Confusion, Conflict, Consensus: Modeling Dialogue Processes during Collaborative Learning with Hidden Markov Models

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Abstract. There is growing recognition that AI technologies can, and should, support collaborative learning. To provide this support, we need models of collaborative talk that reflect the ways in which learners interact. Great progress has been made in modeling dialogue for high school and college-age learners, but the dialogue processes that characterize collaborative talk between elementary learner dyads are not currently well understood. This paper reports on a study with elementary school learners (4th and 5th grade, ages 9-11 years old) coded collaboratively in dyads. We recorded dialogue from 22 elementary school learner dyads, covering 7594 total utterances. We labeled this corpus manually with dialogue acts and then induced a hidden Markov model to identify the underlying dialogue states and the transitions between these states. The model identified six distinct hidden states which we interpret as Social Dialogue, Confusion, Frustrated Coordination, Exploratory Talk, Directive & Disagreement, and Disagreement & Self-Explanation. The HMM revealed that when students entered into a productive exploratory talk state, the primary way they transitioned out of this state is when they became confused or reached an impasse. When this occurred, the learners then moved into states of disputation and conflict before re-entering the Exploratory Talk state. These findings can inform the design of AI agents who support young learners' collaborative talk and help agents determine when students are conflicting rather than collaborating.

Keywords: Collaborative Dialogue · Elementary School Learners · Hidden Markov Models · Dialogue Acts · Pair Programming.

1 Introduction and Related Work

In recent years, there has been growing attention to modeling collaborative talk between elementary school learners in the AIED community by detecting speakers [8], investigating interactive reading companions [15], and providing emotional support to learners [16]. There is a tremendous need to foster good collaboration among young learners [13, 17]. In this paper, we investigate the following research question: *What are the dialogue states that characterize collaborative talk between elementary school learner dyads, and how do these dyads transition between these dialogue states?*

We analyzed collaborative talk between learner dyads in an elementary school classroom during a 45-minute pair programming activity where students interacted with a block-based programming environment. As part of our analysis, we induced a hidden Markov model (HMM), which allows us to map the observed utterances to an underlying set of hidden dialogue states that drive the actions [19]. This approach, where we induce a model from the observable data and then interpret the hidden states to characterize different modes of talk, has shown success in prior work where it has been used to evaluate the importance of collaborative planning discussion [20]; to identify the ways in which learners resolve errors [6], and to detect confusion [22]. While this prior work has illustrated the utility of HMMs for dialogue analysis, they have focused primarily on high school or adult learners. To date, there has been limited research on modeling collaborative talk between elementary-aged learners.

In this work we leverage a leading discourse theory by Mercer et al. that deconstructs collaborative talk into three main components: Exploratory talk, Disputational talk, and Cumulative talk [12, 11]. *Exploratory talk* is an embodiment of collaborative critical thinking [1]. In Exploratory talk, learners may express incomplete thoughts as they forge their own understanding [14]. In *Disputational talk*, learners disagree with each other, make assertions and counter-assertions, and make their own decisions instead of collaborating with their partner [11]. Finally, *Cumulative talk* is characterized by learners constructing shared knowledge by positively and uncritically building on each other's contributions [12]. In our view, a promising approach to moving toward AI-augmented support of collaboration for young learners is to build bottom-up models of their dialogue and explore the ways in which these learners move among states or modes of collaborative talk.

The HMM reported here identified six hidden states, which we interpreted as Social Dialogue, Confusion, Frustrated Coordination, Exploratory Talk, Directive & Disagreement, and Disagreement & Self-Explanation. These six states were derived from Mercer's three main components [12, 11]. The model suggests that the dialogue states that occur between learner dyads are cyclical, and while Exploratory Talk can be interrupted when the learner dyad becomes confused, Disputational Talk can serve as an avenue back to Exploratory Talk once consensus has been reached. To the best of the authors' knowledge, this work is the first to build HMMs on elementary learners' dialogue, and the findings suggest implications for the ways in which AI-augmented technologies can foster productive collaboration among these young learners.

2 Methods

We analyzed a corpus of dialogue between upper-elementary school students collected in spring 2022 during a study in an elementary school in the southeastern

United States, consisting of 44 students that provided assent and parental consent. The school's student body was approximately 72% White/ Caucasian, 15% Hispanic/Latinx, 9% Black/African American, 4% multiracial, and 1% other. The school served a large percentage of economically disadvantaged learners, with 74% of the student body eligible for free or reduced meals. All students were in grade 4 and the mean age was 9.73, with ages ranging from 8 to 11 years old. Of the 44 students, 23 were female, 16 were male, and 5 preferred not to report their gender.

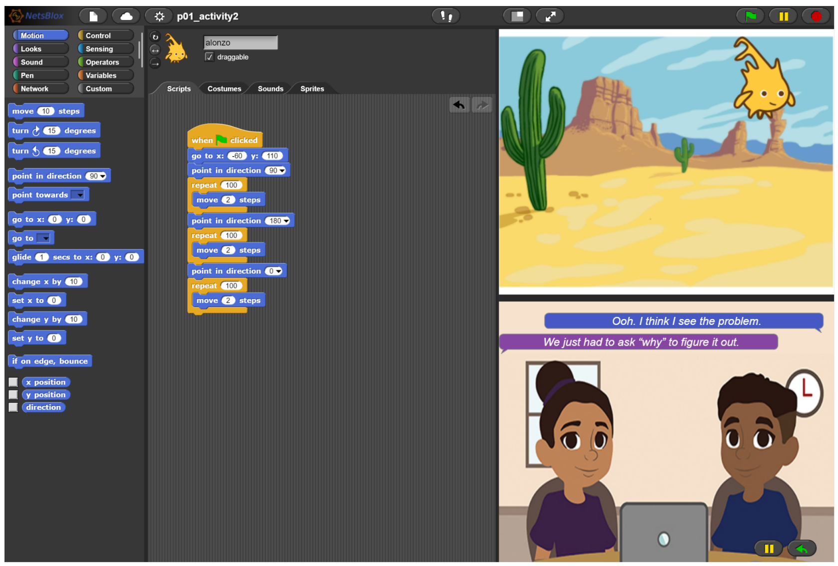

Fig. 1. The collaborative block-based learning environment.

Learning Environment. This study was conducted in our own collaborative block-based learning environment (Figure 1), a system that utilizes the Netsblox block-based coding environment with embedded virtual learning companions. Students are paired into dyads and tasked with completing programming activities using the pair programming framework [24], in which one student is the "driver" controlling the mouse and keyboard and changing the code, and the other student is the "navigator", contributing ideas and suggestions and helping the driver. These students switched halfway through the session. The interface contains instructions for the coding task, a block-based scripting space, and a stage where they can view their code. In the environment, two virtual learning companions, Viviana and Jeremy, model exploratory talk in the form of vignettes, and brief dialogues between the agents that sometimes directly address the learners. These vignettes are designed to influence the uptake of positive collaborative behaviors between the learner dyads. The virtual learning companions stay on screen throughout the session.

Dialogue Tagging. Our corpus contains 22 sessions and 7594 utterances, with an average of 416 utterances per 45-minute session (SD=114, min = 274,

Dialogue Act	Rel. Freq.	Description	Examples
Self-Explanation/ Justification (SE)	14.1%	Explaining the steps they are taking, or thoughts	*"We can put this here to make it happen twice"* *"I did that because of how slow it is"*
Suggestion/ Alternative Idea (SU)	11.5%	Any suggestions when directly talking to their partner.	*"Maybe we should put two of those"* *"How about doubling that?"*
Directive (DI)	8.10%	Telling partner to do something	*"Give me the keyboard"* *"Click that one"*
Agreement/ Acknowledgement (AG)	10.9%	Agreement on any opinion/edit	*"Good job"* *"Ok"*
Confusion/ Help-Seeking (C)	3.94%	Learner directly or indirectly seeking help from their partner	*"I'm confused"* *"I don't know"*
Question - Higher Order (QH)	1.45%	Asks a why question or a question that challenges a partner's idea.	*"Why is he moving like that?"* *"What happens if you keep it that way?"*
Question - Other (QO)	10.4%	Asks anything other than a why question	*"What does that block do?"*
Disagreement/ Negative Feedback (D)	7.12%	Disagreement on any opinion/edit	*"No no no"* *"That is wrong"*
Disagreement w/ Justification (DJ)	0.51%	Disagrees but provides reasoning	*"No, that won't work because it needs to go in a square."*
Antagonistic Action (AN)	1.51%	Actions that cause tension including harmful comments, putting down partner contributions.	*"You are being ridiculous"* *"Stupid"* *"You don't know anything"*
Social (S)	10.6%	Social dialogue	*"Did you hear about James?"* *[Quoting meme]* *"Thank you"*
Directed at Agent (DA)	1.24%	It was said to the agent, not the partner.	*"Thanks, we know we are great"*
Other (O)	18.8%	Something not covered by any of the other tags	*[Reading instructions]* *"Are my headphones working?"* *[Observations, comments on activity]*

Table 1. Dialogue act scheme used in this analysis.

max = 617). We developed a dialogue act taxonomy (Table 1) by drawing upon the exploratory talk framework [12] and a dialogue act taxonomy by Zakaria et al. [25] that was designed for a closely related application with elementary school learners in the classroom.

We modified Zakaria et al.'s [25] taxonomy to isolate exploratory talk dialogue moves, which required collapsing some tags into broader exploratory talk ideas (eg. combining "Self-explanation" with "Justification", and "Suggestion" with "Alternative idea"). Isolating exploratory talk moves was imperative because of their role in supporting student learning through collaboration. Mercer explains that exploratory talk enables partners to achieve a better mutual understanding of the problem [14]. We also added a tag to capture utterances that were directed at the virtual agents[3] to separate them from conversation within the dyad. This

[3] While the agents were not designed to elicit verbal responses from the learners and could not listen or respond, some learners spoke to them nonetheless.

scheme, reported in Table 1, was applied by two independent annotators who achieved a Cohen's kappa of 0.816, a strong agreement [21].

Analysis. We implemented a hidden Markov model (HMM) to model learners' collaborative talk. An HMM is a probabilistic graphical model that can be used to describe hidden processes or states that influence the sequence of observable symbols. HMMs are defined by a set of hidden internal states and a set of evidence states representing observable symbols or actions. Taken together, the states define a set of Bayesian variables with transitions between the hidden states, and emission of the evidence states being governed by probability distributions. In our model, the observable states are the 13 labeled dialogue acts, shown in Table 1. We represented each of the 22 collaborative learning sessions as a sequence of these symbols (dialogue acts) and trained an HMM on these sequences. Our model does not consider the time between the actions or the speaker in each case. In order to identify the best set of hidden states, we trained a series of models ranging from 3 to 12 hidden states using leave-one-out cross-validation over the 22 sessions. We then compared the generated models using the average Akaike information criterion (AIC) score for each number of hidden states. We found that models with six states produced the best AIC scores, on average. We then trained a final model, which we report here.

3 Results

The resulting model (Figure 2) revealed the following six hidden states. The most frequent of the dialogue states (32% of the time) was characterized by a high degree of *Self-Explanation (28%)*, *Suggestion (17%)*, and *Agreement (15%)* constituted 60% of observable symbols. *Higher-Order Questions (3%)* were also most likely to occur in this state out of all six states. These behaviors are consistent with Mercer's characterization of **Exploratory Talk** [14] and we will use that name to refer to this state below.

The next most common state (20% of dialogue) included *Question - Other, Agree, and Suggestion*, and it also had the highest likelihood of *Antagonistic Action (5%)* of all of the states. We label this state **Frustrated Coordination** because a qualitative examination of the dialogue in this state indicates that students are often negotiating computer control, effort, or focus within the dyad. Other studies of elementary pair programming treat this coordination as a distinct dialogue act in its own right [25], and research has long shown that the balance of control can be a source of conflict in pair programming [24].

Sessions were most likely to start in a state characterized by the *Confusion (18%)*, *Suggestion (17%)*, and *Question-Other (10%)* dialogue acts. This state accounted for 13% of the conversations, and we label this state **Confusion**, in line with D'Mello's theory on the dynamics of cognitive disequilibrium [4].

In contrast to the aforementioned states, two states showed a much higher probability of transition to each another than self-transition. The first such state (11% of conversations) is characterized by learners *Directing each other (40%)* and *Disagreeing with each other (19%)*, so we label it **Directive and Dis-**

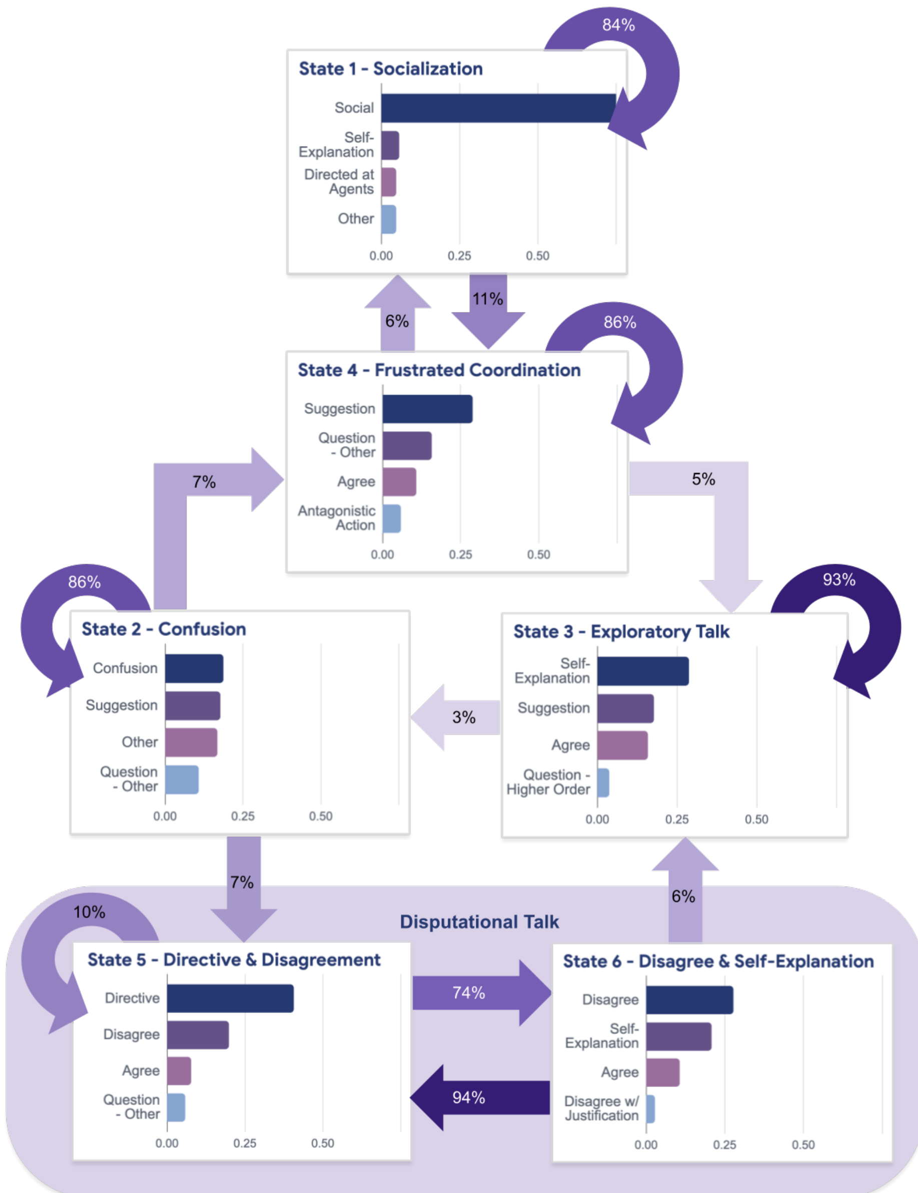

Fig. 2. High-level overview of states and transitions between them.

agreement, while the second state (9% of conversations) is mostly students *Disagreeing with each other (27%)* and *Explaining themselves (20%)*, so we call it **Disagreement and Self-Explanation**. (Interestingly, *Disagreement with Justification is higher in this state (2%)* than in any other state.) Together, we label this tightly alternating pair of states **Disputational Talk**, because this kind of behavior is consistent with Mercer's definition of this type of collaborative talk. Finally, we found a hidden state where observations are almost exclusively *(75%) Social* dialogue acts. This hidden state accounted for 10% of the conversations.

4 Discussion

4.1 Dialogue States

There were five distinct states of conversation in these collaborative programming dialogues: Socializing, Exploratory Talk, Frustrated Coordination, Confusion, and Disputational Talk (representing both *Directive and Disagreement* and *Disagreement and Self-explanation*). The Disputational Talk state cycle was created as a collective because as Figure 2 shows, the two states cycle back and forth instead of dwelling, and they contain many of the same observable symbols.

The **Socializing** state involves off-task discussions and rapport building. It occurs most frequently at the end of the session and at the halfway point when students switch pair programming roles. Other work has found that rapport building has a positive impact on collaborative learning: in work by Madaio et al. (2018), it was discovered that peer tutors and tutees with high rapport demonstrated greater performance than their non-rapport-building counterparts [9]. **Frustrated Coordination** is characterized by students refocusing the dyad on the current task or negotiating control of the computer. This state primarily occurs after the Socialization or Confusion states. A typical example of this dialogue occurs in one session after students were joking around (*"Where's my money?", "There's your $2000."*) Immediately afterward, one of the students dismissed the joke, saying *"Whatever. Okay, let's get back to coding."* This state often includes some antagonism, starting when a student appears to express frustration with their partner (*"No, well, you do it. Since you think you can do everything."*)

Utterances in the **Exploratory Talk** state are characterized by students asking higher-level questions, sharing partial understanding of the work, and listening and providing criticism of their partner's ideas [12]. They are typically focused on the task during this state. Higher-level questions in the Exploratory Talk state usually include the word *why:* for example, *"But why instead of going like this, back, down, back ... Isn't it supposed to be, like, going in a square?"* This is the most frequent state in our corpus and has the highest dwell time distribution (93%). **Confusion** occurs when students hit a roadblock or error in their code, and dialogue generally consists of statements like *"What the heck?"* and *"I don't know what to do now."* Sessions were most likely to begin in this state. While confusion may be perceived as negative, research shows that the moment of uncertainty has a positive impact on learning, because it compels students to stop and revise their understanding to resolve an impasse. [3, 10, 5]. Finally, **Disputational Talk** consists of students making decisions individually and disagreeing with each other, with few attempts to offer constructive criticism or make suggestions (*"Stop, stop. Let me do my work", "No, no, no."*) Researchers consider this dialogue unproductive, as no effort is being made between the students to share their knowledge and work together [11, 25]. This state cycle encompasses two states with a very high probability of back-and-forth transition, *Directive and Disagreement* and *Disagreement and Self-explanation*. While the states have distinct differences, they characterize very similar dialogue. The *Directive and Disagreement* state is perhaps less desirable than *Disagreement and Self-explanation* because the latter state involves more justification for decisions and is the predominant way for students to transition out of the Disputational talk and into Exploratory talk. When both partners accept the justification of an action taken, the dyad is able to move forward.

4.2 Transitions Into and Out of Exploratory Talk

Exploratory talk is thought of as a gold standard of collaborative talk, with students openly sharing and enhancing each others' ideas. In our model, it was the most frequent state. However, we also found that learners spent substantial time in other kinds of talk during collaboration. This section discusses the most common ways students move into Exploratory Talk (Frustrated Coordination and Disputational Talk) and out of it (through Coordination).

S1	*But when we get him into a square I think they know when we put him into a square.*	Suggestion	Exploratory Talk
S2	*Okay. So move 10 steps and then we're gonna repeat that. We're gonna repeat that like...*	Self- Expl.	
S1	*(laughs)*	Social	
S1	*He left.*	Other	
S2	*Um, is he back?*	Question - Other	
S1	*He's not coming back.*	Other	Confusion
S2	*Okay. Repeat.*	Self- Expl.	
S2	*Repeat it four times maybe? Five?*	Self- Expl.	
S1	*Or where is he going?*	Question - Other	
S2	*I don't know where he went.*	Confusion	

Table 2. Annotated dialogue excerpt showing a dyad's transition from Exploratory Talk to Confusion.

Exploratory Talk is the most frequent state, and in our study, it was very unlikely for students to transition out of this kind of dialogue. When a dyad is demonstrating Exploratory Talk and working collaboratively, they build on each other's ideas and work together on completing the task, feeding a positive feedback loop that supports a continuation in this state. For the 3% of the time our learners transitioned out of Exploratory Talk, it was through Confusion; encountering a problem with their code, or getting stuck on the next step in their assignment. Confusion occurs when students reach an impasse and are confronted with an error or contradiction to their expectations and do not know how to move forward [23]. It has been found to positively correlate with learning because it gives students the opportunity to revise their misconceptions about the material [2]. However, for confusion to have a positive benefit in this context, the dyad needs to resolve the confusion to the satisfaction of (ideally) both students.

Confusion can lead to frustration and disengagement during this period of cognitive disequilibrium if the impasse is not resolved [4, 18]. We give an example of this transition in Table 2, an excerpt in which two students reach an impasse while moving the sprite around the screen. When the sprite disappears from the screen due to an error they do not understand yet, the dialogue transitions from Suggestion (SU) to Confusion (C).

Once students entered the Confusion state, there was an 86% chance they would dwell there. In the event (14% probability) of leaving the Confusion state, our dyads transitioned to *Frustrated Coordination (7%)* or *Disputational talk (7%)*. This finding is consistent with literature showing that persistent confusion leads to frustration, among other things [4].

S1	*Why are we taking it out? We already have it working.*	Question - Higher Order	Disputational Talk
S2	*No, take these two out and put this back in there.*	Directive	
S1	*No, we're not scrapping this.*	Disagree	
S2	*No, I'm saying, not, wait, no, look*	Disagree	
S1	*grab that, say "Hello" "Hi, Alonzo". Take that out. Then take the 'touching' out. And then take the 'if-else', put it in there, then go back to control and say 'if', then...*	Directive	
S1	*If. Grab the regular 'if'.*	Directive	
S2	*Okay.*	Agree	
S2	*Wait a minute, we still have to use some blocks right here, so...*	Suggestion	Exploratory Talk
S1	*That's what I'm saying, yeah, that's...*	Agree	
S1	*Else, motion...*	Self- Expl.	
S2	*Oh, wait, you're right.*	Agree	

Table 3. Annotated dialogue excerpt showing a dyad's transition from Disputational Talk to Exploratory Talk.

The transition from Disputational Talk to Exploratory Talk is characterized by students justifying their disagreement and beginning to work cooperatively. Table 3 provides an example in which the students are directing and disagreeing with each other, not making any progress toward a solution, until the dialogue changes from directives (DI) and disagreements (D) to suggestions (SU) and self-explanation (SE), which prompts the dyad to reach a consensus and return to exploratory talk.

Littleton and Light [7] suggest that disputational talk often does not offer constructive criticism, instead making counter-assertions, while exploratory talk offers justified challenges and alternative hypotheses. Students transitioning from Disputational Talk to Exploratory Talk in these sessions specifically utilize justification and self-explanation to challenge their partner, which indicates that the transition between the states occurs because students begin to make justified arguments rather than unfounded assertions.

Frustrated Coordination is the other entry point into Exploratory Talk. A hallmark of Frustrated Coordination is one or both members of the dyad attempting to refocus the conversation on the task, and in exiting this state, students either reach a consensus and transition to Exploratory Talk (5%), or they continue their conflict and transition to Disputational Talk (2%).

4.3 Design Implications

These models of collaborative talk in upper elementary school learners provide implications for determining when to intervene in support of collaborative learning. For example, the models suggest that when students became confused, they almost never returned to productive Exploratory Talk without first having Disputational Talk. In practice, students in the Confused state generally could not come to a consensus on the next step they should take, and a dispute would arise where the dyad would either express their frustration with who is in control (*Frustrated Coordination*) or they would oppose each other's suggestions without considering them (*Disputational Talk*). These frustrated and argumentative dialogues constituted conflict within the dyad, but it appears to be an important part of the cycle that brings students back to Exploratory Talk. If an AI-augmented system can detect when learners enter a Frustrated Coordination or Disputational Talk state from the Confusion state, tailored feedback could guide them to a productive resolution of the unresolved confusion, preventing these conflict states from becoming self-perpetuating. The feedback would likely need to be different depending on whether the goal was for students to move from Frustrated Talk back to Exploratory Talk or for them to move through Disputational Talk, entering the more productive Disagreement & Self-Explanation state within that cycle before returning to Exploratory Talk.

5 Conclusion

Supporting collaborative talk is an important direction for AI-augmented technologies to move into. This paper has presented an analysis of the states and flow of dialogue between elementary students who are collaboratively learning. The results highlight several promising directions for future work. The state of Frustrated Coordination and its relationship to Disputational Talk and Exploratory Talk needs to be further investigated in future work, especially regarding antagonism between partners. Disputational dialogue appears to be an important component of larger cycles of Exploratory Talk, and this cycle of disputational and exploratory talk suggests that conflict between elementary-aged partners is a natural part of reaching a consensus. Tailored feedback could guide these young learners in navigating a dispute productively rather than devolving into unproductive antagonism. With a deeper understanding of collaborative talk between elementary-aged learners, researchers have the potential to improve adaptive feedback in the context of dialogue and ultimately support a better collaborative learning experience.

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