Exploring the Relationship Between the Types of Interactions and Progress on a Task During Collaborative Problem Solving

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Abstract: This study explores the relationship between the types of students' verbal interactions in small groups and the groups' progress on the task. The study takes place in the context of undergraduate face-to-face collaborative problem solving engineering classrooms. Students worked in small groups to solve an authentic, ill-structured engineering task. Students' verbal interactions were analyzed in terms of collaborative, cognitive, and metacognitive dimensions. The types of interactions under each dimension were correlated with the groups' progress on the task. Findings indicated that groups were partially engaged in high quality interactions despite the fact that the task and the technology were designed to promote the types of interactions that positively impact the group processes. Higher group progress scores were associated with more engagement in causal elaborated statements and metacognitive turns. This can inform the design of tasks, technological tools, and instructional models that are used in collaborative problem solving STEM classrooms.

Introduction

Collaborative problem solving can be defined as "a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem" (Roschelle & Teasley, 1995, p.70). It is prominently featured in face-to-face constructivist STEM classrooms (Hmelo-Silver & Chinn, 2016). Research has shown that it can help students achieve higher conceptual understanding and develop skills, such as collaboration and problem solving, that are becoming more critical for success in the current workplaces. However, the successful implementation of collaborative problem solving in STEM classrooms requires a better understanding of the complexity of students' interactions in groups and how these interactions influence the groups' progress on the task. This can inform the design of tasks, technological tools, and instructional models leading to the successful implementation of collaborative problem solving in STEM classrooms. This study examines the types of students' verbal interactions of small groups in face-to-face collaborative problem solving STEM classrooms. The study also explores the relationship between the types of the students' verbal interactions and the group progress on the task.

Coordinating joint attention, creating a joint problem space, discussing proposals, and reaching consensus (Barron, 2003; Hmelo-Silver & Barrows, 2008; Roschelle & Teasley, 1995) are processes that allow students to think together and co-construct knowledge in order to solve the task during collaborative problem solving (Littleton & Mercer, 2013). They may also influence what each group member learns during the activity in terms of content and ways of thinking about how to solve problems (Mercer & Howe, 2012). The quality of these processes is directly influenced by the types of the verbal interactions that take place between the group members which can be evaluated on three dimensions: the collaborative, cognitive, and meta-cognitive dimension (Kaendler et al. 2015, 2016). The collaborative dimension is associated with how the students are participating in the problem solving process and how they are building on each other's ideas as they solve the task. The cognitive dimension is associated with how the students are presenting and handling ideas as they solve the task. The meta-cognitive dimension is associated with how students are monitoring their progress and performance on the task and their participation in and contribution to the group processes. Studies that analyzed students' verbal interactions in collaborative problem solving STEM classrooms focused on either the collaborative (Mercier et al., 2015), cognitive (Hmelo-Silver & Barrows, 2008), or meta-cognitive (Borge & White, 2016) dimension of the interactions. Within each dimension, these studies identified verbal interactions that can help students successfully implement effective group processes. Nevertheless, we still need studies that take place in the context of actual STEM classrooms and analyze students' verbal interactions in multiple groups from the three dimensions. Such analysis can unravel the complexity of these interactions and provide a deeper comprehensive understanding of how group members interact and think together during collaborative problem solving.

Engaging students in effective verbal interactions is not the only goal in design-based implementation research studies that take place in the context of face-to-face collaborative problem solving STEM classrooms. In these contexts, curricular and time constraints impose another important goal: to have groups make progress on a task and arrive at a final solution. For many instructors, this is an indicator that group members have practiced using their content knowledge to solve the assigned task. Thus, in a well-designed task, the group progress is an

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important measure that can indicate if groups are collaboratively figuring out ways and iterating steps that are required to proceed towards a final solution of the task, especially if the task is complex and has multiple solutions or multiple solution paths. Thus, studies that investigate how students work in groups must track the groups' progress on the task during face-to-face collaborative problem solving in STEM classrooms. They must examine this measure and explore the interplay between it and the types of students' interactions in groups in order to understand if the types of student interactions can influence the group progress on the task and vice versa. Findings from these studies can lead to design principles for tasks, technological tools, and instructional models that can promote the types of students' interactions that can positively influence the groups' progress on the task in collaborative problem solving STEM classrooms.

This study takes place in the context of undergraduate face-to face engineering classrooms where students work in small groups to solve an authentic, ill-structured engineering task. The study set out to answer two research questions:

1) What are the types of verbal interactions that groups engage in as they solved an authentic task in face-to-face undergraduate engineering classrooms?
2) What are the types of verbal interactions that characterized groups who were (or were not) making progress on the task?

Methods

A qualitative exploratory design was used in this study, which is a part of a multi-year design-based implementation research project that aims to develop tools to support collaborative problem solving in undergraduate engineering courses (Mercier et al., 2015).

Participants

The participants in this study were 45 undergraduate engineering students (29 males, 16 females) in 14 small groups from four 50-minute discussion sections of an introductory engineering course at a large public university. The four discussion sections took place in a laboratory classroom every week of the semester. Each section was taught by one teaching assistant (TA) and two course assistants (CA). The data for this paper is drawn from a single week of data.

Task

In each of the four 50-minute discussion sections, students worked in their small groups on one task titled 'Distributing Objects on a Shelf'. The task was designed following a four-steps framework that was developed by Shehab and Mercier (2017). In order to complete the task, students needed to use the supplementary material and tools to discuss issues and preform calculations to come up with one recommended and one prohibited distribution of three books and one radio on a shelf in a small store. To solve the task, students needed to make decisions related to the locations of the objects on the shelf and the loads they exert on this shelf. They also needed to solve for the reaction forces and moments and use the calculated values to evaluate whether the distribution they proposed is recommended or prohibited. The task's worksheet was installed on 11-inch tablets with software built specifically for this project. Each student had one tablet; tablets of students in the same group were synchronized, so that members of each group worked on and contributed to the same document (see Figure 1).

Figure 1. Three students in the same group working on the task.

Data collection

During the four discussion sections, groups were video recorded using individual cameras that were installed in the ceiling. Each of the collected video recordings was transcribed in a play-script format.

Data analysis

Types of interactions

To identify how students were interacting in their small groups under the collaborative, cognitive, and metacognitive dimensions, first, each of the 14 collected videos and transcripts were coded using the problem solving coding scheme that is shown in Table 1. Codes were applied at the turn level and were mutually exclusive. To evaluate the interrater reliability, two researchers coded two randomly selected videos. Cohen's kappa was .89. Disagreements were discussed to reach agreement. Next, the coded turns of each transcript were used to divide the video into a set of consecutive thematic episodes (see Table 2). To evaluate interrater reliability on the episodes, two researchers coded two randomly selected videos. The percent agreement was 84%. Disagreements were discussed to reach agreement.

Table 1. Problem solving coding scheme

Code	Definition	Example
Approaching the task	Turns about how to solve the task, such as making sense of the task context (e.g., reading instruction out loud, checking task information given or the goal of the task) and making decisions on how to approach or solve the task.	"*Now it's time to find one that breaks. I feel like we should put them literally all stacked on top of each other.*"
Solving the task	Turns about problem solving (e.g. the application of concepts, procedures, formulas, relationships to solve the task).	"*Where'd you get 0.02*?"
Other	On-task turns that are not approaching or solving the task	"*You're gonna like look over this way and just gonna, like, not understand any of it.*"
Off-task talk	Off-task turns including turns related to technology that are not related to the problem-solving process.	"*I had to go back home to bring my umbrella.*"

Table 2. Themes of the episodes

Episode	Theme
Approaching the task	At least two group members are verbally interacting with one another on how to solve the task.
Solving the task	At least two group members are verbally interacting with one another to apply concepts, procedures, formulas, and relationships as they solve the task.
Quiet task solving	None of the group members are verbally interacting with one another or with the TA.
Off-task talk	At least two group members are verbally interacting with one another on an off-task topic.
Quiet off-task	None of the group members are verbally interacting; however, one or more members are engaged in an off-task activity (e.g. texting using cell phone).
TA/CA with group	At least one of the group members is verbally interacting with the TA or the CA.
TA with whole class	The TA is addressing the whole class and one or more of the group members is attentive.

All turns from episodes coded as approaching the task and solving the task in each video were coded for the collaborative dimension using the collaborative interactions coding scheme that is described in Table 3 to identify how students were interacting to build on each other ideas. The coding scheme was adapted from Higgins et al. (2012). Codes are mutually exclusive. To evaluate interrater reliability, two researchers coded two randomly selected videos. Cohen's kapa was .80. Disagreements were discussed to reach agreement.

Table 3. Collaborative interactions coding scheme

Code	Definition	Example
Self-talk	Comments spoken without clear indication of anticipating a response from others (e.g., murmuring).	Coded turn: (The speaker comments as she focuses on the tablet without facing others.) "*Alrighty*."
Narration	Comments describing what the speaker is thinking or doing; intended for others (typically louder than self-talk) but does not require others responding to the comments.	Coded turn: (The speaker comments as she is solving on the tablet without facing others, but in more clear tone.) "*Alright. And then sum of forces…this is x…pin x equal to zero, sum of the forces Y-*"
Independent – with Uptake	Comment does not reference a previous turn; it is independent of the stream of interaction and is followed by a direct response from another group member	Previous turn: *"Yeah, because I never think of that as Google"* Coded turn: *"Okay, are there forces acting on this?"* Next turn: *"Yes"*
Independent – with No Uptake	Comment does not reference a previous turn; it independent of the stream of interaction and is not followed by a direct response from another group member	Previous turn: *"So, let us finish the prohibited distribution real quick"* Coded turn: *"Wait, so there is one or two shelves?"* Next turn: *"I do not think I can write on my tablet anymore"*
Quasi-interactive	Refers to a previous idea of another but, does not build on it.	Previous turn: *"Oh no, it's just 0.4"* Coded turn: *"Really?"*
Interactive – elaborative	Comment draws on a previous idea by others – elaborating on it.	Previous turn: *"Here you can just turn the books sideways"* Coded turn: *"Yeah, yeah, turn them sideways then the width will be the height, you know what I mean?"*
Interactive – negotiation	Comment puts forwards an argument, either in agreement or disagreement, with a previous idea by others.	Previous turn: *"Is it more even when things are just in the center?"* Coded turn: *"But wouldn't that cause bending?"*

All turns from episodes coded as approaching the task and solving the task in each video were also coded for the cognitive dimension using the cognitive interactions coding scheme that is described in Table 4 to identify how students were interacting to solve the task. The coding scheme was adapted from studies that used coding schemes to code student interactions as they solved open-ended tasks (Hmelo-Silver & Barrows, 2008; Gillies, 2016; Guzey & Aranda, 2017). Codes are mutually exclusive. To evaluate interrater reliability, two researchers coded two randomly selected videos. Cohen's kapa was .81. Disagreements were discussed to reach agreement.

Table 4. Cognitive interactions coding scheme

Code	Definition	Example
Mentions a new idea	A student mentions a new idea not previously introduced	"*If we really wanna knock it out for a prohibited distribution, we could probably just stack them all on top of each other*"
Modifies an idea	A student provides more details (elaboration, explanation, or clarification) about an idea, term, information, or relationship.	"*The more we distribute the weight, the less it is going to do anything internally*"
Accepts an idea	A student indicated agreement with an idea	*"Yes, this is it"*
Rejects an idea	A student indicated disagreement with an idea	*"No, I don't think so"*
Asks an open question	A student asks a question to stimulate further discussion	"*Can we say for assumptions, weight of object is evenly distributed?*"

Asks a simple question	A student asks a question to check answer or clarify something	*"What was the length of the shelf?"*
Other	Statements that do not fit into the previous categories or are unintelligible	*"Are we gonna…"*

Next, to identify the level of complexity of each statement that was coded using the codes presented in Table 3.9 (except Other), the level of complexity coding scheme that is described in Table 5 was used. This coding scheme was adapted from Hmelo-Silver and Barrows (2008) who used it to evaluate the level of complexity of medical students' statements as they solved an open-ended problem. Codes are mutually exclusive. To evaluate the interrater reliability, two researchers coded two randomly selected videos. Cohen's kappa was .84. Disagreements were discussed to reach agreement.

Table 5. Level of complexity coding scheme

Code	Definition	Example
Simple	Claims or assertions without any elaboration or justification	*"I feel like it should be distributed"*
Elaborated	Statements that include definitions, examples, comparisons, judgments, and predictions without reasoning	*"Alright, so they have a 16 and this can add up to 16, then a 30, so possibly put the 16 at the end and the 30 in the middle"*
Causal Elaborated	Explanation of how an event or process occurs, how current state arose, or consequence of a process or event including justifications with targeted concepts	*"It won't really matter that much cause we're gonna have the same thing on the side"*

All turns from episodes coded as approaching the task and solving the task in each video were also coded for the metacognitive dimension using the metacognitive interactions coding scheme that is described in Table 6 to identify how students were interacting to monitor individual or group understanding or progress. This coding scheme was adapted from Hmelo-Silver and Barrows (2008) who used it to mark the meta-cognitive statements of medical students as they solved an open-ended problem. This code was either applied or was not applied to each problem solving turn. To evaluate the interrater reliability, two researchers coded two randomly selected videos. Cohen's kappa was .85. Disagreements were discussed to reach agreement.

Table 6. Metacognitive interactions coding scheme

Code	Definition	Example
Meta	A student explicitly assigns duties to other group members	*"So I will calculate the reaction force, can you do the shear?"*
	A student follows up on assigned duties	*"Did you calculate BY?"*
	A student checks another student's understanding	*"You know what we are doing right now, right?"*
	A student explicitly expresses lack of understanding	*"I do not really know how to do the math"*
	A student explicitly describes the plan or problem solving step to other members	*"I think there is only 3 forces, it is not really that much, so we have to section it 3 times"*
	A student checks own understanding of a concept or a solution step with other members	*"Okay, I think we section it like right after the horizontal part, right?"*

In order to answer the first research question, what are the types of interactions that groups engage in as they solve authentic tasks in face-to-face collaborative problem solving undergraduate engineering classrooms, the proportion of the codes in the collaborative dimension, cognitive dimension and metacognitive dimension were calculated for each of the 14 groups. Next, the mean proportion of each code was calculated across groups. Also, the proportion of each code (simple, elaborated, causal elaborated) in the level of complexity coding scheme was calculated for each of the 14 groups. Next, the mean proportion of each code was calculated.

Progress on task

In order to score the group progress during the task, a list of steps that were required to solve the task was developed in coordination with the course instructor. The list was used to develop a scoring scheme presented in Table 7. Then, using the videos and transcripts of the Approaching the task and Solving the task episodes, the progress of each of the 14 groups was scored. Each group received one score. Two researchers coded four randomly selected videos. The percent agreement was 100%. Disagreements were discussed to reach agreement.

Table 7. Scoring scheme for group progress on task

Score	Description
0	The group just explored the task without making any attempt to solve it collaboratively.
1	The group just explored the task and collaboratively performed steps that are common to both the recommended and prohibited distributions of the objects on the shelf.
2	The group explored the task and collaboratively performed steps to come up with either the recommended or the prohibited distribution of the objects on the shelf but did not arrive to a solution for either one.
3	The group collaboratively performed steps and arrived at a solution for either the recommended or the prohibited distribution of the objects on the shelf.
4	The group collaboratively performed steps and arrived at a solution for either distribution of the objects on the shelf. The group also collaboratively performed steps for the other distribution of the objects on the shelf but did not arrive to a solution for it.
5	The group collaboratively performed steps and arrived at solutions for the recommended and the prohibited distribution of the objects on the shelf.

In order to answer the second research question, what are the types of interactions that characterize groups who were (or were not) making progress on the task, biserial correlation coefficients were calculated for the proportions of the codes under the collaborative, cognitive, and metacognitive dimensions and the groups progress scores.

Results

Figure 2 shows the mean proportions of the codes under the collaborative dimension of the 14 groups. Students' collaborative verbal interactions were dominated by Quasi-Interactive turns. They included few Interactive-Elaboration and Interactive-Negotiation turns. Group members tended to refer to each other ideas without building on them by elaboration or negotiation. Also, students' verbal interactions included more Independent-With Uptake turns than Independent-No Uptake turns. Group members tended to respond to ideas that are independent of the stream of interaction.

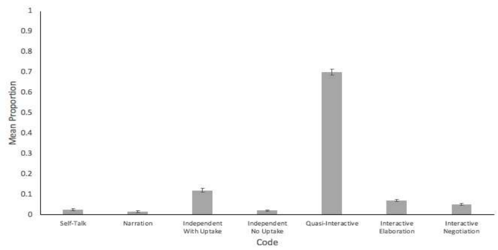

Figure 2. The collaborative dimension of students' verbal interactions.

Figure 3 shows the mean proportions of the codes and the level of complexity of the statements under the cognitive dimension of the 14 groups. Students' cognitive interactions were dominated by Modifies an idea turns and Accepts an idea turns. They included few Mentions a new idea turns and Rejects an idea turns. Group members tended to provide details about an idea or agree with an idea more than introducing new ideas or rejecting an idea. Students' cognitive interaction statements were dominated by simple statements. They included few Elaborated and even fewer Causal Elaborated statements. Group members tended to provide Simple statements that do not include definitions, examples, comparisons, judgments, predictions, or explanations of how an event or process occurs, how current state arose, or consequence of a process or event including justifications with targeted concepts. Also, students' cognitive interactions included more Asks a closed question turns than Asks an open question turns. Group members tended to ask questions to check an answer or clarify something more than ask questions to stimulate further discussions.

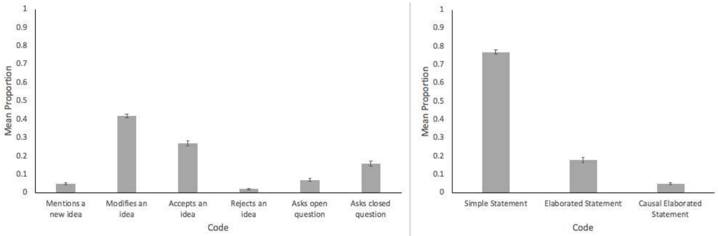

Figure 3. The cognitive dimension of students' verbal interactions.

Figure 4 shows the mean proportions of the codes under the metacognitive dimension of the 14 groups. Students' interactions included few metacognitive turns to monitor individual or group understanding of the task or the groups' progress on the task.

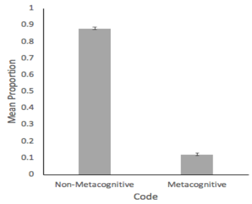

Figure 4. The metacognitive dimension of students' verbal interactions.

In terms of the groups' progress on the task, none of the groups just explored the task without making any attempt to solve it collaboratively (Score of 0). Also, none of the groups just explored the task and attempted to collaboratively solve the steps that are common to both the recommended and prohibited distributions (Score of 1). Five groups explored the task and attempted to collaboratively perform steps to come up with either the recommended or the prohibited distribution of the objects on the shelf but did not arrive to a solution for either one (Score of 2). Three groups attempted to collaboratively perform steps and arrived at a solution for either the recommended or the prohibited distribution of the objects on the shelf. Five groups collaboratively performed steps and arrived at a solution for either distribution, also they attempted to collaboratively perform steps for the other distribution of the objects on the shelf (Score of 4). Only one group collaboratively performed steps and arrived at solutions for the recommended and the prohibited distribution of the objects on the shelf (Score of 5).

The biserial correlation coefficients were calculated for the proportions of the codes under the collaborative, cognitive, and metacognitive dimensions and the groups' progress scores. Results indicated that there is a weak correlation between the proportion of each of the collaborative dimension codes and the group progress score. Higher group progress is not associated with more engagement in any of the verbal interaction under the collaborative dimension. However, results indicated that there are strong negative correlations between the proportion of *mentions a new idea* turns and the group progress scores (r=-.57) and the proportion of *rejects an idea* turns (r=-.45) and the group progress scores. Higher group progress is associated with less engagement in mentioning new ideas and rejecting ideas. In addition, there is a strong positive correlation only between the proportion of *causal elaborated* statements (r=.55) and the group progress scores. Higher group progress is associated with more engagement in explanations of how an event or process occurs, how a state arose, or consequence of a process or event including justifications with targeted concepts than groups that had lower group progress scores. Results also indicated that there is a strong negative correlation between the proportion of *non-metacognitive* turns and the group progress score (r=-.72). Also, there is a strong positive correlation between the proportion of *metacognitive turns* and the group progress score (r=.72). Higher group progress is associated with more engagement in monitoring individual understanding and the performance of the group on the task.

Conclusions and implications

This study took place in the context of undergraduate face-to-face collaborative problem solving engineering classrooms. Students worked in small groups to solve an authentic, ill-structured engineering task. Students' verbal interactions were analyzed under the collaborative, cognitive, and metacognitive dimensions. The types of interactions under each dimension were correlated with the group progress on the task. Findings indicated that groups were partially engaged in high quality collaborative problem solving interactions despite the fact that the task and the technology were designed to promote and facilitate the types of interactions that are known to positively impact the group processes. Findings also indicated that higher group progress was associated with more engagement in causal elaborated statements and metacognitive turns. These findings align with prior research showing that getting students to engage in high quality collaborative problem solving interactions in actual classrooms is challenging. However, in this study, the approach that was used to simultaneously analyze the interactions in terms of the collaborative, cognitive, and metacognitive dimensions identified those interactions that should be considered, more than others, when designing tasks, technological tools, and instructional models to promote and guide students to implement high quality interactions. One example can be to explicitly teach groups how to implement causal elaborated statements and metacognitive turns during collaborative problem solving. Research has shown that when students participate in activities that involve practicing and reflecting on their collaborative skills and developing class ground rules for verbal interactions, they tend to engage in high quality collaborative interactions (Mercer & Littleton, 2007; Gillies, 2016). Nevertheless, this research has been performed with elementary school students and may not be suitable for undergraduate students in light of their age and duration of the discussion session. Designing similar activities to explicitly teach undergraduate students in STEM about collaboration and testing the impact of these activities on the quality of their collaborative problem solving interactions are directions for future research.

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