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RESEARCH REPORT

Categorizing Classroom-based Argumentation in Elementary STEM Lessons: Applying Walton's Types of Argument Dialogue

Jonathan K. Foster[a1], Joanna G. Schneider[b], Lorraine Franco[b], Yuling Zhuang[c], Barbara A. Crawford[b], AnnaMarie Conner[b]

[a]*University of Virginia, USA;* [b]*University of Georgia, USA;* [c]*Emporia State University, USA*

Abstract:
Argumentation is a practice that spans STEM disciplines and is an explicit goal for K12 students in reform-based standards documents. The purpose of this study was to investigate the applicability of Douglas Walton's theoretical model for describing the types of argument dialogue encountered in elementary classrooms focused on learning concepts in science, mathematics, and computer coding. We examined two elementary teachers' STEM classrooms to explore the types of argument dialogue that were evident. We found evidence of six types of dialogues: persuasion, negotiation, information-seeking, deliberation, inquiry, and discovery based on Walton's model. Our findings demonstrate the applicability of Walton's types of argument dialogue to argumentation in elementary STEM contexts. Even though our work takes place in the United States with teachers of children in grades 3-5 (ages 8-10 years), we believe our approach is applicable to other dialogues found in K12 STEM education. We postulate that students having opportunities to engage in arguments with a diverse range of goals (e.g., to prove a hypothesis, to persuade, or to exchange information) is important for their development in learning how to argue in STEM.

Keywords: *Collective argumentation, Walton's dialogue types, STEM, elementary education, Toulmin diagrams*

1 Corresponding Author: 405 Emmet St S, Charlottesville, VA, USA, Email: fosterjk@virginia.edu

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Argumentation is an explicit goal for K12 students in curricular recommendations in STEM education (K–12 Computer Science Framework [CSF] Steering Committee, 2016; National Governors Association [NGA] Center for Best Practices & Council of Chief State School [CCSS] Officers, 2010; Next Generation Science Standards [NGSS] Lead States, 2013). For example, in science, students may argue by using evidence to explain various phenomena. In engineering, students may argue to determine the best solution to a design challenge. In mathematics, students may argue to critique the reasoning of others or to establish a result; and in computer science, students may argue to describe and justify their computational solutions. These examples illustrate different goals for argumentation within curriculum recommendations for STEM education.

Argumentation is also a professional practice that cuts across the STEM disciplines. STEM professionals will need to be able to proficiently craft multiple arguments with distinct goals. We highlight how some STEM professions may engage in arguments with different goals. For example, scientists may need to persuade others in the scientific community that a new methodology is more reliable and valid in comparison to an accepted standard. Other times scientists may need to provide argument-driven informative arguments to the public as in the case of climate change and the COVID-19 pandemic. Mathematicians work together to prove or disprove mathematical conjectures, such as was the case when Andrew Wiles and other mathematicians jointly constructed mathematical proofs that ultimately lead to confirming Fermat's Last Theorem. These brief examples illustrate just some of the various goals for argument dialogues: to resolve methodological issues within a scientific community, to exchange information with the public, or to prove a mathematical conjecture.

Douglas Walton (1998, 2010) theorized how different goals for argument dialogues shape the nature of argumentative discourse. We reason that Walton's types of argument dialogue are informative for STEM education, especially for understanding students' opportunities to learn how to argue across the STEM disciplines. Our purpose in this study was to operationalize Walton's theoretical model for analyzing the types of argument dialogue in which elementary teachers and students engage when learning STEM content such as mathematics, science, and coding with robotics.

Our study differs from most previous studies using Walton's dialogue theory because we considered both the content of the argument components and their relationship (i.e., the structure of the arguments). Previous studies privileged the content of the argumentative discourse in relation to the types of argument dialogue. For example, Rapanta and Christodoulou (2022) applied Walton's dialogue theory by examining the content of whole-class discussions led by the teacher in secondary science and social science classrooms. We built on their study by applying Walton's dialogue theory to data gathered in elementary classrooms that considered the content and structure of the arguments. Furthermore, we were more inclusive in our data analysis parameters by including whole-class and small-group discussions with and without the teacher's participation. The significance of our study includes the development of a method for investigating the types of argument dialogue found in natural and authentic settings of elementary STEM classrooms. This study may be useful to other STEM education researchers interested in supporting arguments of different kinds as students engage in learning STEM concepts through argumentation and learning how to argue in STEM.

Theoretical Framework and Related Literature

Collective Argumentation

Argumentation is the process by which individuals construct and critique arguments; an argument is the product of argumentation (Nussbaum, 2011). In this study, we use the term collective argumentation when teachers or students make claims and provide evidence and reasoning to support them in a social setting (Conner et al., 2014; see also Forman et al., 1998; Krummheuer, 1995; Whitenack & Knipping, 2002; Yackel, 2002). Other researchers have similarly described our sense of collective argumentation as collaborative argumentation (Nussbaum, 2008), critical discussions (Keefer et al, 2000), accountable talk (Michaels et al., 2008), and exploratory talk (Mercer, 2000). Collective argumentation and these other similar classroom-based discussions have been found to promote students' conceptual understanding of content (Kim & Hand, 2015; Nussbaum, 2008; Walshaw & Anthony, 2008; Webb et al., 2019).

Toulmin's Model for Argumentation

Toulmin's (1958/2003) model for argumentation has been a prominent theoretical framework for education researchers studying the content and structure of argumentation (Nussbaum, 2011). Many mathematics and science education scholars have applied Toulmin's model to analyze argumentation practices in classrooms (e.g., Cross, 2009; Erduran et al., 2004; Krummheuer, 1995; Osborne et al., 2004; Yackel, 2002; Zohar & Nemet, 2002). We follow Krummheuer's (1995) adaptation of Toulmin's model and the work of other mathematics education researchers building on Krummheuer's work (e.g., Forman et al., 1998; Knipping, 2008; Rasmussen et al., 2015; Yackel, 2002). The core structure of Toulmin's model includes a statement that is being established (i.e., claim) with evidence to support the statement (i.e., data), and reasoning justifying the relation of the evidence for supporting the statement (i.e., warrant). Other argument components in Toulmin's model include statements describing the circumstances or conditions under which the warrant may not be valid or applicable (i.e., rebuttals), statements about the authority of the warrant (i.e., backings), and statements about the certainty of the claim (i.e., modal qualifiers). These argument components or statements are determined from the interactions of the collective and are not predefined by logic or the contents of the statement (Krummheuer, 1995; Yackel, 2001).

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In this study, extended Toulmin diagrams (See Figure 1; Conner, 2008) framed our understanding of the content and structure of arguments and the participation of the teacher and students in the process of collective argumentation. We used extended Toulmin diagrams for the following reasons. First, extended Toulmin diagrams allow us to signify who contributed which argument components (claim, data, warrant, etc.) through line style and color. Red solid lines denote teacher contributions, blue dotted lines denote student contributions, and purple dot-dash lines denote joint teacher-student contributions. If a warrant is not explicitly stated by a teacher or her students, then it is inferred from context and stated within a cloud. In fact, Toulmin (1958/2003) asserted that warrants and backings are often left implicit unless there is an explicit need for clarity. For example, a mathematics classroom community over time may develop normative ways of reasoning and members may not provide explicit reasoning (i.e., warrants) for well-established claims or backings for the permissibility of their warrants (Rasmussen et al., 2015). Second, extended Toulmin diagrams allow us to signify teacher or student actions that either directly prompt or respond to argument components. For example, if a teacher restates a student's claim, a solid red line oval with the teacher's restatement would be placed on the student's dashed-line blue claim box. Furthermore, the extended Toulmin model allows us to capture an argument component that performs more than one function, such as a component that functions as a claim in the beginning of an argument and then as data for a subsequent claim (Conner, 2008). To attend to these components with more than one function, an extended Toulmin diagram places the component within one box and labels all functions (e.g., Data/Claim; see Figure 1). The extended Toulmin model follows Whitenack and Knipping's (2002) distinction between Toulmin's warrants and backings[2].

[2] We note that backings are almost always implicit within our conceptualization of collective argumentation because they indicate the relevance of the warrant in the field in which the argument is situated (see also Toulmin, 1956/2003, p. 95-98).

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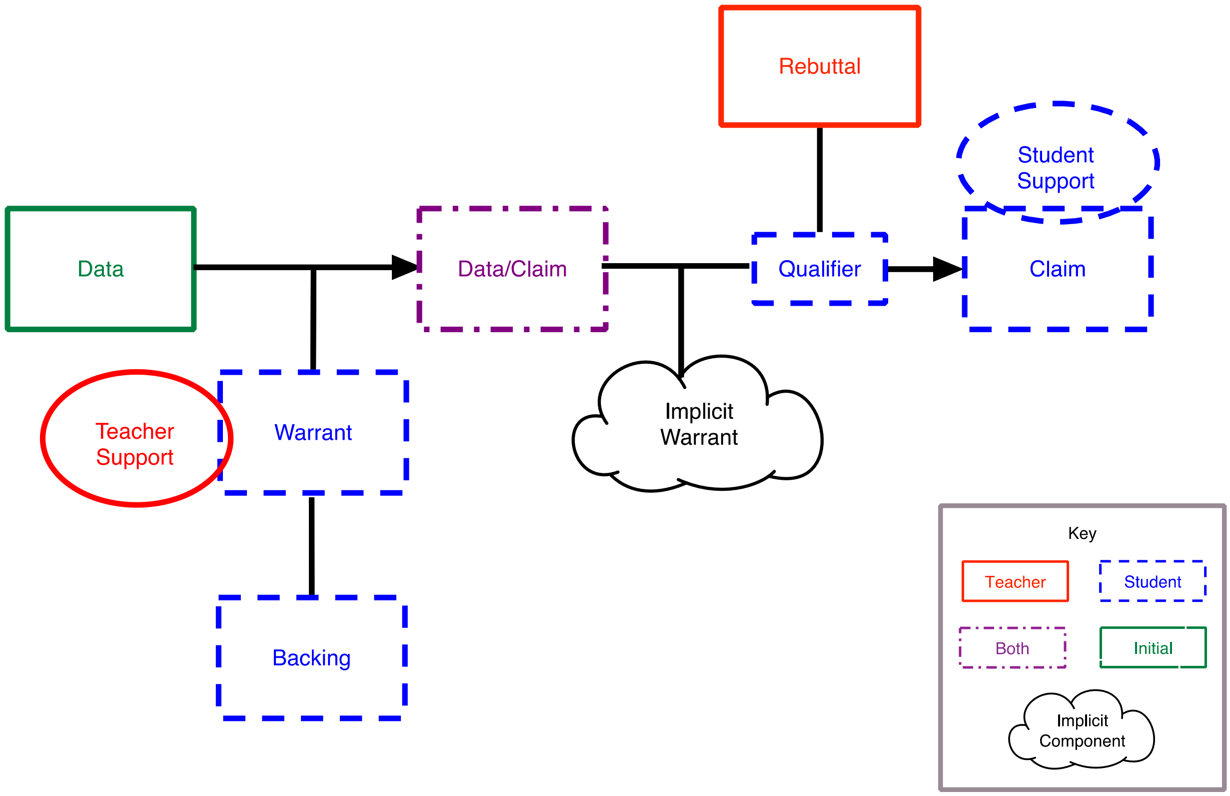

Figure 1. Extended Toulmin (1958/2003) Diagram

Note. Adapted from "Expanded Toulmin diagrams: A tool for investigating complex activity in classrooms" by Conner, 2008, *Proceedings of the Joint Meeting of the International Group for the Psychology of Mathematics Education 32 and the North American Chapter of the International Group for the Psychology of Mathematics Education XXX*, p. 361-368.

Walton's Dialogue Theory Model: Types of Argument Dialogue

Walton (1998) defined dialogue as a "framework in which two (or more) parties reason together with each other by verbal exchanges in order to fulfil a conventionalized goal" (p.6), a definition we find consistent with our conception of collective argumentation. Walton (2022; 1998) theorized seven types of argument dialogue, which differ in terms of the initial situation from which the argument arose, the goals of each participant, and the overall goal of the argument dialogue. Table 1 summarizes these seven types in terms of these criteria. In addition to these types, Walton and Krabbe (1995) posited the existence of complex dialogue, a single sequence of dialogue that contained a shift from one type of dialogue to another. These dialogical shifts occur when the context or topic of the argument changes within the dialogue. Walton's types of argument dialogue framed our understanding of students' and teachers' goals and the goal of the argument dialogue.

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Table 1.
Walton's Types of Argument Dialogue

Type	Initial situation	Participant's goal	Goal of dialogue
Persuasion	Conflict of opinions	Persuade other party	Resolve or clarify issue
Inquiry	Need to have proof	Find and verify evidence	Prove (disprove) hypothesis
Discovery	Find an explanation	Find suitable hypothesis	Discover best hypothesis
Negotiation	Conflict of interests	Get what you want most	Reasonable settlement
Information-seeking	Need Information	Acquire or give information	Exchange information
Deliberation	Practical Choice	Coordinate goals/actions	Decide best action
Eristic	Personal conflict	Hit out at opponent	Reveal deeper conflict

Note. From "Formal Dialogue Models for Argumentation in Education and Linguistics" by D. Walton, 2022, *Learning, Culture and Social Interaction,* Advance online publication.

Toulmin and Walton: Complementary Argumentation Models

Although Toulmin's model has a different focus from Walton's model for describing argumentation, these models are complementary with each other when analyzing classroom-based collective argumentation (Nussbaum, 2011). At their core, Toulmin's and Walton's models of argumentation both position argumentation as dialectical, meaning one party may put forth an argument with the other party providing "counterarguments, refutations, elaborations, questions, and other argument related speech acts to achieve a common purpose" (Nussbaum, 2011, p.87). However, these models seek to describe the argumentation with different grain sizes. Toulmin's model considers the microstructure of arguments; by which we mean the model seeks to describe the content of argument components (e.g., claims or warrants) and distinguish the relationship (i.e., structure) among argument components. In comparison, Walton's types of argument dialogue consider the macrostructure of arguments; by which we mean the model seeks to describe the normative ways in which individuals participate in argumentation and their collective goals.

In order to investigate argumentation at the macrostructure level, we faced the challenge of assessing the teacher's and students' participation goals and the goal of the argumentation in

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the moment. Guided by Walton's (1998; 2010) theory that the content and structure of arguments are shaped by the participants' goals, we used Toulmin's model for argumentation to first model the content and structure of the argument and thus consider the arguments-as-products. Then, using Walton's model, we inferred participants' goals and classified the dialogue type and thus considered the arguments-as-process. Toulmin's model has been used to assess the content and structure of arguments in classrooms (e.g., Conner et al., 2014; Erduran et al., 2004; Rasmussen et al., 2015), but, to our knowledge, no one has used Toulmin's model to assist with the classification of arguments into Walton's types of argument dialogue.

Background and Methods

The Professional Development (PD) Project

The larger project from which this study comes focused on increasing the ability and willingness of elementary teachers to include coding using argumentation into their general curriculum. It consisted of two cohorts of elementary (grades 3-5, ages 8-10 years) school teachers (30 teachers total) from suburban and rural schools in the southeastern United States. These teachers participated in a one-semester PD course, which focused on enhancing teachers' knowledge of collective argumentation and its application within the context of STEM learning, increasing teachers' ability to code robots, and developing teachers' capacity to use collective argumentation in coding activities integrated with content learning.

The Collective Argumentation Learning and Coding (CALC) framework provided the structure for the PD course activities and content for teachers (Conner et al., 2021). The CALC framework includes three elements: teacher support for collective argumentation, choice of tasks, and coding content. Teacher support for collective argumentation is based on a framework in mathematics education and conceptualizes support as providing a direct contribution (e.g., a claim), asking questions to prompt a contribution (e.g., requesting elaboration), or supporting the contribution in some other way (e.g., restating the claim) (Conner et al., 2014). Choice of task element includes the content learning goals, whether the intellectual demand of the task is likely to engage students in higher order reasoning, and the extent to which the task is likely to be motivating and engaging for students. The coding content element includes common coding control structures that are likely to be accessible for elementary students. Sample PD content and activities included having teachers create a set of directions (i.e., pseudocode) to instruct a person how to complete a task, introduction to various coding control structures and their applications, and describing the characteristics of argumentation from videos of mathematics and science instruction.

After the PD course, we followed 10 teachers into their classrooms to support their design and implementation of lessons using the CALC approach and observed how they engaged students in argumentation. The research team observed up to three lessons in each participating teacher's classroom.

Study Design and Case Selection

Our qualitative study adapted case study approaches (Stake, 1995; Merriam, 1998) with an instrumental focus as it tests the application of Walton's (1998, 2010) dialogue theory to the phenomenon of argumentation in elementary STEM lessons. We bound the case to episodes of argumentation in two teachers' STEM lessons. Our research question was: What types of argument dialogue are evident in elementary STEM lessons?

Participants and Their Lessons

We chose Sarah and Erica (pseudonyms) for this study because they were the only two teachers observed teaching lessons that included all three disciplines of mathematics, science, and coding with robotics. Sarah was a Gifted Resource Specialist who worked with second through fifth grade students. She had been teaching for over 20 years, her certification was in elementary education, and she taught all levels from Pre-K to fifth grade over the course of her career. Starting in the fall of 2018, her school moved to a push-in co-teaching gifted model, wherein Sarah went into advanced content classes to co-teach with the general classroom teacher. Sarah's school classified this model as Advanced STEAM (Science, Technology, Engineering, Arts, and Mathematics) Inquiry Project-Based Learning; the content Sarah taught was dependent on where the students were in their inquiry-based units.

Sarah's first lesson was a coding-focused lesson with a basis in the engineering design process. Her second was a mathematics lesson on equivalent representations of decimals and fractions. Her third was a science lesson about surface features on Mars. All three lessons involved a coding component, with the first and second lessons involving a greater emphasis on coding than the third.

Erica was an early career teacher with 6 years of teaching experience; 2 years as an elementary STEM teacher for kindergarten through fifth grade students and 4 years as a fourth-grade teacher. Her certification was in elementary education. In fall of 2019, Erica taught fourth-grade students. She described several of her students as advanced in STEM content areas, meaning they were above grade level in content knowledge.

Erica's first lesson was a science lesson focused on simple machines. Her second lesson was a mathematics lesson about scale factors and polygons. Her third lesson was a mathematics lesson about the relationships between distance, time, and speed. All three lessons involved a coding component, with the second and third lessons involving a greater emphasis on coding than the first.

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Table 2.
Overview of Teachers' Lessons

Teacher	Lesson	Goal(s)	Instructional Days	Video Recordings [hh:mm]
Sarah	1	Students will use proportional reasoning to determine the time delay for a robot traveling 6, 12, and 24 inches.	2	01:42
	2	Students will move flexibly among equivalent representations of fractions and decimals and identify ways to shorten coding sequences using mathematical structure.	1	01:35
	3	Students will apply their understanding of surface features on Earth to make predictions about what caused the surface features on Mars.	2[a]	01:46
Erica	1	Students will design and create Rube Goldberg machines and identify at least three different simple machines in their design.	1	09:30
	2	Students will create a coding sequence for a robot to travel the perimeter of a polygon and similar polygon.	1	06:30
	3	Students will understand the relationship between speed, time, and distance by holding one parameter constant, varying another parameter, and then measuring the outcome of the third parameter.	2	07:16

Note. [a] Research team was unable to observe the second instructional day for this lesson.

Data Collection

As part of the PD project, we video recorded three STEM lessons in each of Sarah's and Erica's classrooms. At least two members of the research team videotaped each of the lessons. One camera was used to record the teacher's actions and at least one other camera was used to record small group interactions. This resulted in approximately 5 hours of video recordings from Sarah's lessons and 23 hours of video recordings Erica's lessons to be used for data analysis. There were considerably more hours of video recording from Erica's lessons because multiple cameras focused on small groups of students during Erica's lessons, which also extended over several hours. A research team member collected the tasks and handouts used during the lessons.

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Data Analysis

Reduction of the Data for Analysis

At least two members of the research team, one of whom observed and video recorded the lesson, identified and transcribed potential episodes of collective argumentation focused on mathematics, science, or coding content. An episode of argumentation at minimum included a student or teacher making a claim with data and warrant accompanying it, with recognition that sometimes the warrant could be implicit (Toulmin, 1958/2003). We extended the episode if a teacher or student continued the argument by building from a previous argument component. We ended the episode if the collective's data, claim, and warrant did not build on a previous argument component. We were inclusive in our analysis of arguments by including instances when a teacher or student attempted to make a mathematical, scientific, or coding-related claim. We did not limit our analysis to arguments that were deemed mathematically or scientifically correct by our expert opinion. We excluded arguments that were quarrels or "a kind of angry or adversarial verbal exchange based on a conflict between two parties" (Walton, 1998, p. 178). This kind of dialogue is characterized by Walton as eristic. We excluded eristic dialogues because this type of verbal exchange falls outside our definition of collective argumentation and is not included in reform-oriented standards for argumentation in STEM education (CCSS, 2010; K-12 CSF Steering Committee, 2016; NGSS, 2013).

Next, the team met together to reach consensus regarding if the identified episodes included collective argumentation, excluding episodes that did not meet our criteria. We identified 57 (approximately 74 minutes) and 37 (approximately 50 minutes) episodes of argumentation from Sarah's and Erica's lessons, respectively. As part of the larger research study, we randomly selected episodes to obtain at least 5 minutes of small-group arguments and 10 minutes of whole-class arguments for each teacher observed. This random selection was done iteratively. We kept randomly selecting episodes until each threshold was met. We decided to limit the data by random selection to provide a balanced and representative selection of episodes of collective argumentation across all the teachers observed as part of the larger research study.

Creation of Extended Toulmin Models and Transcripts

To represent the content and structure of the collective argumentation in the lessons, we created extended Toulmin's (1958/2003) diagrams for each episode of collective argumentation (as described in Conner, 2008; See Figure 1). A subgroup of at least two research team members watched the episodes of argumentation and examined tasks used in the lesson, enriched the transcripts with teacher's and students' gestures, and developed extended Toulmin diagrams. If the subgroup could not reach consensus on the Toulmin model for an episode, then the subgroup would ask members of the research team that observed and video recorded the lesson for their input on the context of the episode and their interpretation of the argument's structure. The research team met until consensus was reached on the extended Toulmin models for each episode. These extended Toulmin diagrams and annotated transcripts were our primary data source for this study.

Interpretation of the Argument Dialogue from the Extended Toulmin Model and Transcripts

To analyze the types of argument dialogue in the lessons, we began examining the content and structure of the extended Toulmin models and transcripts to categorize each episode of collective argumentation into one of Walton's seven dialogue types by using an adapted version of a decision tree to determine the type of argument dialogue (Walton & Krabbe, 1995, p. 81). In the original decision tree by Walton and Krabbe, discovery dialogue was not included. Discovery dialogue was proposed by McBurney and Parsons (2001) as an additional type of argument dialogue. Walton (2019) accepted discovery dialogue as a new type of argument dialogue and agreed with McBurney and Parsons's distinction between inquiry and discovery dialogues. In an inquiry dialogue, the statement to be proved true is set at the beginning of the dialogue, whereas in discovery dialogue, the truth of a statement only emerges during the dialogue. Therefore, there is no statement set early on to be proven or disproven in a discovery dialogue. Other educational researchers (Macagno, 2022; Rapanta & Christodoulou, 2022) have also taken up this distinction between inquiry and discovery argument dialogues. We added the question "Is the aim to prove or disprove?" to our adapted tree to distinguish between inquiry and discovery dialogues (see Figure 2).

As an example of applying our adapted decision tree, when determining if there was conflict during the argumentation episode, we looked at structural features within the extended Toulmin models that may suggest conflict, such as rebuttals or competing claims. In the Findings section, we explicate how we used the decision tree in Figure 2 to interpret the extended Toulmin models to identify the type of argument dialogue. We also describe general trends between the extended Toulmin models and argument dialogue types.

To confirm our interpretation of the argument dialogue type based on the extended Toulmin models, we triangulated our interpretation by going back to the annotated transcripts or video recording to identify confirming or disconfirming evidence of the initial situation, teacher's and students' goals, and the goal of the dialogue for our interpretation of the dialogue type as recommended by Walton and Krabbe (1995). At least two research team members met to discuss their classification with evidence. If consensus could not be reached among the subgroup, the episode of argumentation was brought to the entire research group and was discussed until consensus was reached.

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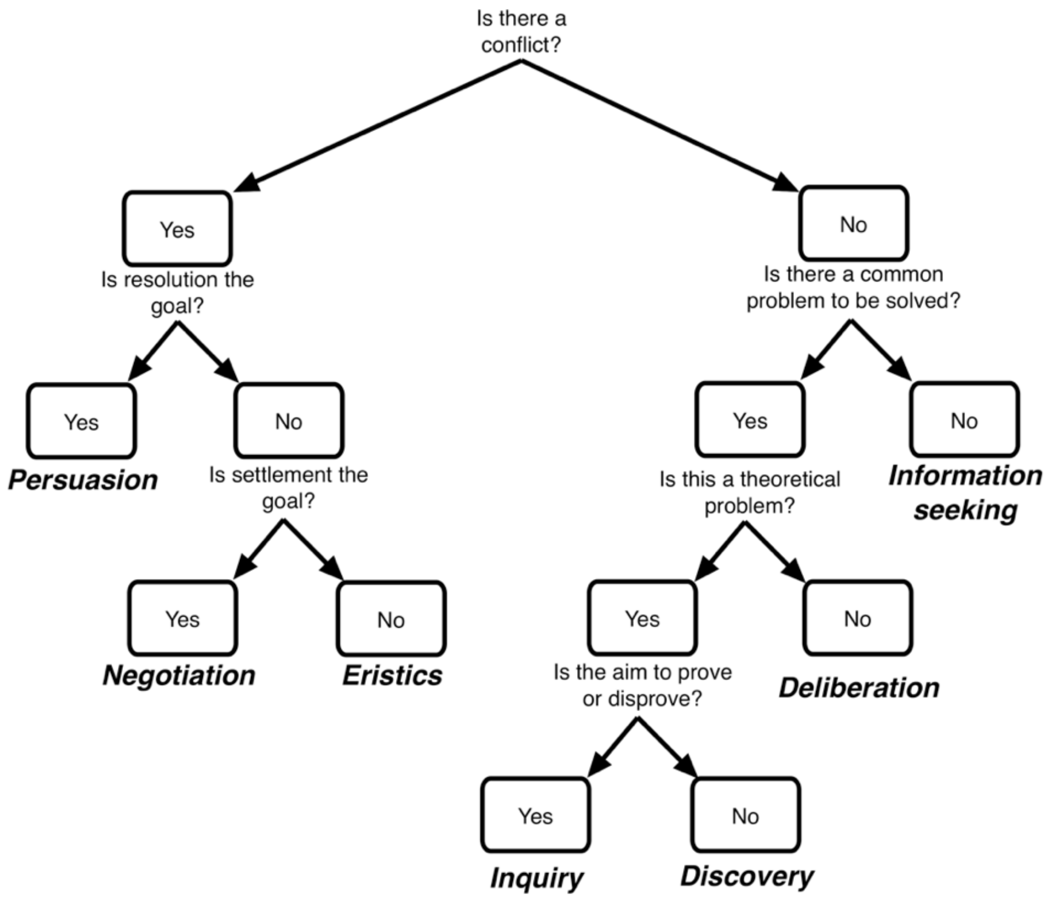

Figure 2. Decision Tree for Classifying the Type of Argument Dialogue

Note. Adapted from *Commitment in dialogue: Basic concepts of interpersonal reasoning* by D. Walton and E. C. Krabbe, 1995, p. 81, SUNY Press.

Findings

We begin by providing an overview of the types of argument dialogue across the three lessons in each of Sarah's and Erica's classrooms. We then present illustrative argumentation episodes for each dialogue type that we found in these elementary STEM lessons to answer the question of what types of arguments were evident in elementary STEM lessons. Our purpose in presenting these episodes is to demonstrate how formal models of argumentation theory (Toulmin and Walton) can be applied to model the argumentation in elementary classrooms. We also use these illustrative episodes to highlight the content, structure, and dialogue goals within a specific argument dialogue and summarize argument diagram trends across dialogue types.

Sarah's and Erica's Enactment of Argumentation and Types of Argument Dialogue

We randomly selected 26 and 21 episodes of argumentation from Sarah's and Erica's three lessons, respectively, for a total of 47 episodes of argumentation. Two of the episodes included a dialogical shift between argument dialogue types and thus we analyzed a total of 49 argument dialogues (See Table 3). A total of 5 episodes were chosen where the primary focus of the dialogue was coding, 21 episodes were chosen with a primary focus of mathematics, and 25 episodes were chosen with a primary focus of science practices.

The majority of the 49 argument dialogues were either information-seeking (17, 35%) or deliberation (14, 29%). These types of argument dialogue appeared in arguments when the contents focused on mathematics, science, or coding. Also appearing in the data with some frequencies were persuasion (7, 14%) and discovery (7, 14%) argument dialogues. Persuasion and discovery argument dialogues were only evident when the content of the argument centered on mathematics and science. To an even lesser extent, negotiation and inquiry argument dialogues were evident in the data. There were two negotiation argument dialogues in Erica's science lesson. One inquiry argument dialogue was found in each of Sarah's and Erica's lessons with the content of the argument focused on mathematics. There were no eristic argument dialogues because we excluded these types of dialogues from analysis.

Table 3.
Argument Classifications by Teacher and Disciplinary Focus

Walton's Types of Argument Dialogue	Sarah's argument dialogues			Erica's argument dialogues			Total
	Coding focused	Math focused	Science focused	Coding focused	Math focused	Science focused	
Persuasion	0	2	1	0	1	3	7
Negotiation	0	0	0	0	0	2	2
Eristic	0	0	0	0	0	0	0
Information-seeking	2	3	8	0	3	1	17
Deliberation	1	5	1	2	1	4	14
Inquiry	0	1	0	0	1	0	2
Discovery	0	0	2	0	4	1	7
Total	**3**	**11**	**12**	**2**	**10**	**11**	**49**

Note. The information in this table is intended to give a descriptive summary of the nature of argument dialogues in the data. A comparison of the number of argument dialogues across teachers or disciplines is not appropriate because these numbers do not provide a complete representation of the arguments across Erica's and Sarah's lessons. The order of the types of dialogues in the table mirrors the order in the findings.

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A Persuasion Argument

This first illustrative episode of argumentation (diagrammed in Figure 3) is a persuasion type of argument dialogue. It comes from Erica's first lesson during a small-group interaction with Erica present. The students were working on a portion of their Rube Goldberg machine, which was supposed to move a ball into a box (Data 3.2). Prior to the episode, students unsuccessfully tested their machine (Data 3.1). Erica came over after the testing and asked the students how the test went (Support 3.3), prompting this argument. One student claimed they need to shorten the string tying the ball to their robot (Data/Claim 3.1), and another student thought they needed to make the string longer (Data/Claim 3.2).

We used our adapted decision tree (
) to aid our inference for the dialogue type classification. First, we considered whether there were any potential conflicts in the given argument, referring specifically to conflicting points of view (Walton & Krabbe, 1995). In our extended Toulmin models, we observed a conflict is often represented with competing claims, counterclaims, or rebuttals. Figure 3 included a set of counterclaims (Data/Claims 3.3 and 3.4) and a rebuttal (Rebuttal 3.1). Therefore, our analysis concluded that there were potential conflicts in this episode of argumentation. One conflict arising early in the argument was the disagreement about whether a shorter or longer string will solve the students' design issues (Data/Claim 3.3 and Data/Claim 3.5). We determined that resolution was the overall goal because each student was trying to convince Erica and the other student that their claims were correct (Warrants 3.1 and 3.2). However, resolution was not reached because neither student successfully convinced the other of their point of view, as evidenced by the two parallel claims at the end of the argument (Claim 3.6 and Claim 3.8).

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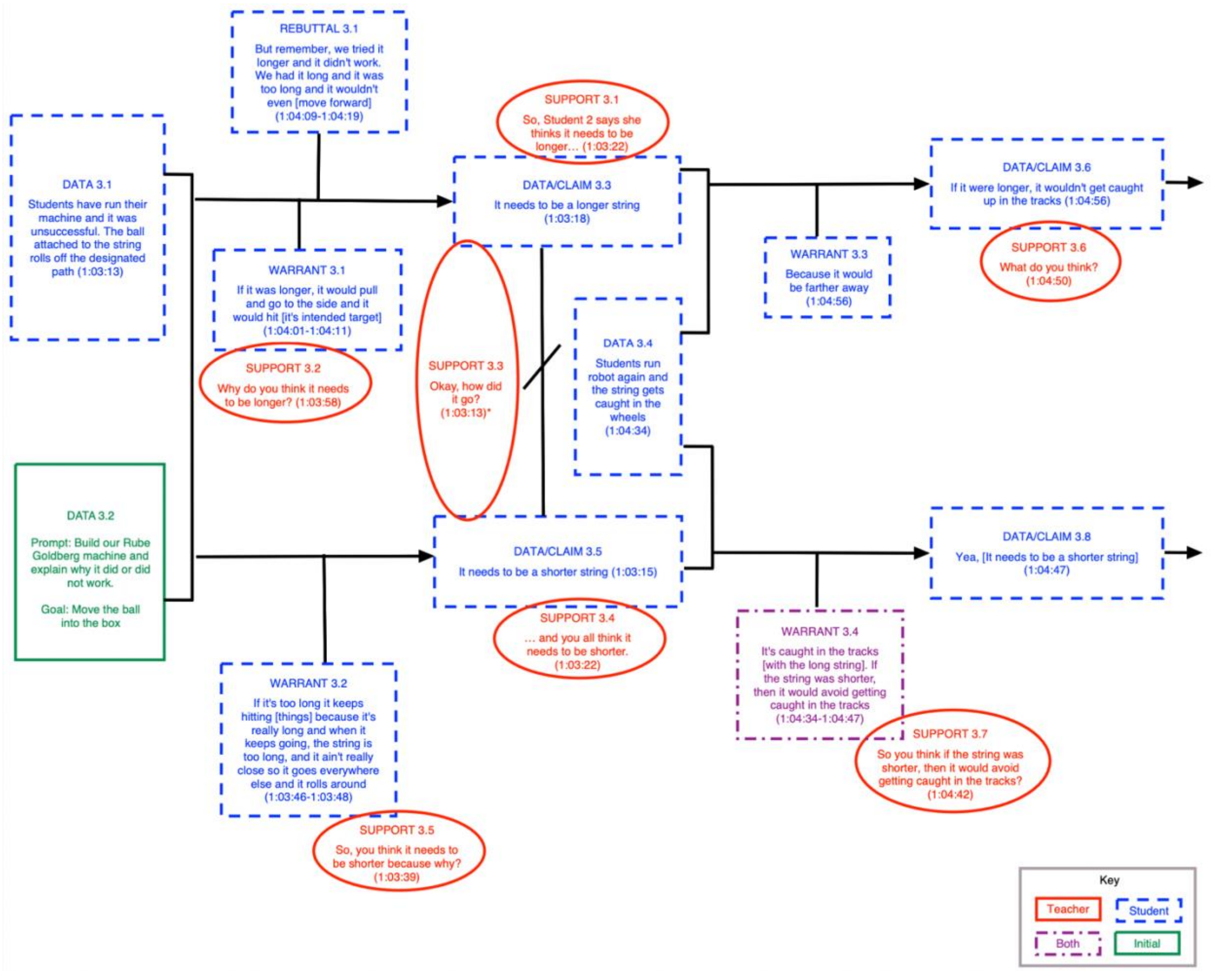

Figure 3. Extended Toulmin Diagram of a Persuasion Argument Dialogue

Note. Numbers in the diagram correspond to references in text. This argument continues in Figure 4.

To check the validity of this finding, we compared this argument with Table 1, which gives the criteria for each type of dialogue according to Walton's classification. In persuasion dialogue, the initial situation should be a conflict of opinions, which fits with this argument because the initial situation was a disagreement about whether a shorter or longer string would work better. The participant's goals should be to persuade the other party, which is true here: The students were seeking to convince Erica and each other. The overall goal of the dialogue should be to resolve or clarify the issue. As stated previously, while resolution was not reached in this

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episode, we determined that resolution was a goal. The episode of argumentation depicted in **Error! Reference source not found.**, therefore, met the all the criteria for persuasion dialogue.

A Negotiation Argument

Our second illustrative example is a direct continuation of the previous persuasion argument dialogue example, with two of the final claims in **Error! Reference source not found.** (Claims 3.9 and 3.11) corresponding to the initial data in **Error! Reference source not found.** (Data 4.1 and 4.2). At the beginning of this episode, the small group had reached an impasse, with neither side able to convince the other of their perspective as evidenced by the two parallel pieces of data (Data 4.1 and 4.2). Erica prompted the students to think about how they could proceed despite this impasse (Support 4.1). Eventually, the students decided they could test both shorter and longer string on their machine to see which one would work better (Claim 4.1).

This episode still involved conflict because no resolution was reached previously. However, resolution is no longer the goal of the dialogue because neither side is attempting to persuade anymore. Walton and Krabbe (1995) elaborated that a settlement is a way of "finding a compromise that will be attractive to both parties" (p. 72). Using this elaboration, we concluded that the goal of this episode was settlement because Erica prompted students to think about what they could do to move forward with their machine design and students came to decide they could try both options.

Erica's support for argumentation instigated this dialogical shift. She questioned how they could proceed despite their disagreement (Support 4.1), prompting the students to look for a compromise instead of remaining fixated on convincing one another that their idea was correct (Claim 4.1). She affirmed their decision to try both suggestions (Supports 4.2 and 4.3). When one student tried to suggest they would only try a longer string if a shorter one didn't work (Support 4.4), she reminded them of their compromise (Support 4.5) and helped students articulate why trying both was a good idea (Warrant 4.1).

We again compared our understanding of the episode of argumentation to the criteria in Table 1 to validate our finding. A negotiation dialogue should have a conflict of interest as the initial situation, and in this episode the conflict is still the disagreement about what length string to use. The goal of the dialogue should be reasonable settlement, and participants' individual goals should be getting what they want most. In this case, the students wanted to try their idea, so the reasonable settlement that gives them each what they want most is the decision to try both lengths. This episode therefore met all the criteria for negotiation dialogue.

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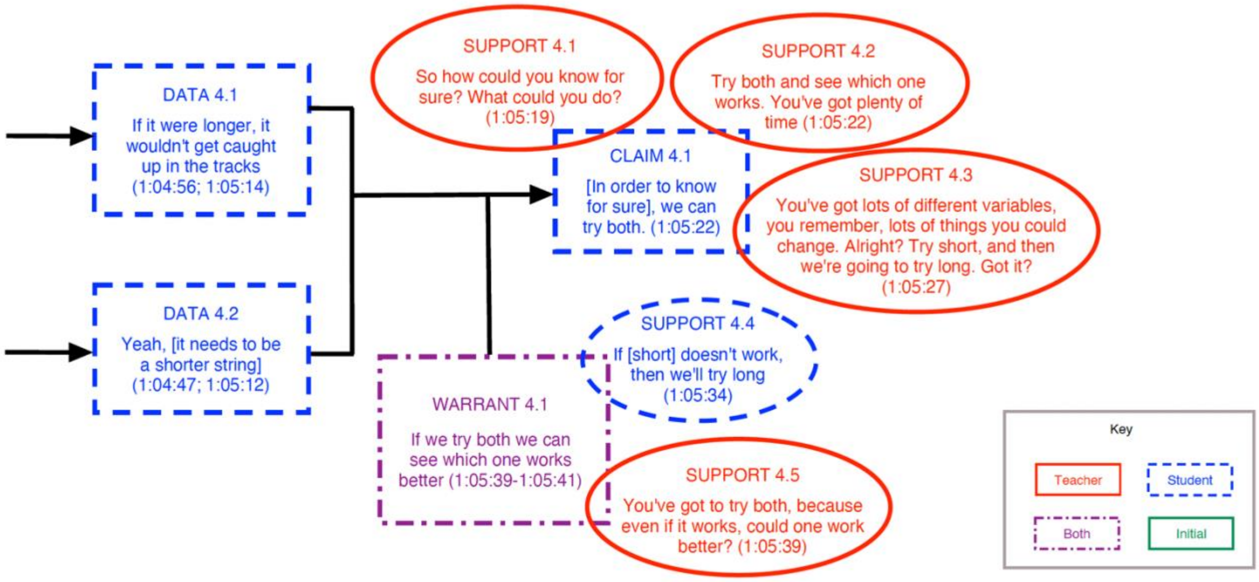

Figure 4. Extended Toulmin Diagram of a Negotiation Argument Dialogue

Note. Numbers in the diagram correspond to references in text. This argument dialogue is a continuation of the dialogue diagramed in Figure 3.

An Information-seeking Argument

The third episode of argumentation (diagrammed in Figure 5) is an example of an information-seeking type of argument dialogue. It comes from Sarah's second lesson during a small-group interaction with Sarah present. The students were tasked with developing a coding sequence that would program a robot to travel around a meter square such that the area enclosed by the robot's path of travel would be six-tenths of the meter square. Students were given a meter square partitioned into 10 equal sized pieces (See Data 5.1 in Figure 5).

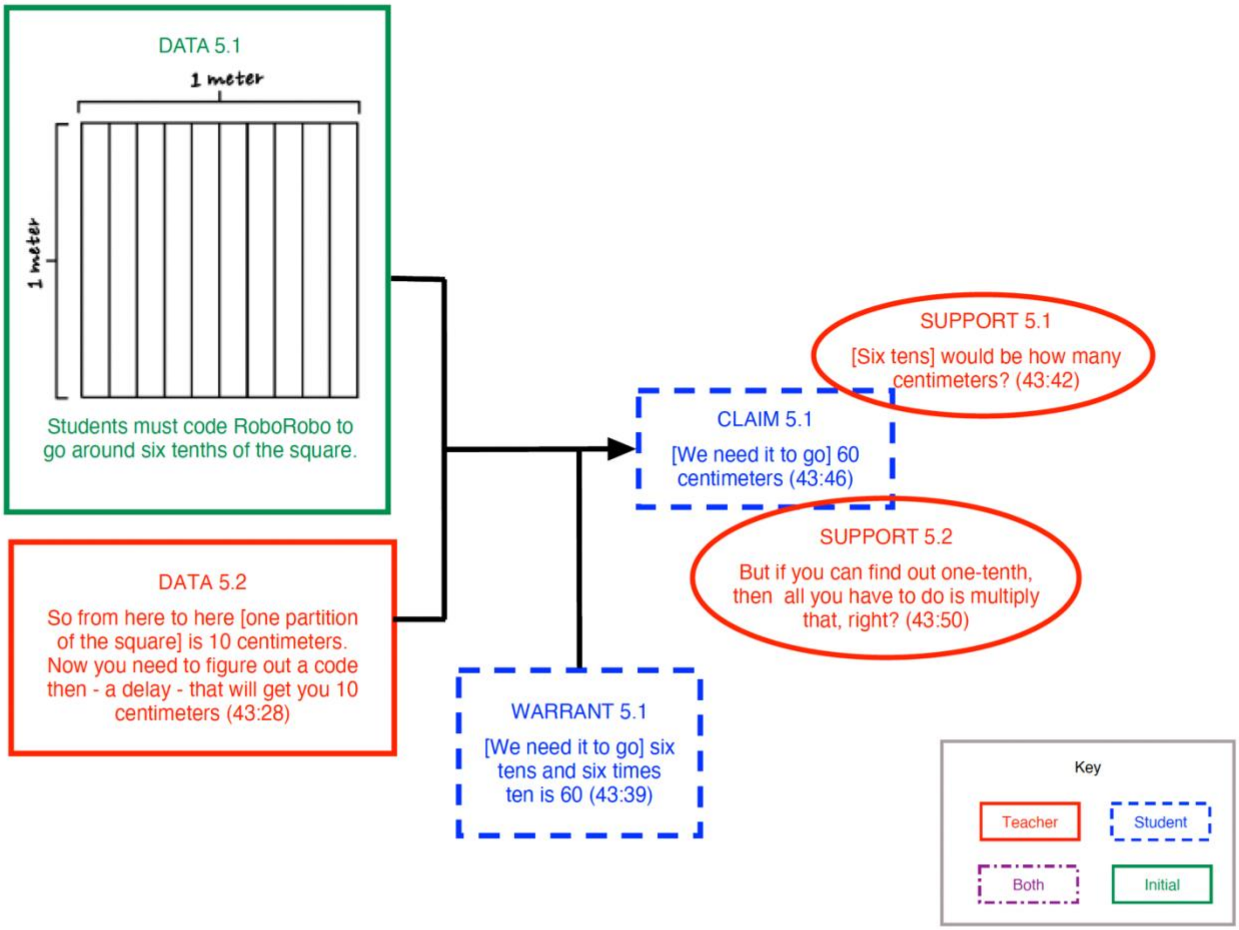

Figure 5. Extended Toulmin Diagram of an Information-Seeking Argument Dialogue

Note. Numbers in the diagram correspond to references in text.

In our analysis of this episode, there does not appear to be any conflicts as evidenced by a lack of competing claims, counterclaims, or rebuttals in the extended Toulmin's model (Figure 5). As in the previous episodes of persuasion and negotiation types of argument dialogue, a conflict can be represented with competing claims, counterclaims, or rebuttals in an extended Toulmin model. Within this episode, there is a lack of a common problem or task to be solved because students and Sarah were still exchanging relevant information to support students in solving the ultimate task of programming the robot. If they were solving the task, then there would have been evidence in students' or Sarah's claims about the time delay for 10 centimeter and the coding structure for the robot. During this episode, the students and Sarah were focused on the lengths of sections from meter square, which were relevant to solving the task, but they had not yet focused on the time delay necessary for completing the task as evident in Sarah's initial prompt, "Now you need to figure out a code then – a delay – that will get you 10 centimeters" (Data 5.2 in Figure 5).

Again, we compared our understanding of the episode of argumentation to the criteria in Table 1 to validate our finding. There was an unstated need of information at the beginning of the episode. Prior to the episode, students determined that one-tenth of a meter was approximately 4 inches. Upon hearing the students were measuring in inches, Sarah asked students to measure in centimeters. Sarah's request for centimeters prompted a need for new measurements for students. The goal of the argument dialogue was to exchange information. Sarah provided information not known to the group; the students did not know that one-tenth of a meter was 10 centimeters. When Sarah stated to students that they should be working in centimeters, students began trying to determine the length of one-tenth of a meter by using a ruler. Upon seeing and hearing students discussing their measurements, Sarah provided new information (Data 5.2 in Figure 5). Students also provided information to Sarah that six tens would be 60 centimeters (Claim 5.1 in Figure 5) at Sarah's request (Support 5.1 in Figure 5). Therefore, Sarah sought to give students information that one-tenth of a meter was 10 centimeters and acquired information from students that six-tenths of a meter was 60 centimeters.

A Deliberation Argument

Our next episode of argumentation is an illustration of deliberation type of argument dialogue. This episode comes from Erica's second lesson. In the episode, a small group of students were attempting to program their robot to travel forward a certain distance and then turn around and come back to the starting distance (Data 6.1). Erica was not present during this interaction. A student claimed the robot needed to turn 180 degrees (Data/Claim 6.1) with reasoning to support the claim by simulating two turns of 90 degrees (Warrant 6.1). A second student questioned whether the turn would be 80 degrees (Support 6.1). A third student misspoke that the turn would be 80 degrees but corrected to confirm the turn is 180 degrees (Support 6.2). As the first student attempted to change the code, they realized that program does not support input values not in the range of -128 to 127 (Data/Claim 6.2 and Warrant 6.2). The students decided to use two lines of code for turning (Claim 6.3 and Support 6.3) because two turns of 90 degrees is a turn of 180 degrees (Warrant 6.3) and meets the constraints of the programming language (Data/Claim 6.2 and Warrant 6.2)

Deliberation dialogue is not adversarial like persuasion dialogues; it is a collaborative dialogue that seeks to solve a practical problem or issue (Walton, 1998). As shown in the diagram (Figure 6), there is no evidence of conflicts (that is, there are no competing claims, counterclaims, or rebuttals). However, diagrams classified as deliberation dialogues may still have these structural elements. As Walton (1998) stated, "In many, but not all, cases of deliberation, there is a conflict between two possible courses of action, and a choice needs to be made between them" (p. 151). Deliberation dialogues are distinguished from information-seeking dialogues in that deliberation dialogues seek to solve a common problem. As evident in the content of Data/Claim

6.2 and Warrant 6.2, the students encountered a problem when the programming language for the robot would not accept numeric values greater than 127. This problem was not a theoretical problem, but it was a practical limitation of the programming language that the students did not expect. A student offered a potential solution by modifying their code to have the robot turn 90 degrees twice to complete the 180-degree turn needed to return to the starting point.

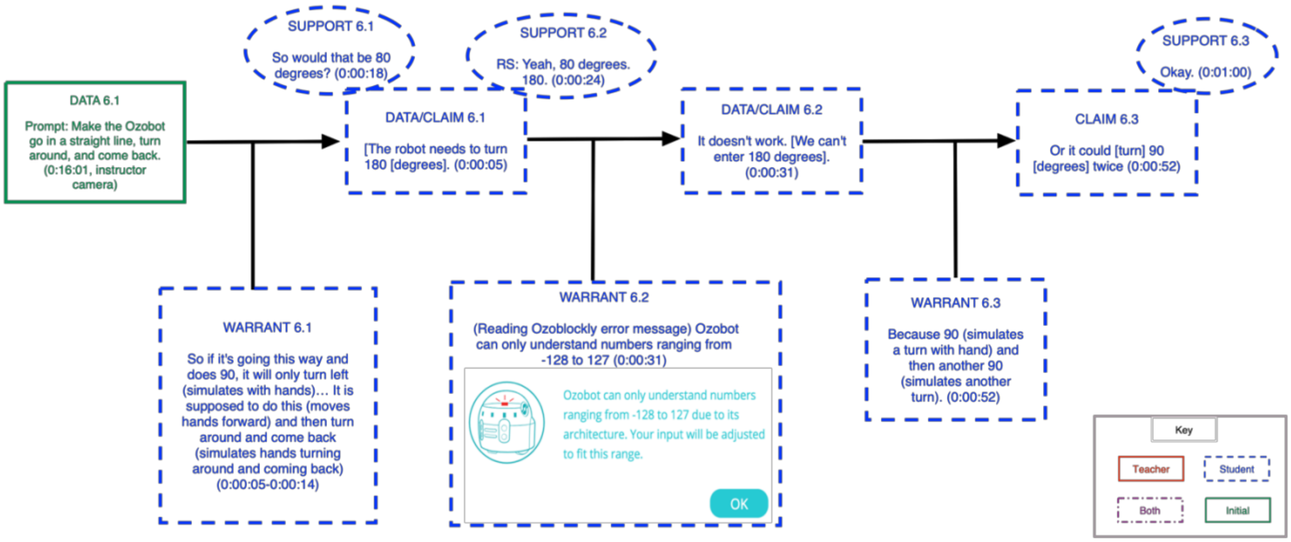

Figure 6. Extended Toulmin Diagram of a Deliberation Argument Dialogue

Note. Numbers in the diagram correspond to references in text.

In summary, the students encountered an initial dilemma when the programming language would not accept their original input of 180-degree turn (Data/Claim 6.2). Together, the students had a set goal of making the robot turn around to come back, which they agreed was a 180-degree turn (Data/Claim 6.1; Supports 6.1 and 6.2). When facing the dilemma of how to turn 180 degrees given the limitations on the numerical value inputs in the programming language, a student offered a potential solution with their reasoning (Claim 6.3 and Warrant 6.3). Collectively, the group agreed this was the best course of action to take given these limitations (Support 6.3). Therefore, the argument met the validation for our finding of this deliberation dialogue with Table 1.

An Inquiry Argument

Our illustrative example of inquiry dialogue comes from a whole class discussion during Erica's third lesson. At this point in the lesson, students had collected data individually about how far their robot could travel in 5 seconds at different speeds, and they had graphed each group's data on the board. Prior to the start of this episode, Erica asked students to describe the relationship between speed and distance. One student suggested that the relationship between speed and distance at a constant time was similar to the relationship between time and distance

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at a constant speed (Claim 7.1), which they had discussed as a class the previous day (Data 7.2). As a group, the students used their previous discussion and data (Data 7.1 & 7.3) to elaborate that speed and time both affect distance, and specifically, an increase in the robot's speed will cause it to go further (Data/Warrant/Claim 7.2). Erica then asked the rest of the class to consider whether their data supported that claim (Support 7.7), directing their attention to the graph on the board (Support 7.8). The class agreed (Claim 7.3), and with additional prompting from Erica (Supports 7.9, 7.10, & 7.11), they decided that the fact that their distance got farther every time their speed got faster (Warrant 7.3) meant that their data supported the original student claim.

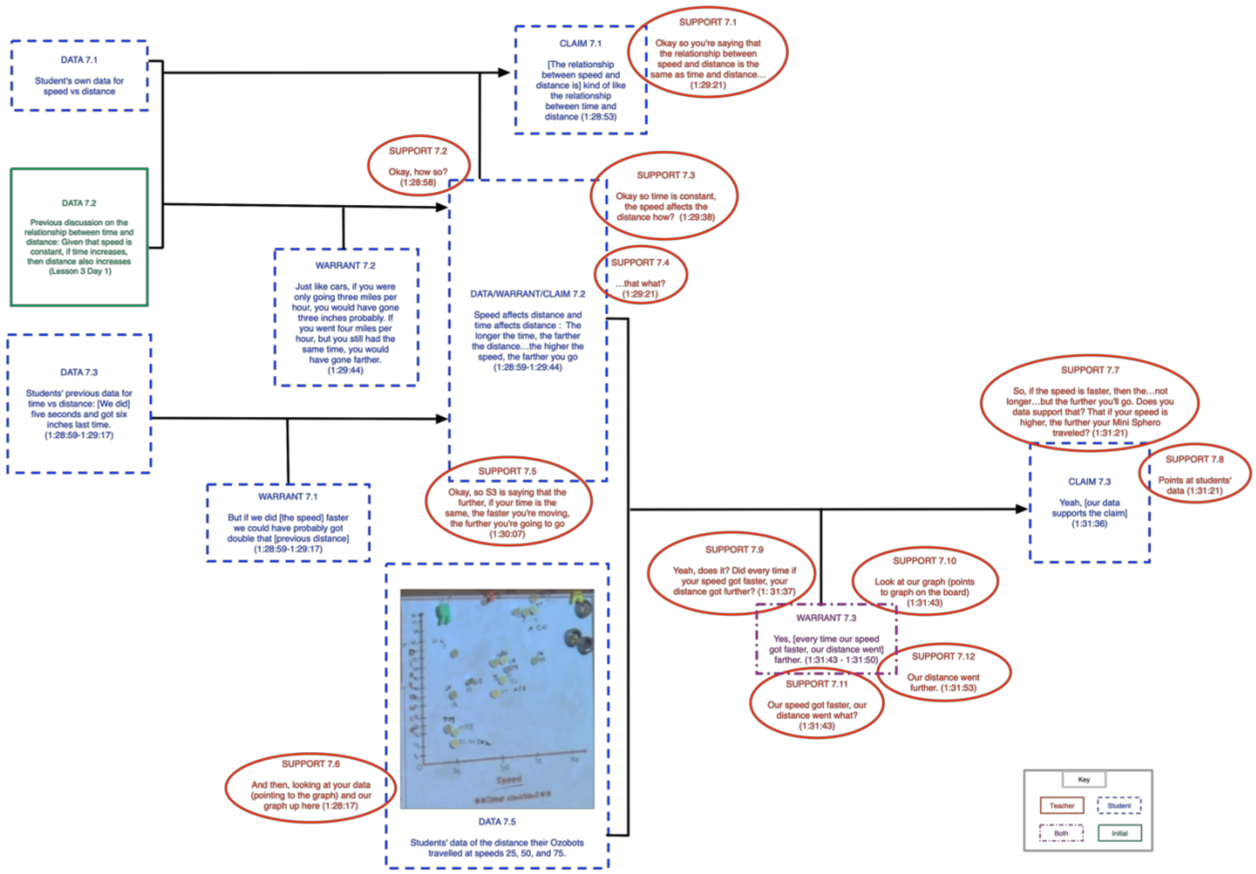

Figure 7. Extended Toulmin Diagram of an Inquiry Argument Dialogue

Note. Numbers in the diagram correspond to references in text.

To categorize this argument dialogue, we first concluded that there was no conflict in this episode in the sense that Walton intended, which eliminated persuasion, negotiation, and eristic dialogues. Next, we had to determine whether there was a common problem to be solved. The common problem was the relationship between speed and distance that the students were exploring. This common problem meant that this could not be an information-seeking dialogue. In this episode, students were not searching for a course of action to pursue, so we decided that this problem was a theoretical one, which meant this dialogue could be either inquiry or discovery. The distinction between these two types is particularly subtle, with discovery dialogue seeking to develop a hypothesis or proposition, while inquiry dialogue seeks prove or disprove a proposition. In this case, a student put forward a hypothesis (Data/Warrant/Claim 7.2) and the rest of the class evaluated the validity of this claim (Claim 7.3 and Warrant 7.3). We therefore decided the goal of the dialogue was to prove or disprove, which made this episode of argumentation an inquiry argument dialogue.

As a validity check of our decision of inquiry, we checked the initial situation, participant's goal, goal of dialogue for discovery in Table 1. We concluded that the initial situation for this episode was that students needed to prove the relationship between speed and distance using the evidence they collected with their robots., which fit with the initial situation given for inquiry dialogue. The goal for each participant and goal of the dialogue was to find and verify evidence to prove their hypothesis, which can be seen with Erica's support (Support 7.7) and the final claim (Claim 7.3). These goals matched those from Table 1 for inquiry.

A Discovery Argument

The final episode is the argument dialogue type of discovery, which is diagrammed in

. In this episode, a small group of students, without Sarah's presence, were analyzing a given photograph of Mars. They were tasked with making and justifying claims about the potential causes of the surface features on their photo of Mars. One student put forth the idea that the surface feature could have been caused by water (Claim 8.1). Another student suggested a potential justification for this idea (Warrant 8.1), saying that the pattern on the surface looked like bubbles, and the first student agreed with this reasoning and elaborated on it (Warrant 8.1 and Support 8.1).

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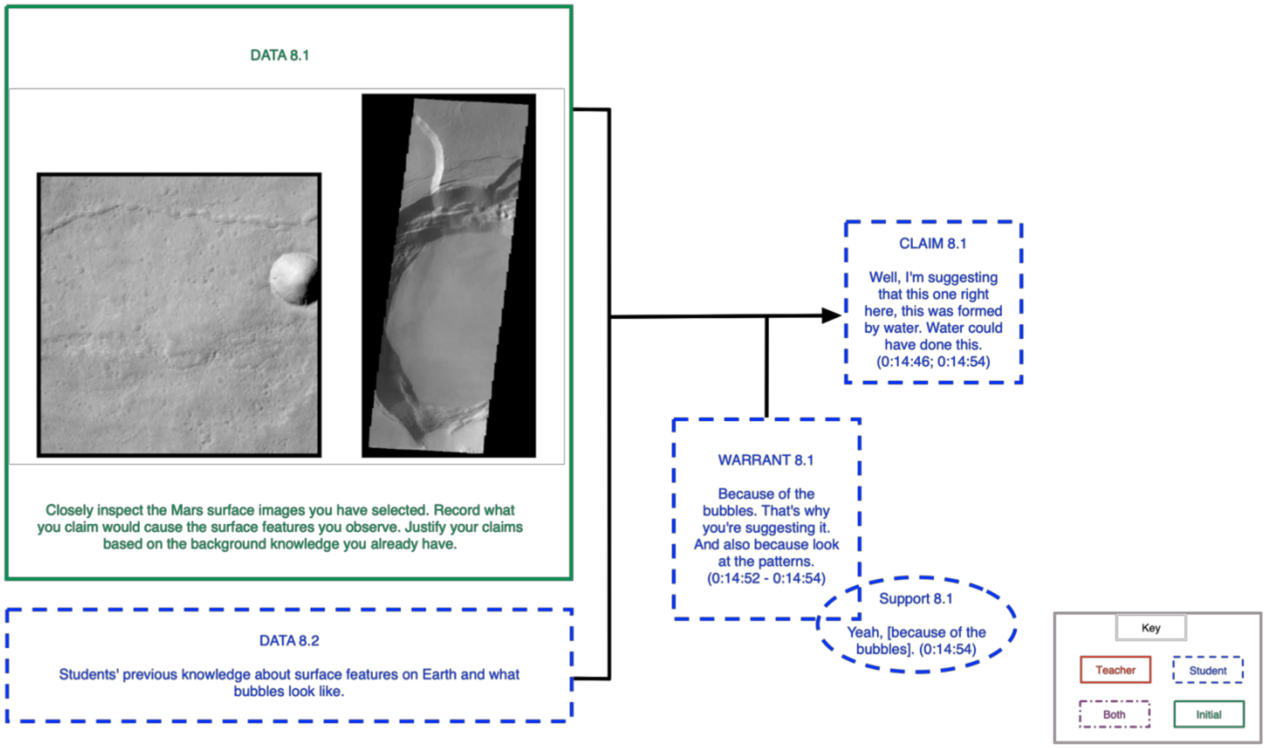

Figure 8. Extended Toulmin Diagram of a Discovery Argument Dialogue

Note. Numbers in the diagram correspond to references in text.

In this episode, multiple students contributed to the argument without resulting in any counterclaims or rebuttals, which suggests that there was no conflict of opinions. There was a common problem, as evidenced by the question in the initial data (Data 8.1) and the collaborative creation of the claim and warrant. Since the common problem is not one with an actionable solution, it fit the definition for a theoretical problem. This brought us to the last two types of dialogue, discovery and inquiry. From

, in inquiry dialogue the goal is to prove or disprove a particular proposition, such as the student claim (Data/Warrant/Claim 7.2) in the previous example. In this argument, there was no expectation to prove or disprove anything. The students were instead attempting to make sense of information given to them (i.e., photographs of Mars' surface). This led us to classify this argument as discovery dialogue.

As a final validity check of our decision of discovery, we checked the initial situation, participant's goal, goal of dialogue for discovery in Table 1. We concluded that the initial situation for this episode was that students needed to find an explanation for what caused the surface

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features on Mars, which fit with the initial situation given for discovery dialogue, to find an explanation. The goal for each participant was to find and defend their ideas for what caused the surface features, and the overall goal of the dialogue was to choose the best idea on what caused the surface feature. These goals matched those from the table for discover, which were to find a suitable hypothesis and discover the best hypothesis, respectively.

Discussion

We examined the applicability of Walton's (1998, 2010) types of argument dialogue for describing episodes of argumentation in elementary STEM lessons. Across six lessons with different STEM foci, we transcribed and diagrammed 47 episodes of argumentation using the extended Toulmin's (1958/2003; Conner, 2008) model. Then, we classified the episodes using Walton's types of argument dialogue. We determined that two episodes of argumentation contained a dialogic shift, and so our final analysis consisted of 49 argument dialogues. We found that the two US elementary teachers and their students engaged in six of the seven dialogue types: deliberation, discovery, information-seeking, inquiry, negotiation, and persuasion argument dialogues. We did not find evidence of eristic dialogues because we excluded episodes of argumentation that were purely student quarrels. The results extend previous findings that only identified a subset of these types of argument dialogue (information-seeking, discovery, inquiry, and persuasion) in secondary science and social science classrooms (Rapanta & Christodoulou, 2022). Our results also extend previous findings by revealing elementary students can engage in some of these argument dialogues without the teacher directly facilitating the argumentation (see argument diagrams in Figures 6 and 8).

Types of Argument Dialogue in the STEM Lessons

Our study provides initial insights into the types of argument dialogue present in elementary STEM lessons. The most common type of argument dialogue we identified was information-seeking, followed closely by deliberation. Excluding eristic dialogue, the two least common types were negotiation and inquiry. There could be various reasons for these different frequencies in argument dialogue outcomes: students' knowledge and beliefs about STEM disciplinary practices (Baytelman et al., 2020; Nussbaum et al., 2008), teacher's role in the argument dialogue or their beliefs about argumentation discourse (Conner & Singletary, 2021; Walshaw & Anthony, 2008), or the nature of the instructional task (Felton et al., 2009, 2015; Gilabert et al., 2013).

Overall, few of the arguments in our data were initially adversarial (i.e., persuasion, negotiation, and eristics; see left branch of Figure 2). Most of them were collaborative in nature (i.e., information-seeking, deliberation, inquiry, and discovery; see right branch of Figure 2). Some researchers contend that argument dialogues with an initial adversarial situation are not

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supportive of building knowledge or learning STEM concepts (e.g., Felton et al., 2015). They recommend teachers promote argument dialogues that are more collaborative and cooperative. Other scholars are more inclusive in their assessment of argument dialogue types for building knowledge (e.g., Aberdein, 2020; Rapanta, 2018). For example, Rapanta (2018) posited that persuasion dialogue types, along with information-seeking, discovery, and inquiry dialogues, have pedagogical potential for students to critically examine each other's ideas. Comparably, Aberdein (2020) was even more inclusive of the argument dialogue types that mathematicians engage in to build knowledge: inquiry, persuasion, information-seeking, deliberation, and negotiation. We recognize that argumentation is important for students to develop their understanding of STEM concepts, but our study is unable to clarify if certain types of argument dialogue are more productive for learning STEM concepts.

Learning to Argue in STEM

Both arguing to learn STEM concepts and learning to argue are important in STEM education (Staples & Newton, 2016; von Aufschnaiter et al., 2008). While the nature of our data does not allow for claims about which types of argument dialogue are productive for building STEM knowledge in elementary classrooms, our illustrations and descriptions of the argument dialogues may provide insights about learning to argue in STEM for researchers and teachers.

First, we contend these opportunities to learn to argue within various argument dialogues are vital for preparing a future STEM workforce. If students are limited in their opportunities to learn to argue within certain dialogue types, then they could be ill equipped for their STEM profession. For example, Gainsburg et al. (2016) noted that persuasion is not often a goal of engineer's arguments. They noted that engineers often make use of their knowledge of scientific and mathematical models to deliberate between potential design solutions to a problem. Future engineers with limited opportunities to develop their understandings of how to engage in deliberation argument dialogues but many opportunities to develop their understanding of persuasion argument dialogues may not be prepared to engage in the kind of argumentation needed for their role.

Second, the study provides evidence that elementary students can engage in argumentation for multiple purposes. The students in Sarah's and Erica's classrooms attempted to persuade classmates about design solutions for a simple machine, negotiated a plan to test designs for simple machines, used information about the relationship between centimeters and meters to develop reasoned based claims, deliberated how to modify their coding sequence given input restrictions in the programming language, used data to prove their conjectures about the relationship between speed and distance, and developed reasonable hypothesizes about what caused surface features on Mars. They were able to engage in multiple types of argument dialogue. It is, however, unknown if this is comparable for other students in the US and around

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the world. Future research may extend our findings to other contexts to determine if other teachers provide similar experiences to engage in different types of argument dialogue during STEM instruction.

Contributions to Argumentation Theory and Research

Toulmin and Walton did not develop their models for argumentation for educational research purposes. Still, Toulmin's model has been productive for educational researchers wanting to describe the structure and content of arguments in classrooms (Nussbaum, 2011). In comparison, Walton's model for argumentation has not been taken up to the same extent as Toulmin's; even though there are researchers who have advocated for Walton's model or have applied parts of his theory for educational research (e.g., Felton et al., 2015; Mextaxas et al., 2016; Nussbaum, 2011; Ozdem et al., 2013; Rapanta, 2018; Rapanta & Christodoulou, 2022). Walton (2022) acknowledged that authentic linguistic data from education contexts are important sites for testing and building upon formal argumentation models. In our study of the argumentative discourse in two elementary teacher's STEM lessons, we did not find a need to expand or modify Walton's theory of argument dialogues to be able to accurately describe the nature of the argumentation. When viewed alongside studies such as that of Rapanta and Christodoulou (2022), which applied a modified version of Walton's theory to a secondary science context, our findings support the idea that Walton's types of argument dialogue is applicable for modeling argumentation in educational contexts. Our study specifically identified examples, not yet described by others, of the negotiation argument dialogue type in a STEM educational context.

Our method of analysis contributes to classroom-based argumentation research by coordinating two argumentation models. Argumentation models can serve various purposes. Toulmin's model describes the structure and content of arguments. Walton's types of argument dialogue describe the ways in which people tend to argue. Our method of analysis brought these two purposes together. In the moment of argumentation, educational researchers are not able to probe a teacher's or students' goals. However, researchers are often able to capture the contents of the dialogue with audio and video recordings. From these recordings, researchers have used Toulmin models to describe the content and structure of arguments. Building on Walton's claim that the content and structure of arguments are shaped by participants' goals, we drew on the content and structure in Toulmin's models to make inferences about participants' goals and thus describe a type of argument dialogue. To our knowledge, no one has coordinated Toulmin's model for argumentation and Walton's types of argument dialogue for research in this manner, although Kolstø and Ratcliffe (2007) suggested such a coordination as promising for research and teacher education. Our combining of Walton's types of argument dialogue with Toulmin's model expands the analytical power of Toulmin's models for STEM education researchers to not only be able to describe the content and structure of the argument but also be able to describe the

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nature of the argumentation (i.e., the initial situation, participants' goals, and the goal of the argument dialogue).

We believe coordinating argumentation models can enrich our understanding of the nature of argumentation in STEM classrooms. Other scholars, Macagno et al., (2015), Metaxas et al. (2016), and Ozdem et al. (2013), coordinated Toulmin's model for argumentation and Walton's argumentation schemes, which are classifications for the patterns of reasoning found in warrants and backings (e.g., justifying a claim based on an expert's opinion). Note that Walton's argumentation schemes are different from Walton's types of argument dialogue. Like these scholars, we found the combined perspective of Toulmin and Walton offers a systematic way for researchers to examine the nature of argumentation in often-messy classroom interactions.

Contribution to Practice

The purpose of argumentation is often cast as to persuade others (Meiland, 1989). Walton's types of argument dialogue provide a more holistic description of the varying nature of goals for argumentation and is more aligned to what have been described in the field of STEM education. Providing teachers with Walton's types of argument dialogue may be productive in supporting them to think about the kinds of argumentation in which they want to engage their students. The examples in this paper provide teachers and teacher educators illustrations for each of Walton's types of argument dialogue and exemplify features we found typical of these types of argument dialogue. While we do not claim these arguments are ideal or should be replicated in classrooms, these examples do illustrate the distinguishing features of the types of argument dialogue within a context with which elementary teachers may identify.

Furthermore, combining the extended Toulmin models and Walton's model for argument dialogues may reveal ways in which teachers support students' engagement in certain types of argument dialogue during dialogical shifts. Recall, Erica's supportive actions (Support 4.1-4.3; 4.5) were significant in shifting the persuasion argument dialogue (Figure 3) to one of negotiation (Figure 4). Analyzing teachers' supportive actions during dialogical shifts may illuminate ways teachers support students' engagement with specific dialogue types. Cataloguing and describing these supportive actions may assist teachers in planning and guiding students in learning how to argue and arguing to learn in STEM.

Conclusion

We believe all students need opportunities to engage in a variety of argument dialogues across the STEM disciplines. Whether proving a hypothesis (inquiry), deciding on the best available course of action (deliberation), or resolving an issue to persuade another party (persuasion), students' engagement in these types of argument dialogue (and others) create different opportunities to learn through disciplinary-based argumentative discourse. If students are given opportunities to develop their argumentative practice with only a subset of argument dialogues, then they could be ill-prepared for the complexities of argumentation in the STEM disciplines. Our approach of applying Walton's dialogue theory to extended Toulmin models facilitates a systematic way to investigate the content, structure, and opportunities for various goals of argumentation across STEM disciplines.

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References

Aberdein, A. (2020). Dialogue Types, Argumentation Schemes, and Mathematical Practice: Douglas Walton and Mathematics. *Journal of Applied Logics, 8*(1), 159-182.

Baytelman, A., Iordanou, K., & Constantinou, C. P. (2020). Epistemic beliefs and prior knowledge as predictors of the construction of different types of arguments on socioscientific issues. *Journal of Research in Science Teaching*, *57*(8), 1199–1227. https://doi.org/10.1002/tea.21627

Conner, A. (2008). Expanded Toulmin diagrams: A tool for investigating complex activity in classrooms. *Proceedings of the Joint Meeting of PME,* 32, 361-368.

Conner, A., Crawford, B. A., Foutz, T., Hill, R. B., Jackson, D. F., Kim, C., & Thompson, S. A. (2021). Argumentation in primary grades STEM instruction: Examining teachers' beliefs and practices in the USA. In J. Anderson & Y. Li (Eds.), *Integrated Approaches to STEM Education: An International Perspective* (pp. 427–446). Springer International Publishing. https://doi.org/10.1007/978-3-030-52229-2_23

Conner, A., & Singletary, L. M. (2021). Teacher support for argumentation: An examination of beliefs and practice. *Journal for Research in Mathematics Education*, *52*(2), 213–247. https://doi.org/10.5951/jresematheduc-2020-0250

Conner, A., Singletary, L. M., Smith, R. C., Wagner, P. A., & Francisco, R. T. (2014). Teacher support for collective argumentation: A framework for examining how teachers support students' engagement in mathematical activities. *Educational Studies in Mathematics*, *86*(3), 401-429. https://doi.org/10.1007/s10649-014-9532-8

Cross, D. I. (2009). Creating optimal mathematics learning environments: Combining argumentation and writing to enhance achievement. *International Journal of Science and Mathematics Education*, *7*(5), 905–930. https://doi.org/10.1007/s10763-008-9144-9

Erduran, S., Simon, S., & Osborne, J. (2004). TAPping into argumentation: Developments in the application of Toulmin's Argument Pattern for studying science discourse. *Science Education*, *88*(6), 915-933. https://doi.org/10.1002/sce.20012

Felton, M., Garcia-Mila, M., & Gilabert, S. (2009). Deliberation versus dispute: The impact of argumentative discourse goals on learning and reasoning in the science classroom. *Informal Logic*, *29*(4), 417. https://doi.org/10.22329/il.v29i4.2907

Felton, M., Garcia-Mila, M., Villarroel, C., & Gilabert, S. (2015). Arguing collaboratively: Argumentative discourse types and their potential for knowledge building. *British Journal of Educational Psychology*, *85*(3), 372–386. https://doi.org/10.1111/bjep.12078

Forman, E. A., Larreamendy-Joerns, J., Stein, M. K., & Brown, C. A. (1998). "You're going to want to find out which and prove it": Collective argumentation in a mathematics classroom. *Learning and Instruction*, *8*(6), 527–548. https://doi.org/10.1016/S0959-4752(98)00033-4

Gainsburg, J., Fox, J., & Solan, L. M. (2016). Argumentation and decision making in professional practice. *Theory Into Practice*, *55*(4), 332–341. https://doi.org/10.1080/00405841.2016.1208072

Gilabert, S., Garcia-Mila, M., & Felton, M. K. (2013). The effect of task instructions on students' use of repetition in argumentative discourse. *International Journal of Science Education*, *35*(17), 2857–2878. https://doi.org/10.1080/09500693.2012.663191

ISSN: 2149-8504 (online)

K–12 Computer Science Framework Steering Committee. (2016). *K–12 Computer Science Framework*. http://www.k12cs.org

Keefer, M. W., Zeitz, C. M., & Resnick, L. B. (2000). Judging the quality of peer-led student dialogues. *Cognition and Instruction*, *18*(1), 53–81. https://doi.org/10.1207/S1532690XCI1801_03

Kim, S., & Hand, B. (2015). An analysis of argumentation discourse patterns in elementary teachers' science classroom discussions. *Journal of Science Teacher Education*, *26*(3), 221–236. https://doi.org/10.1007/s10972-014-9416-x

Kolstø, S. D., & Ratcliffe, M. (2007). Social aspects of argumentation. In S. Erduran & M. P. Jiménez-Aleixandre (Eds.), *Argumentation in Science Education: Perspectives from Classroom-Based Research* (pp. 117–136). Springer Netherlands. https://doi.org/10.1007/978-1-4020-6670-2_6

Krummheuer, G. (1995). The ethnography of argumentation. In P. Cobb & H. Bauersfeld (Eds.), *The emergence of mathematical meaning: Interaction in classroom cultures* (pp. 229-269). Erlbaum.

Macagno, F. (2022). Coding relevance. *Learning, Culture and Social Interaction*, *36*, 1-15. Advance online publication. https://doi.org/10.1016/j.lcsi.2019.100349

Macagno, F., Mayweg-Paus, E., & Kuhn, D. (2015). Argumentation theory in education studies: Coding and improving students' argumentative strategies. *Topoi*, *34*(2), 523–537. https://doi.org/10.1007/s11245-014-9271-6

McBurney, P., & Parsons, S. (2001). Chance discovery using dialectical argumentation. In T. Terano & Jinkō Chinō Gakkai (Eds.), *New Frontiers in Artificial Intelligence: Joint JSAI 2001 Workshop Post-Proceedings*. Springer.

Meiland, J. R. (1989). *Argument as inquiry and argument as persuasion. Argumentation, 3*(2), 185–196.

Mercer, N. (2000). *Words and minds: How we use language to think together*. Routledge.

Merriam, S. B. (1998). *Qualitative research and case study applications in education.* Jossey-Bass.

Metaxas, N., Potari, D., & Zachariades, T. (2016). Analysis of a teacher's pedagogical arguments using Toulmin's model and argumentation schemes. *Educational Studies in Mathematics*, *93*(3), 383-397. https://doi.org/10.1007/s10649-016-9701-z

Michaels, S., O'Connor, C., & Resnick, L. B. (2008). Deliberative discourse idealized and realized: Accountable talk in the classroom and in civic life. *Studies in Philosophy and Education*, *27*(4), 283–297. https://doi.org/10.1007/s11217-007-9071-1

National Governors Association Center for Best Practices & Council of Chief State School Officers. (2010). *Common core state standards for mathematics.* http://corestandards.org/

Next Generation Science Standards Lead States. (2013). APPENDIX F: Science and Engineering Practices in the Next Generation Science Standards. In *Next Generation Science Standards: For States, By States* (pp. 382–412). The National Academies Press. https://doi.org/10.17226/18290

Nussbaum, E. M. (2008). Collaborative discourse, argumentation, and learning: Preface and literature review. *Contemporary Educational Psychology*, *33*(3), 345-359. https://doi.org/10.1016/j.cedpsych.2008.06.001

Nussbaum, E. M. (2011). Argumentation, dialogue theory, and probability modeling: Alternative frameworks for argumentation research in education. *Educational Psychologist*, *46*(2), 84–106. https://doi.org/10.1080/00461520.2011.558816

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching*, *41*(10), 994-1020. https://doi.org/https://doi.org/10.1002/tea.20035

Ozdem, Y., Ertepinar, H., Cakiroglu, J., & Erduran, S. (2013). The nature of pre-service science teachers' argumentation in inquiry-oriented laboratory context. *International Journal of Science Education*, *35*(15), 2559–2586. https://doi.org/10.1080/09500693.2011.611835

Rapanta, C. (2018). Potentially argumentative teaching strategies—And how to empower them. *Journal of Philosophy of Education*, *52*(3), 451–464. https://doi.org/10.1111/1467-9752.12304

Rapanta, C., & Christodoulou, A. (2022). Walton's types of argumentation dialogues as classroom discourse sequences. *Learning, Culture and Social Interaction*, *36*, 1-15. Advance online publication. https://doi.org/10.1016/j.lcsi.2019.100352

Rasmussen, C., Wawro, M., & Zandieh, M. (2015). Examining individual and collective level mathematical progress. *Educational Studies in Mathematics, 88*(2), 259-281. https://doi.org/10.1007/s10649-014-9583-x

Stake, R. E. (1995). *The Art of Case Study Research*. SAGE Publications.

Staples, M., & Newton, J. (2016). Teachers' contextualization of argumentation in the mathematics classroom. *Theory Into Practice*, *55*(4), 294–301. https://doi.org/10.1080/00405841.2016.1208070

Toulmin, S. E. (2003). *The Uses of Argument*. Cambridge University Press. https://doi.org/10.1017/CBO9780511840005 (Original work published 1958)

von Aufschnaiter, C., Erduran, S., Osborne, J., & Simon, S. (2008). Arguing to learn and learning to argue: Case studies of how students' argumentation relates to their scientific knowledge. *Journal of Research in Science Teaching*, *45*(1), 101–131. https://doi.org/10.1002/tea.20213

Walshaw, M., & Anthony, G. (2008). The teacher's role in classroom discourse: A review of recent research into mathematics classrooms. *Review of Educational Research*, *78*(3), 516–551. https://doi.org/10.3102/0034654308320292

Walton, D. N. (1998). *The New Dialectic: Conversational Contexts of Argument*. University of Toronto Press.

Walton, D. (2010). Types of dialogue and burdens of proof. *Frontiers in Artificial Intelligence and Applications*, *216*, 13–24. https://doi.org/10.3233/978-1-60750-619-5-13

Walton, D. (2019). How the context of dialogue of an argument influences its evaluation. In F. Puppo (Ed.), *Informal Logic: A "Canadian" Approach to Argument* (pp. 196–233). Windsor Studies in Argumentation.

Walton, D. (2022). Formal dialogue models for argumentation in education and linguistics. *Learning, Culture and Social Interaction*, *36*, 1-4. Advance publication online. https://doi.org/10.1016/j.lcsi.2020.100388

Walton, D., & Krabbe, E. C. (1995). *Commitment in dialogue: Basic concepts of interpersonal reasoning*. SUNY Press.

ISSN: 2149-8504 (online)

Webb, N. M., Franke, M. L., Ing, M., Turrou, A. C., Johnson, N. C., & Zimmerman, J. (2019). Teacher practices that promote productive dialogue and learning in mathematics classrooms. *International Journal of Educational Research*, *97*, 176–186. https://doi.org/10.1016/j.ijer.2017.07.009

Whitenack, J. W., & Knipping, N. (2002). Argumentation, instructional design theory and students' mathematical learning: A case for coordinating interpretive lenses. *The Journal of Mathematical Behavior*, *21*(4), 441–457.

Yackel, E. (2001). Explanation, justification and argumentation in mathematics classrooms. In M. van den Heuvel-Panhuizen (Ed.), *Proceedings of the 25th International Conference on the Psychology of Mathematics Education* (Vol. 1, pp. 9–23). IGPME.

Yackel, E. (2002). What we can learn from analyzing the teacher's role in collective argumentation. *The Journal of Mathematical Behavior*, 21(4), 423-440. https://doi.org/10.1016/S0732-3123(02)00143-8

Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching*, *39*(1), 35-62. https://doi.org/https://doi.org/10.1002/tea.10008

ISSN: 2149-8504 (online)