered to the group, critical remarks might tamp out sufficient exploration of a part of the design space. However, critical questions might also be useful to help students flesh out design ideas or think through the problem in ways that require new ways of thinking. Alternately, affirmation seems important to keeping conversations flowing and so instructors might try to model that practice for their students and clarifying the importance of letting someone know they were heard and understood. These kinds of discursive patterns can also be analyzed across varying gender compositions of groups, as our data had accounted for, or potentially across varying cultural groups as well. Such further analyses could reveal ways in which educators can better encourage equitable brainstorming discourse among students. We argue that by being able to describe and model equitable and productive discursive practices, engineering educators can help students develop more effective ways of communicating and interacting during brainstorming and other design activities.

Conclusion

When educators have the language to identify and describe particular modes of student discourse, we can use that language to recognize relevant aspects and enhance teaching and learning. Our codebook provides a useful tool that can characterize student interactions during periods of a design project or activity. These different modes of discourse help offer a way to examine the nature of a brainstorming session and the potential relationships among, for instance, idea quantity and the prevalence of supportive vs critical remarks. Given the way that conceptual brainstorming discussions can influence downstream thinking and “lock in” different aspects of a design, it is important that we can better understand how to promote a fuller exploration of the engineering design space through the language and discourse used in brainstorming. With a better understanding of the different kinds of talk students might engage in and how that talk affects interactions and outcomes from brainstorming, engineering educators can use these findings to inform their own design pedagogy. Moreover, this codebook offers a means to examine equity within the design process, by counting both the turns taken and the nature of the discourse during those turns, we can better understand relationships between interactions and outcomes that can help educators identify and encourage equitable and just interactions. Analyzing student discourse during brainstorming is critical to improving both processes and outcomes, and we hope this codebook can offer a useful means to engage with that analysis

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