ISSN: 2325-3290 (online)
Dialogic Pedagogy
an International Online Journal

Analyzing science teachers' support of dialogic argumentation using teacher roles of questioning and communicative approaches

Jonathan Kilpelä
University of Jyväskylä, Finland

Jenna Hiltunen
University of Jyväskylä, Finland

Markus Hähkiöniemi
University of Jyväskylä, Finland

Kaisa Jokiranta
JAMK University of Applied Sciences, Finland

Sami Lehesvuori
University of Jyväskylä, Finland

Pasi Nieminen
University of Jyväskylä, Finland

Jouni Viiri
University of Jyväskylä, Finland

Abstract

The purpose of this study is to investigate how teachers use different types of discourse to support dialogic argumentation. Dialogic argumentation is a collaborative process in which students construct arguments together and examine arguments presented by their peers. Science teachers can use argumentation as a vehicle to help students gain a working understanding of science content and the nature of science and its practices. Whole-class closing discussions from video-recorded lessons are analyzed to study the discourse used to support argumentation by two physics teachers in lower secondary schools. Analysis of discourse includes coding of communicative approach at the episode level and coding of teacher roles of questioning at the level of speaking turns. Student argumentation is also assessed on the basis of dialogicity and complexity of arguments. Findings characterize different ways of orchestrating argumentative discussions. Authoritative episodes were characterized by the presence of the dispenser role, with teachers retaining ownership over ideas and classroom activities to emphasize the correctness of a justification. Dialogic episodes of classroom interaction showed openness to student perspectives, but teachers' use of questioning roles revealed different ways of orchestrating argumentative discussions. The moderator role granted ownership of ideas to students to either pursue a single student's argument in more depth or to directly contrast opposing justifications. Less commonly used were the roles of coach and participant, which teachers used to elicit student justifications in more depth or support students in examining the arguments of their peers. Examination of discourse

using multiple frameworks revealed differences in teachers' values and the impact of the use of teacher questioning roles on student contributions to argumentative discussions.[1]

***Keywords**: argumentation, dialogic argumentation, science education, teacher questioning, whole class discussion*

Jonathan Kilpelä is a teacher-researcher who graduated with a Master of Arts in Educational Sciences from the University of Jyväskylä. After working as a research assistant in the Department of Teacher Education at the University of Jyväskylä, Jonathan currently teaches secondary science at the International School of Helsinki.

Jenna Hiltunen is a project researcher at the Finnish Institute for Educational Research, University of Jyväskylä. Her research interests include mathematics learning, international assessment studies, and dialogic argumentation for mathematics learning.

Markus Hähkiöniemi works as a Senior Lecturer in the Department of Teacher Education at the University of Jyväskylä. His research interests include inquiry-based mathematics teaching, technology enriched mathematics learning, classroom interaction, and argumentation.

Kaisa Jokiranta is a specialist at LIKES in the University of Applied Sciences in Jyväskylä. She is currently studying support of university students' wellbeing and physical activity.

Sami Lehesvuori works as a Senior Lecturer in the Department of Education at the University of Jyväskylä. His research interests include dialogic teaching, classroom interaction in science teaching, argumentation in science teaching, and science teacher education and professional development.

Pasi Nieminen works as a Senior Lecturer in the Department of Teacher Education at the University of Jyväskylä. His research interests include differentiation in inquiry-based science learning, argumentation in science and mathematics education, assessment in science and mathematics education, and multiple representations in physics learning.

Jouni Viiri is a professor emeritus at the Department of Teacher Education at the University of Jyväskylä. His research interests include classroom interactions in science teaching and learning, simulations in science teaching and learning, assessment, models and representations, eye-tracking studies, and automated speech recognition.

Science teachers should make it a central aim to foster student argumentation skills (Mercer, 2009; Osborne, 2010), as emphasized in the national curricula (Finnish National Agency for Education, 2016; NGSS Lead States, 2013). Although student argumentation is supported by many factors, including task design, curriculum, and cultural factors (Asterhan & Schwarz, 2016, Berland & McNeill, 2010), teacher questioning strategies play a critical role in this process (Simon, Erduran, & Osborne, 2006). Facilitating opportunities for learners to engage with argumentation practices requires teachers to use diverse forms of discourse, including dialogic discourse. By describing discourse used in science lessons, this research seeks to clarify how teachers can support or hinder dialogic argumentation using teacher roles of

[1] **Acknowledgments:** This study was funded by the Academy of Finland (project number 286576) and the Finnish Cultural Foundation (fund number 00160353). The authors declare that they have no conflict of interest.

questioning (Chen, Hand, & Norton-Meier, 2017) and their communicative approaches (Mortimer & Scott, 2003).

According to some studies, argumentation skills are vital for forming a deep understanding of science content and learning about the nature of science (Osborne, 2010). Rather than acquiring isolated fragments of scientific knowledge, learners should interact with the process of scientific argumentation and move through the steps of inquiry, gathering data, and constructing and negotiating arguments (Chen & Steenhoek, 2014). When students listen to their peers and critically evaluate how other arguments compare with their own ideas, it offers "a means for improving the quality of the student experience, the depth of student thinking, and the learning of science itself" (Osborne, 2010, p. 466). Engaging in these practices mirrors, to some extent, the practices of the scientific community and allows for the essential experience of students to authentically contribute with their own unique voice to a community of practice, as highlighted by Matusov and von Duyke (2010) in their discussion of internally persuasive discourse. In this way, argumentation is not an isolated goal but rather serves as a "vehicle to drive students in the whole process of inquiry" (Chen, Hand, & Park, 2016, p. 280). Whereas argumentation is an essential part of scientific communication, there is still a call for highlighting the social aspect and the role of interaction in facilitating non-disputatious and constructive participation in educational dialogue (Mercer et al., 2009).

Accordingly, in this study, we explore how argumentation and related interactions can be enriched through dialogicity. In general, dialogicity refers to the mutual consideration of different voices, views, and ideas (Bakhtin, 1986). When drawing specifically on dialogic argumentation, Nielsen (2013) describes this as "a specialized way of arguing in which the participants not just defend their own claims, but also engage constructively with the argumentation of their peers" (Nielsen, 2013, p. 373). Structurally, an argument consists of a claim and evidence, reasoning, or data that supports the claim. Dialogic argumentation, however, specifically addresses the language processes in which students examine and present claims and evidence. Importantly, it focuses on the interaction furthering critical thinking and reasoning (Lehesvuori et al., 2017). Dialogic argumentation then requires not only the implicit or explicit presentation of the structural elements of an argument but also that students engage with each other's ideas and examine the reasoning brought up by their peers.

Dialogic argumentation relates to the broader social construction of knowledge (Vygotsky, 1978), as the relationships between claims and evidence are discussed, examined, and modified on the social interpsychological plane, then internalized on the intrapsychological plane. However, whereas the social construction of knowledge approaches the learning process in general, dialogic argumentation specifically addresses the extent to which the reasoning leading to claims is made clear and the extent to which participants respond to others' justifications. An example may illustrate this best: the social construction of knowledge could include the social sharing and comparison of knowledge, building to a broader shared understanding. Within that knowledge may lie implicit understandings or justifications that are not clearly stated. Dialogic argumentation, however, entails specifically the social aspect of examining not only what is known but how that knowledge relates to a conclusion or justification of a claim (Hähkiöniemi et al., 2022).

Promoting dialogic interactions in classrooms has been described as a prerequisite to developing argumentation (Berland & McNeill, 2010, Lehesvuori et al., 2017, McNeill & Pimentel, 2010). However, pedagogical approaches facilitating dialogic interactions are difficult for teachers to master, as they require "the 'know-how' of being able to engage students in dialogic interactions" (Scott, Mortimer, & Aguiar, 2006, p. 624). At the core lies a tension: teachers must implement communicative approaches that give students a chance to ideate and explore but also scaffold students in the meaning making processes (Ford & Forman, 2015; Mortimer & Scott, 2003). The orchestration of questioning routines that are open to a wide

range of potential student responses presents a challenge to teachers due to the unpredictable nature of student responses. This, in turn, may even lead teachers to discourage over-enthusiastic intellectual engagement as a means of limiting the scope of discussion (Kennedy, 2005). These challenges highlight the need to further understand how teachers orchestrate dialogic discussions in which they grant partial ownership of ideas or activities to their students.

Teacher questioning and orchestration of discussions should not be considered the only factors that influence student argumentation. Students' questions are also seen to have a clear impact on the thinking processes of their peers (Chin and Osborne, 2008), and the quality of questions formulated by students was linked to productive oral argumentation. The nature of the initial question driving a line of inquiry was shown to play a part in orchestrating the type of dialogic argumentation that followed (Chin and Osborne, 2010). Basic information questions presented by students (which include both factual and procedural questions) do little to stimulate further discussion or critical analysis. In contrast, wonderment questions include comprehension, prediction, anomaly detection, application, and planning or strategy questions (Chin, Brown, & Bruce, 2002). These wonderment questions were seen to "stimulate students to generate explanations and propose solutions to problems" (Chin et al., 2002, p. 540). While the questions generated by students undoubtedly have an effect on the nature of argumentative discussions, the focus of this study, however, remains on examining the teacher's questioning role.

Mercer (2008) calls for analyses of classroom interactions which include a temporal element to supply better ways of analyzing classroom interactions as a continuing, social mode of thinking. In relation, Chen et al. (2017) advocate for research on appropriate contexts and sequences for teachers to use different roles of questioning. This requires reaching a deeper understanding of how teachers use authoritative and dialogic communicative approaches (Scott et al., 2006). The focus on promoting dialogic interaction is rationalized by continuously prevailing authoritativeness in science classrooms, often characterized by transmission modes of teaching and little allowance for alternative viewpoints and extended dialogue (Mercer et al., 2009; Lehesvuori et al., 2018). The aim of this study is to build an understanding of how teachers can orchestrate classroom interactions in science and support dialogic argumentation in whole-class discussions.

Literature

Dialogic interactions in science

The term *dialogic* has been widely used in the field of research on classroom interaction. For example, definitions of dialogic pedagogy (Matusov, 2009), dialogic communicative approach (Scott, 2006), and dialogic space (Wegerif, 2010) draw on Bakhtin's (1986) idea of equal consideration of different voices and ideas. In slight contrast, Alexander (2006) highlights the purposefulness and cumulativeness of joint construction of knowledge in descriptions of and principles for dialogic teaching. In this study, these two aspects are considered equally important, on one hand by highlighting the importance of equal consideration of different voices (dialogue with authenticity) and on the other hand by highlighting the importance of purposeful discussion of subject content (dialogue with purpose). Enabling student exploration of ideas and reasoning is considered to be an essential part of the meaningful learning of science (Barreto et al., 2021).

Although the nature of science is fundamentally dialogic (Ford and Forman, 2015), teacher-centered authoritative approaches dominate science teaching (Hiltunen et al., 2016; Lehesvuori, Viiri, Rasku-Puttonen, Moate, & Helaakoski, 2013; Osborne, 2010). Teachers who view themselves as experts in the learning community maintain ownership over learning activities (Donnelly et al., 2014), stifling dialogic

argumentation. Teachers frequently hold to a direct transmission model of knowledge transfer (Scott et al., 2006), especially when encountering less familiar content areas (Nurkka, Mäkynen, Viiri, Savinainen, & Nieminen, 2012) and when attempting to convey correctness or emphasize the scientific perspective (Lehesvuori, Ramnarain, & Viiri, 2018).

Due in part to overly dominating teacher-directed and authoritative interactions, McNeill and Pimentel (2010) observe that students view the goal of science as simply getting the right answer rather than a process of persuasion. Likewise, Watson, Swain, and McRobbie (2004) found that students construct arguments with low frequency and of low quality. Even if dialogic interactions are emphasized, it remains a challenge to ensure that students are authentically engaging and not performing a sterile "procedural display" (Bloome, Puro, & Theodorou, 1989, as cited in Ford & Forman, 2015, p. 150).

Although dialogicity is also about a shared and collective endeavor between teachers and students (Alexander, 2006), the decision to pursue dialogue remains in the control of teachers (Mercer, 2009). Students have little motivation to share their ideas if the teacher actively exercises power as the subject authority (Davies, Kiemer, & Meissel, 2017). In order to promote critical thinking and reasoning, teachers must grant their students "constrained intellectual authority" (Ford & Forman, 2015, p. 146). Ford and Forman (2015) discuss a paradox in which "instruction must be constraining and directive in some sense, but also provide opportunities for students to develop a deep understanding of scientific concepts and investigations" (p. 144). Science itself as a practice is fundamentally dialogic, so to implement this "constrained intellectual authority," a science teacher must take some ownership of whole-class discussion but also let the students practice the skills of listening and responding to other ideas in a dialogic setting.

Teacher orchestration of whole-class discussion

The interaction in science classrooms has been shown to follow a traditional triadic Initiation-Response-Follow-up (IRF) pattern (Lemke, 1990; Sinclair & Coulthard, 1975). When a teacher's follow-up turn is more probing by nature, the IRF structure may evolve into an extended IRPRP-pattern[2] (Scott et al., 2006). Whereas the dominance of the IRF-pattern implies prevailing authoritativeness, extended dialogues are potentially linked to dialogic interaction. A teacher initiation turn, i.e., often a question, is essential when opening up the space for student thinking (Chin, 2007). Flexibility in questioning routines is essential when the goal of teacher questioning is not simply to evaluate what students know but rather when the goal is to build upon student ideas to construct joint understanding and stimulate productive thinking (Chin, 2007).

Teacher orchestration of whole-class discussions has been studied from a variety of perspectives, including question types (McNeill & Pimentel, 2010), communicative approaches (Scott et al., 2006), and pedagogical practices (Simon et al., 2006). Chin (2007) describes the functions of teacher questions, emphasizing the role of revoicing student ideas to make connections between student ideas. Chin described teachers using questions in a very purposeful way to weave together student ideas and bridge the gap between a student's knowledge and the questions posed in classroom discussion. Teacher questioning is situated by Chin in four main categories: a) Socratic questioning, b) verbal jigsaw, c) semantic tapestry, and d) framing. The purpose of Socratic questioning is to guide students' thinking using a series of questions. Verbal jigsaw helps students to understand the relationships between specific scientific terminology and how they can be used in relation to one another. Semantic tapestry serves to integrate concepts to create an overall conceptual understanding of the connections between topics, and framing is used to clarify "the relationship between a question and the information that it addresses" (Chin, 2007, p. 823). Other studies classify teacher talk using over a dozen types of teacher talk (Soysal, 2018; Vrikki,

[2] An IRPRP-pattern would take the form of Initiation-Response-Prompt-Response-Prompt and may continue for several turns.

Wheatley, Howe, Hennessy, & Mercer, 2019). Specifically, Soysal (2018) describes teacher discursive moves such as probing, challenging, prompting, and affirming. These are used to track long-term trends and are linked to different stages of argument-based inquiry. Scott (1998) also categorizes teacher discursive moves, labeling them as "forms of pedagogical intervention" (p. 56) based on the major strands of the teaching narrative: developing scientific knowledge, supporting student meaning making, and maintaining the narrative.

In this study, we approach the concepts of teacher discursive moves and teacher questioning using two frameworks that succinctly capture two essential properties of teacher-student interaction in a whole-class discussion. First, the communicative approaches framework can be applied to classify the resulting discourse along two dimensions, as shown in Figure 1. Within the vertical dimension, an authoritative communicative approach is restricted to a single point of view, while a dialogic communicative approach values multiple perspectives. In the horizontal dimension, interactive or noninteractive talk refers to how many speakers participate in the discourse. Combining the two dimensions creates four communicative approaches: authoritative/noninteractive, authoritative/interactive, dialogic/noninteractive, and dialogic/interactive (Mortimer & Scott, 2003). Shifts in the communicative approach imply a shift in teaching purpose (Lehesvuori et al., 2013). Scott and Ametller (2007) describe cycles in which teachers use a dialogic communicative approach to open up topics, allowing students to make connections to prior knowledge of a topic, followed by an authoritative communicative approach to close down the discussion, acting as a seed for further dialogue.

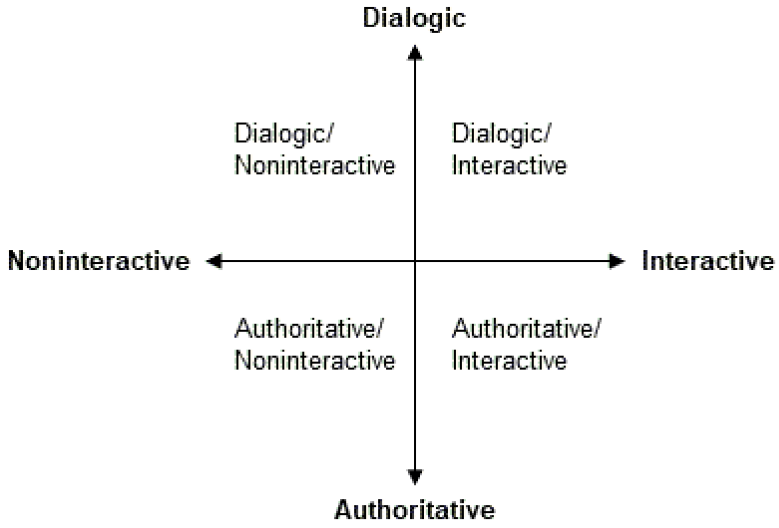


Figure 1. Four classes of communicative approach (Scott et al., 2006, p. 611)

Defining the dominant communicative approach of an episode of talk requires firstly interpreting if the teacher considers a range of ideas (dialogic) or focuses on a singular perspective (authoritative). For the second dimension, the framework describes talk that includes multiple participants (interactive) or only a single participant (noninteractive) (Mortimer & Scott, 2003). Although this framework creates 4 distinct categories, it must also be recognized that both the dialogic and interactive components exist along a continuum (symbolized by the arrowheads in Figure 1), that is, some episodes may include more strong dialogic elements than others, and the amount of interaction can vary from completely noninteractive, to slightly interactive, to a high level of interaction with frequent exchanges between students and the teacher. However, the communicative approaches framework alone does not offer a detailed picture of how a whole-

class discussion unfolds on a turn-by-turn basis. Instead, the intention of the framework is to analyze whole episodes of classroom talk.

In order to bring a greater level of detail to individual speaking turns, this study also utilizes the teacher roles of questioning framework (Chen et al., 2017), which categorizes teacher utterances into four categories, as seen in Figure 2. These categories approach the concept of dialogic talk from a different perspective than the communicative approach framework. Specifically, in the teacher roles of questioning framework, a distinction is made between the ownership of ideas and the ownership of classroom activities. This recognizes that although discourse may include students' ideas, students may not necessarily have ownership over the classroom activity. For instance, a teacher may recognize students' ideas but dictate who may speak and when, in which case the student has ownership of the ideas, but the teacher has more ownership of the activity. As shown in Figure 2, ownership of ideas and ownership of the activity are plotted in separate dimensions, creating four teacher roles of questioning. Within each role, several sub-categories are identified, which correspond to some degree with teacher discursive moves (Scott, 1998; Soysal, 2018). This framework orients these discursive moves along 2 independent axes. The name of the framework seems to suggest that only teacher questions are analyzed, but the framework is used by Chen et al. (2017) to describe a variety of teacher utterances used within a questioning routine or whole-class discussion, so in reality, the framework applies to other statements made by a teacher, not just questions.

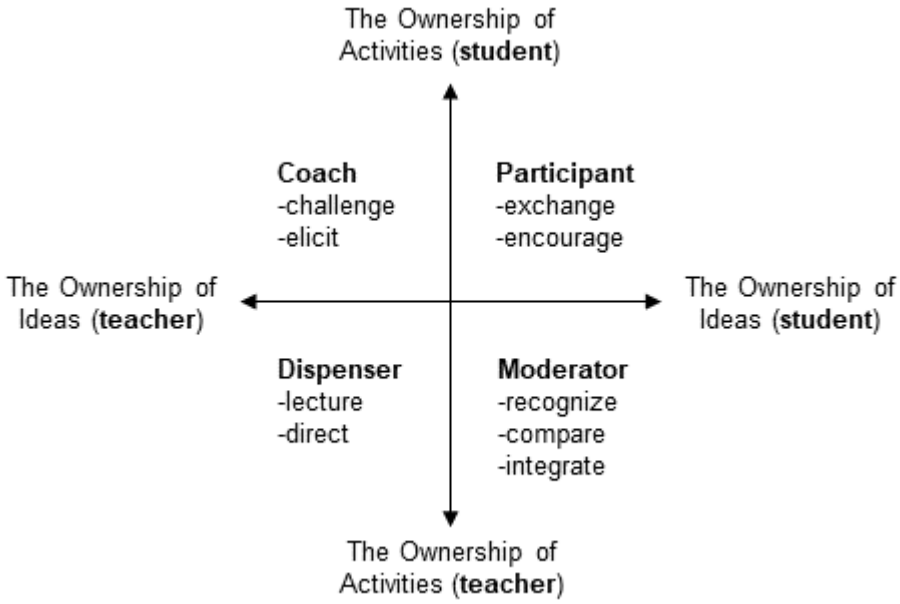


Figure 2. Framework for teacher questioning roles (Chen et al., 2017, p. 384). Subcategories are combined to create four roles, arranged by ownership of ideas and activity.

The most teacher-centered teacher role is the *dispenser*, in which the teacher retains ownership of ideas and activities by presenting information (utterance coded as 'lecture') or directing ideas and activities ('direct'). The most student-centered teacher role is *participant*, which grants ownership of ideas and activities to students. In the participant role, the teacher and students can openly share ideas ('exchange'), or the teacher may encourage students' ideas ('encourage'). The other two roles exhibit more of a shared sense of ownership. In the *moderator* role, the teacher 'recognizes,' 'compares,' and 'integrates' student ideas into the whole-class discussion. Importantly, the teacher refrains from acting as an authority on the subject matter and allows students' ideas to take precedence. Conversely, when the teacher is in the *coach*

role, students have ownership over turn-taking norms and the flow of whole-class discussions, but the teacher challenges students' reasoning ('challenge') and works to make student reasoning more explicit ('elicit'). To further clarify these categories, Table 1 includes specific examples analyzed in this text to illustrate each code in more detail.

Table 1
Teacher questioning roles (Chen et al., 2017)

Teacher questioning role and subcategory	Description	Example
Dispenser		
-lecture	-An exposition of a given subject intended to present information and conceptual relationships	-Now of course we could consider this fact card F, because it says the same as G, but in different words, that there is no horizontal section of the graph.
-direct	-Any response or instruction used to lead the direction of students' ideas and activities	-There aren't [any places on the graph], or it doesn't look like it. But there should be how many of them, Emilia? -What did Card G say? Read that one again.
Moderator		
-recognize	-Any response used to identify students' ideas or arguments	-[pointing at graph, after statement shared by student] These should be parallel.
-compare	-Any response used to examine ideas or arguments in order to note similarities and differences	-And then you, Jenna, had that same [card] G, that the other groups had used quite a bit. It says that the temperature doesn't change. -Okay, now we have two different opinions. Leevi can start, then Jesse follows.
-integrate	-Any response used to synthesize or incorporate students' ideas as a whole	-The boys claim that this graph is wrong. It doesn't show the situation where water is heated from ice to steam. Does fact card G support the boys' claim?
Coach		
-challenge	-Any response used to critique students' ideas or arguments	-But are they the correct temperatures? -[But] it's right here, 100 degrees.
-elicit	-Any response used to make students' implicit ideas more explicit	-So two phase changes. How do you know the temperatures, are there cards that help with that?
Participant		
-exchange	-Any response used to share ideas with students	-Well that makes two of us who are unsure, then!
-encourage	-Any response used to inspire students' ideas	-Okay, those were good comments! How should that go?

Note. Descriptions of categories are definitions presented by Chen et al., 2017 (pp. 399-401). Examples are taken directly from the transcript presented in this manuscript, except for the examples for the role of participant, which are selected from Johanna episodes 1 and 2, which were not included in this manuscript.

Similarities can also be seen between the teacher roles of questioning framework and teacher questioning strategies[3], as described by Chin (2007). A question-based prelude may fit into the role of dispenser or moderator, depending on how the teacher controls the activity. Socratic questioning strategies such as pumping and reflective toss align to some extent with the role of moderator, as might a verbal jigsaw. A constructive challenge could likely fit into the role of coach, and the semantic tapestry strategy of focusing and zooming may fit into the role of participant and moderator. However, in all of these cases it would depend on the context of the question and how it is used. Attributing the ownership of activities and ideas in the teacher roles of questioning framework relies on looking back at the historical aspect of talk (Mercer, 2008) throughout the thread of a discussion.

The communicative approaches framework and teacher roles of questioning framework were chosen due to their ability to describe a wide range of discourse. They are versatile because they rely on two independent dimensions to produce the categories of talk instead of selecting from a list of nominal categories. In both frameworks used in this study, the dimensions span from one extreme to another and could theoretically include any content-related classroom discussion. Moreover, each framework depicts a continuum of control between students and teachers, aligning with the reality of classroom interactions, as ownership and control of ideas or activities are shared between students and teachers. Chen et al. (2017) discuss the "tension between ownership of both ideas and activities" (p. 395), presenting discourse as a negotiation between parties rather than recognizing only separate, dichotomous types of communication. The models can complement each other in analysis, as the communicative approaches framework offers a broader, episode-level view of classroom discourse, while the teacher roles of questioning gives a more detailed picture of individual speaking turns. Specifically, using the teacher roles of questioning framework to consider how the ownership of classroom activities is shared between the teacher and students may offer clarification into the specific "moves" that teachers use to gather and steer student ideas in whole-class discussions. In turn, this may reflect how teachers grant students "constrained intellectual authority" previously discussed by Ford and Forman (2015).

Figure 3 shows a theoretical visualization of how these two frameworks could interact in episodes of whole-class discussion. The episodes in Figure 3 represent theoretical examples and are not tied to the analysis of data. In these theoretical examples, the communicative approach moves from authoritative/interactive in Episode A to dialogic/interactive in Episodes B and C. Within each episode, the dominant teacher roles of questioning are circled, and arrows represent shifts between different teacher roles of questioning. In Episode A, a teacher uses the roles of dispenser and coach in an authoritative/interactive episode. Episodes B and C show a teacher primarily using the role of moderator in dialogic/interactive episodes but include some shifts between the other three roles. These theoretical examples show how episodes of talk could be classified from the perspective of two independent frameworks, with the communicative approach framework offering a holistic episode-level overview, and the teacher roles of questioning showing how ownership of ideas and the activity shift back and forth between the teacher and students within these episodes.

[3] Chin (2007) describes four holistic questioning-based approaches: Socratic questioning, verbal jigsaw, semantic tapestry, and framing (p. 823). Within each approach are more specific strategies. The strategies referenced here include (a) question-based prelude: posing a question to frame a topic of discussion, (b) pumping: asking students to share more about their ideas, (c) reflective toss: following up a student statement with a reflective question, (d) verbal jigsaw (includes two strategies: verbal cloze and association of key words and phrases): co-constructing statements with students when using new terminology, (e) constructive challenge: questions intended to guide students in addressing misconceptions, and (f) focusing and zooming: guiding students to think at both the smaller, microscopic scale and the larger, macroscopic scale.

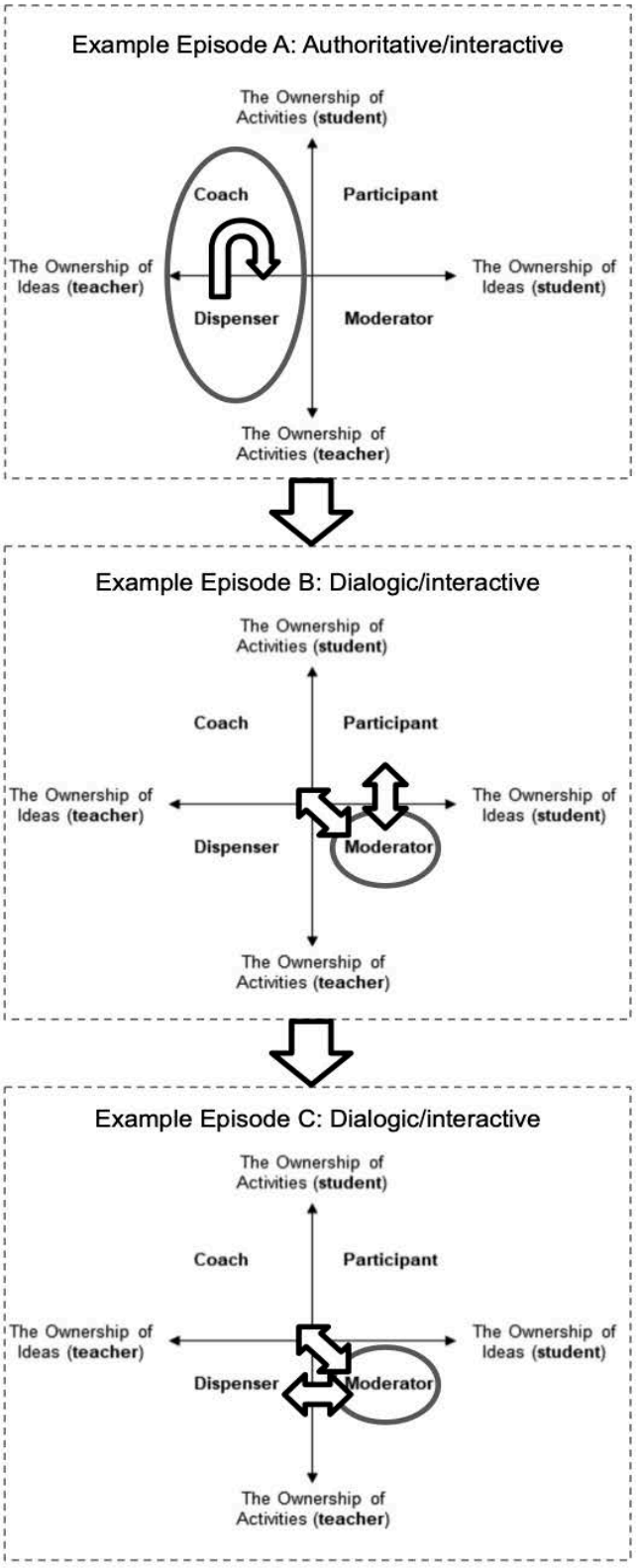


Figure 3. Visualization of types of discourse present in theoretical episodes of whole-class discussion from the perspective of communicative approach (Scott et al., 2006) and teacher roles of questioning (Chen et al., 2017).

Student contributions in argumentative discussion

This study focuses not only on the ways that teachers contribute to whole-class discussion, but also analyzes the arguments created by students. One way to analyze logical components of argumentation could be to use Toulmin's argument pattern, which breaks arguments down into claims, warrants, data, rebuttals, and/or backing (Toulmin, 1958, in Osborne, Erduran, & Simon, 2004). For example, Chin and Osborne (2010) created an analytical framework to assess the quality of oral argumentation between students. However, methodologies that rely on deconstructing arguments into these elements often lack in transparency. As Nielsen (2013) observes, "what tend to remain invisible are the numerous decisions the analysts must make to match specific pieces of data to the Toulminian codes, as well as the negotiations among coders over different possible applications of the model" (Lunsford, 2002, in Nielsen, 2013, p. 384).

As an alternative, this study uses a coding scheme developed by Hähkiöniemi et al. (2022). This coding analyzes if students back up claims using justifying moves, divided into describing support (DS) and articulating reasoning (AR), as shown in Table 2. This analysis does not require identifying specific components of arguments but instead compares arguments with predefined criteria for AR based on the type of reasoning used. Thus, this coding scheme places higher value on arguments where students transparently articulate reasoning. However, it does not attend to dialectical features and thus is not used to assess the dialogicity of argumentation sequences.

Finally, in order to assess if student argumentation qualifies as dialogic argumentation, we examined if students engaged with other students' justifications by using actions like challenging, elaborating, questioning, or any other responses that directly refer to the justifications or evidence presented by other students. As this study focuses more on the actions of the teacher, we did not produce codes to examine the dialogic elements of student argumentation separately, as described by Hähkiöniemi et al., 2022 as "dialogic moves."

Table 2 *Coding of student argumentation using justifying moves (Hähkiöniemi et al., 2022)*

Justifying move	Description
Articulating reasoning (AR)	Student explicitly explains why a claim can be concluded from what is known. In other words, a student explains the line of reasoning leading to a claim, making the reasoning visible.
Describing support (DS)	Student presents facts, calculations, observations, figures, etc. to support the claim without articulating reasoning. The support must be related to the content of the lesson.

Research questions

As demonstrated in our review of literature, previous studies have focused on describing communicative approaches used by teachers (e.g., Scott, Mortimer, & Aguiar, 2006), teacher questioning roles (e.g., Chen et al., 2017), the quality of students' written questions and oral arguments in small groups (Chin & Osborne, 2010), the functions of teacher questions in scaffolding student thinking (Chin, 2007), and different types of student dialogic and justifying moves (Hähkioniemi et al., 2022). This study focuses more specifically on a multi-layered analysis of communicative approaches, teacher questioning roles, and student dialogic argumentation. We aim to characterize different ways of orchestrating discussions and to examine how teacher questioning roles impact students' contributions to discussions. A critical theme in

our analysis borrows from the teacher questioning roles framework (Chen et al., 2017), specifically examining how ownership of ideas and activities can shift from the teacher to students. Accordingly, the guiding research questions for this paper are:

1. How can teacher roles of questioning and communicative approaches be used to characterize different ways of orchestrating argumentative whole-class discussions?

2. How does the use of different teacher questioning roles affect students' contributions to argumentative discussions?

Research Methods

Context

This study is part of a broader research project targeting dialogic argumentation for learning. The project includes a 2-year professional development program focusing on dialogicity and argumentation practices for math and physics teachers in Finnish lower secondary schools (see Lehesvuori et al., 2017). Researchers work alongside teachers to design lessons promoting argumentation. After lessons are implemented, researchers and teachers discuss and reflect on video recordings from the lessons. For this study, two teachers, Maria and Johanna, were selected because both employed a base level of dialogicity. Specifically, observations from lessons with these teachers showed that classroom discussion in their lessons more frequently exhibited a mutual consideration of multiple ideas without direct evaluative feedback. In this way, these two teachers were sometimes "open" to a range of ideas, drawing a contrast to other teachers who participated in the professional development program, who rarely strayed away from a more traditional IRF pattern (Lemke, 1990). Both teachers teach the same age group in the same region, and classes were similar in terms of size and gender ratio (13–15 students, 62–67% boys). Thus, the educational context in each class is comparable.

Data Collection

Participating teachers implemented the lessons, which were video recorded and transcribed. Both students' and teachers' names have been replaced with pseudonyms. For data collection, a researcher positioned at the rear of the room recorded each lesson with a handheld video camera, and teachers wore a lapel microphone. Stationary video cameras with internal microphones were also positioned at student workstations.

The lesson selected for this study lasted for one class period and included an argumentation task using fact cards. Student groups were given a temperature/time graph and discussed if it correctly represented ice being heated and turning into steam. For reference, the fact cards and graphs used in the lesson are included in Appendix A. Students worked in small groups, prepared written arguments, and participated in a teacher-orchestrated whole-class discussion. Only the whole-class discussions are analyzed. In these discussions, teachers were advised to encourage students to share the reasoning that they had included in their written arguments. The argumentation task presented in this lesson (using fact cards to evaluate the accuracy of graphs) is an adaptation of a similar task presented by Chin and Osborne (2010) in their research on the quality of students' written arguments. Whereas Chin and Osborne focus on students' written arguments, the questions that students generate, and the quality of oral arguments in small groups, this study uses a similar task but analyzes the role of the teacher in supporting these discussions in a whole-class setting.

Data Analysis

At first, open notes from videos were made to become familiar with the data. The communicative approaches framework (Mortimer & Scott, 2003) was then used to code whole-class discussion at an episode level. Each video was transcribed with all speakers identified, but to protect the anonymity of participants, pseudonyms have been assigned to them in the transcripts. All coding was done by the primary researcher. The transcript was utilized as the primary data source. Video data were used to gain context of speaking turns. Episodes of whole-class discussion were defined by the topic of discussion, e.g., discussing if Graph 4 is correct. For each episode, the dominant communicative approach was assessed by determining if the talk included multiple speakers (interactivity) and if the teacher was open to and non-evaluative of student ideas (dialogicity).

The teacher roles of questioning framework (Chen et al., 2017) was used to analyze teacher talk. All verbal utterances were included, as even direct statements may elicit a response. An utterance is defined as a "unique idea contributing to the discussion" (Chen et al., 2017, p. 382). Thus, one turn can contain multiple utterances, for example, if there is a clear transition from one idea to a new topic, or a single utterance can span across multiple turns in the case of a speaker completing the thought of another. However, the majority (94%) of speaking turns contained only one utterance, so the term *turn* is substituted for *utterance* to improve the readability of the transcript. Disciplinary measures taken by the teacher and talk unrelated to the scientific discussion were coded as irrelevant, for example, discussing at what time the class ends or correcting a misbehaving student. Each relevant utterance was coded as a subcategory of the framework and subsequently combined into the four teacher roles of questioning.

The teacher roles of questioning framework was adapted to account for moments when teachers intentionally give students space to speak. Although these instances lacked a teacher utterance to code, the teacher's decision not to speak can be more significant than the decision to speak. Deliberate teacher silence implies that students have ownership of both the ideas and the activity. To address this, any time students took a minimum of four speaking turns without teacher input, a new sub-category of the participant role was created, labeled *wait*. Several of these episodes included longer pauses in which students waited for teacher input, but the teacher allowed student discussion to continue without adding their own input.

The final stage of coding assessed student argumentation. All student utterances were considered as a contribution to the whole-class discussion and analyzed to determine if they constructed arguments during these utterances. Any arguments created by students in this lesson were coded, making no distinction between arguments that were presented on their own or those that were produced as a challenge to another student's claim, that is, a counter-argument. All of the arguments presented in the analysis of this study related directly to the science content of the lessons, but this framework could also be used for a variety of other arguments. When students constructed arguments, these instances were analyzed to identify if students offered a justifying move. Justifying moves were coded as AR or DS, using criteria presented in Table 2. In addition, it was examined whether students addressed the justifications presented by their classmates or merely presented their own isolated reasoning with no reference to arguments presented by their peers. In order to aid in this assessment, a visual representation of the whole-class discussion was used, including arrows to signify when a speaking turn responds to or refers back to a previous speaking turn.

In order to portray discourse in greater detail, teacher roles of questioning and student argumentation are superimposed in a graphical representation (see Figure 4 below and Figures 8-11 in the Findings section), similar to Hiltunen et al. (2016) and Lehesvuori et al. (2013). The dominant communicative approach in each episode is noted. Arrows highlight the development of student

argumentation sequences and portray the individual speaking turns as part of a chain of communication (Scott, Mortimer, & Aguiar, 2006). Arrows show when a speaking turn refers to or responds to any previous turn. The arrows point backward to illustrate how discourse unfolds in response to preceding turns. The transcript for these episodes is included in quotations alongside the graphical representation to illustrate the progression of the discussion. Due to space limitations, the transcript is edited for readability. For example, a few sentences have been summarized by phrases written in parentheses, and stutters and most false starts have been edited.

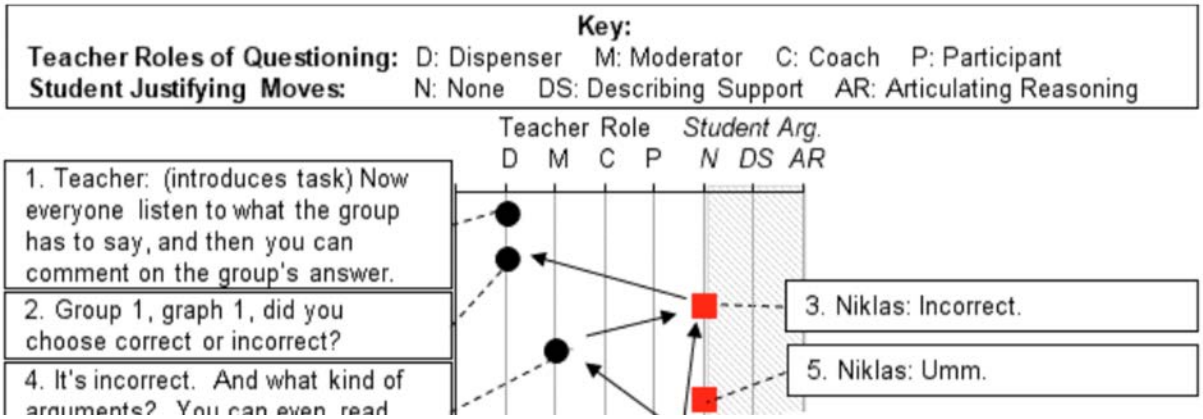


Figure 4. Extract from visual representation used to illustrate teacher roles of questioning and student justifying moves.

Reliability

To assess reliability, a second researcher also coded teacher roles of questioning using a sample consisting of approximately 20% of the data. Inter-rater agreement was measured using Cohen's kappa. Substantial agreement was found for a set of 33 teacher utterances, κ = .684, with 79% agreement, interpreted using criteria discussed by Landis and Koch (1977).

A third researcher also coded student argumentation to assess reliability. Almost perfect agreement (97%) was found for a set of 192 student turns (κ = .882) in determining whether or not a student turn included a justifying move (includes both DS and AR). Designating turns as DS or AR involved deeper interpretations of discourse. Of the 27 turns coded as justifying moves, moderate agreement was found in designating turns as DS or AR (κ = .516), with 82% agreement. After comparison, researchers negotiated all disagreements.

Findings

Overview of the whole-class discussions

The whole-class discussion from Maria's lesson lasted 11 minutes and was divided into five episodes based on topics of discussion. In each episode, Maria asked student groups if their graph was correct, and groups supported their claim. Maria closed the lesson with a summary of the discussion. Johanna's whole-class discussion lasted 25 minutes and consisted of nine episodes. During the first eight episodes, Johanna guided students to focus on supporting arguments from student groups, breaking the discussion into smaller pieces. Johanna also closed the lesson by summarizing the main points.

Figures 5 and 6 show each teacher's use of communicative approaches throughout the entire discussion. In the graphs, the most teacher-centered communicative approach is positioned at the bottom of the vertical axis, and the most student-centered communicative approach is positioned at the top of the

vertical axis. The other two categories of communicative approach are placed in between, but it should be noted that there is no clear basis for the ranking of these other two, that is, the graph is not intended to convey that a dialogic/noninteractive approach should be considered to be "ranked more highly" than authoritative/interactive.

Although both teachers were directed to have the same lesson objectives, Maria used an authoritative communicative approach more often than Johanna did. As shown in Figure 5, dialogicity was present in the middle of the discussion, but Maria opened and closed with sequences of authoritative talk by asking closed questions and reformulating student contributions. As shown in Figure 6, Johanna used a dialogic/interactive communicative approach for the first eight episodes and closed with an authoritative/noninteractive communicative approach. Both teachers used some amount of dialogic/interactive communicative approach to encourage students to share their ideas and engage in critical discussions with other groups. Both teachers also used an authoritative/noninteractive communicative approach to emphasize the scientific perspective when closing the discussion.

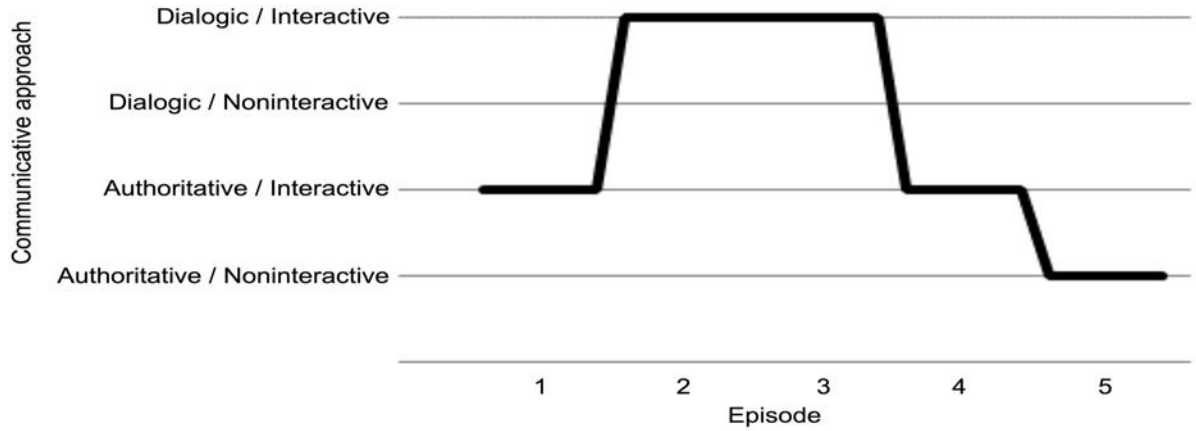


Figure 5. The dominant communicative approach used by Maria during episodes of whole-class discussion. The vertical sorting of communicative approaches is not intended to signify that they are ranked quantitatively and is used only to visualize shifts between communicative approaches.

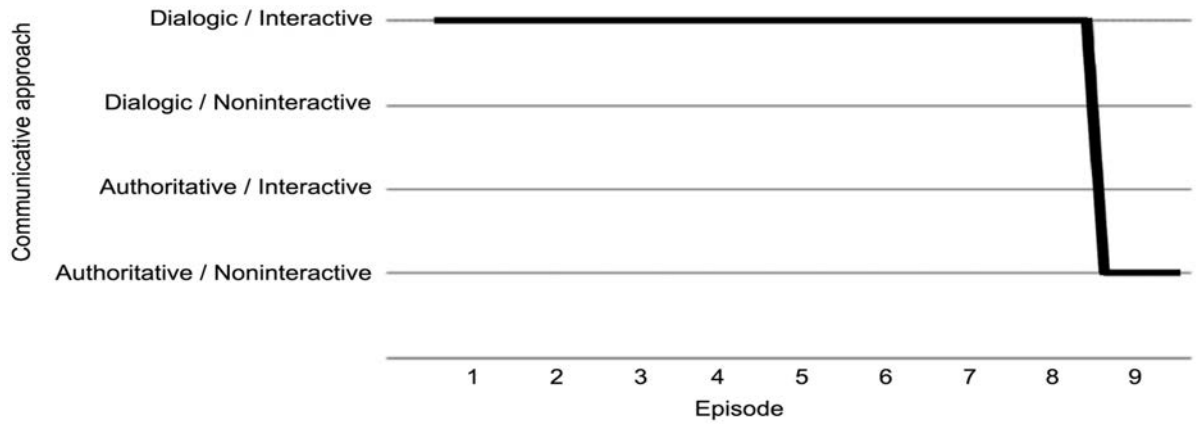


Figure 6. The dominant communicative approach used by Johanna during episodes of whole-class discussion. The vertical sorting of communicative approaches is not intended to signify that they are ranked quantitatively and is used only to visualize shifts between communicative approaches.

Shifting the focus to teacher roles of questioning, all four roles were observed at some point in both lessons. This is represented in Figure 7, which shows the frequency of questioning roles used by each teacher during dialogic or authoritative episodes. The dispenser role dominates authoritative episodes but is rare in dialogic episodes. In dialogic episodes, the moderator role was most common for both teachers, accounting for over half of teacher utterances. The use of the coach and participant roles varied slightly between teachers. In dialogic episodes, Maria used the coach and participant roles sparingly, combining to approximately 15% of teacher utterances (n = 34). In slight contrast, the coach and participant roles accounted for over 30% of teacher utterances (n = 100) in dialogic episodes in Johanna's lesson.

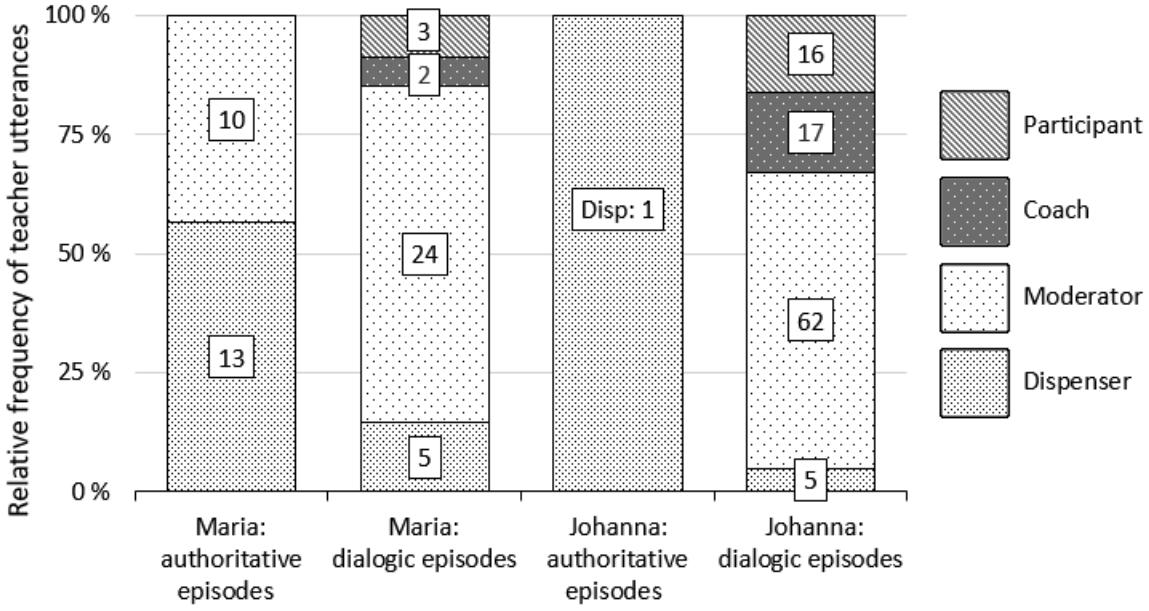


Figure 7. Relative frequency of teacher roles of questioning, grouped by teacher and communicative approach. Data labels indicate the number of utterances within categories.

Figure 7 also shows how the teachers used roles of questioning in conjunction with communicative approaches. In this study, authoritative episodes are characterized by the dispenser role, while dialogic episodes include all roles. This implies that while staying within the bounds of a single communicative approach, a teacher can use a variety of roles of questioning to serve different functions. This is exemplified later in this text in Figure 11, where Johanna utilizes four roles within a dialogic/interactive episode.

From these general observations of the lessons, we can see that a variety of teacher questioning roles can be used within both dialogic and authoritative episodes. Simply describing an episode as authoritative or dialogic does not provide sufficient nuance to describe the types of questioning routines that a teacher may be using. Similarly, depicting the frequency of teacher questioning roles tells very little about how these roles were used and how these may have impacted students' contributions.

Episode-level analysis

For further analysis of discourse, we examined individual episodes of classroom discussion with a greater level of detail, utilizing the teacher roles of questioning framework (Chen et al., 2017), presented in Figure 2 and Table 1, and the coding of student argumentation using justifying moves (Hähkiöniemi et al., 2022), previously presented in Table 2. Overall, this study revealed some instances of students sharing

Articulating Reasoning (AR), but more often, students only provided Describing Support (DS) for claims. The following episodes of discussion in Figures 8–11 are used as examples to examine how teachers used different roles of questioning to support student argumentation and dialogic aspects of argumentation. These episodes were selected to highlight different aspects of how teacher questioning roles could be used in argumentative discussions. In each graph, teacher roles of questioning were plotted along the left, and student argumentation was plotted along the right. Quotations were included for turns contributing to the content-related discussion. For reference, see the fact cards and graphs used in the lesson in Appendix A. In order to focus on the content-related ideas, some speaking turns have been rephrased for brevity, but the content and purpose of the speaking turns remain true to the transcript. Arrows highlighted instances when a turn refers back to or responds to a previous turn. The dominant communicative approach was noted for each episode.

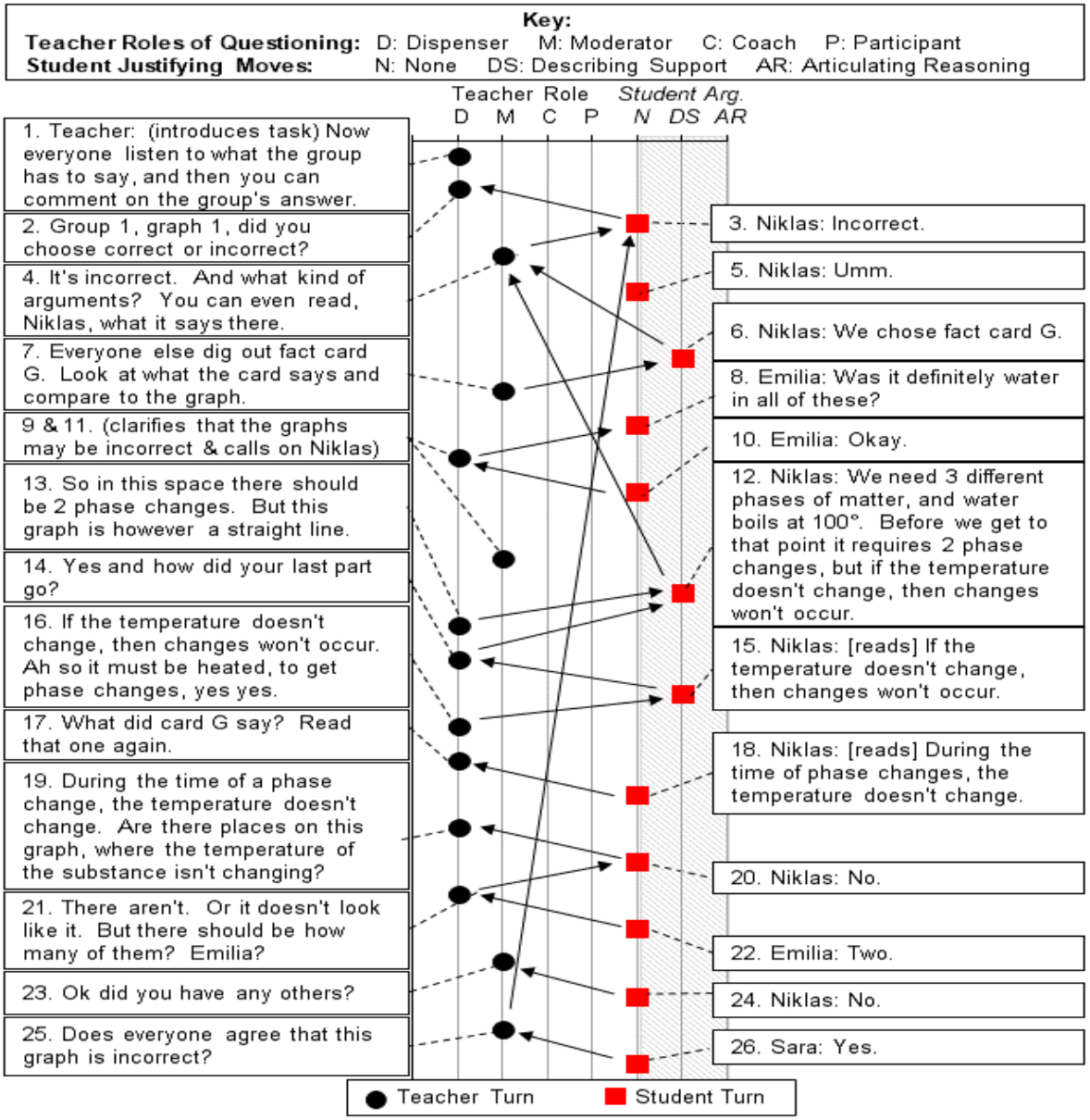


Figure 8. Maria episode 1 demonstrates an authoritative/interactive communicative approach. Arrows indicate instances in which turns refer to or respond to previous turns.

The first episode (Figure 8) from Maria's lesson was coded as authoritative/interactive, exemplified by teacher turns emphasizing the teacher's ideas interspersed with limited student responses. Maria used the moderator role (turn 4) to invite Niklas to verbally present his group's argument (turns 6 and 12). Although she retained control of turn-taking, Maria supported student argumentation at first by showing explicit interest in students' ideas in the moderator role. However, Maria's use of the dispenser role to follow up on Niklas's argument did not support further development of the argument. In turns 13 and 16, Maria substantially reworded and transformed ideas presented by Niklas in turns 12 and 15. In these turns, Maria added new information and presented the argument as her own without approval from Niklas. Specifically, Niklas made no reference to the graph itself and stated that a change in temperature was required for a (phase) change. Maria corrected that statement by restating that heating, or the addition of energy, is required for a phase change to occur. Due to our observation that the teacher was taking ownership of the ideas by focusing specifically on this additional information and controlling the questioning routine, these turns have been coded as dispenser. In turns 19 and 21, Maria used closed questioning to present the relevance of Fact Card G in support of the claim that the graph was incorrect. By the time other students were invited to evaluate the argument (turn 25), the teacher had taken ownership of the claim that the graph was incorrect, shutting down divergent thinking. In this context, turn 25 was just a rhetorical device to close the discussion.

In summary, this episode showed a mostly authoritative/interactive communicative approach with an emphasis on confirming one justification. At the beginning of the episode, we saw an invitation for student ideas as the teacher used the role of moderator, but then upon recognizing the elements of a correct answer, the teacher took ownership of the ideas with the role of dispenser to emphasize this correctness. Although Niklas constructed a well-supported argument, Maria used the dispenser role to focus on clarifying the scientific perspective rather than prompting dialogic argumentation. Instead of immediately bringing this claim forward to the rest of the class for it to be further evaluated, justified, or challenged, the teacher focused on confirming one specific justification. Prompting dialogic argumentation, in this case, would not have been limited only to finding students who disagree with this claim. It could also have included finding students who agreed but found other ways of justifying their claims. In this way, the teacher could have allowed students to directly compare their arguments with Niklas's argument, drawing out argumentation that is more dialogic in nature.

In episode 3 of Maria's discussion (Figure 9), Maria used a dialogic/interactive approach to explore Jenna's group's arguments. Although there is not a high level of student-student dialogic interaction present, the teacher was frequently non-evaluative of Jenna's statements. Therefore, this episode, on the whole, was considered somewhat dialogic and coded accordingly. Following Maria's invitation (turn 71), Jenna shared AR (turns 72–74). These turns were coded as AR because Jenna explicitly stated the reasoning leading from her observations to her claim. In turns 73 and 75, Maria used the coach role to elicit a further element of Jenna's argument. However, Jenna's response did not match Maria's expectations, so Maria used the dispenser role (turns 77 and 81) to make the point. In turns 80 and 82, Jenna was no longer constructing her own argument but instead was filling in the blanks of Maria's questioning routine. In these turns (77 and 81), Maria took control of the ideas, as well as the activity of the questioning routine, matching with the role of dispenser. These turns also illustrate the challenges in coding the teacher roles of questioning. Superficially, it may seem that this exchange would fit the role of moderator (specifically the subcategory of *recognize* - refer to Table 1), as it has the surface-level features of asking for student input. However, upon further consideration, it was our interpretation that Maria was not recognizing a student's idea, but rather Maria was the one who had recognized that there is indeed another fact card that could have been used to support this claim. Upon recognizing this, Maria prompted a student to read this fact card aloud for the class. This case may also reflect that true ownership of the

activity or idea is never solely possessed by one party or another and that the reality of classroom discourse is that there is a degree of shared ownership, reflected by the continuum represented in both Figures 1 and 2.

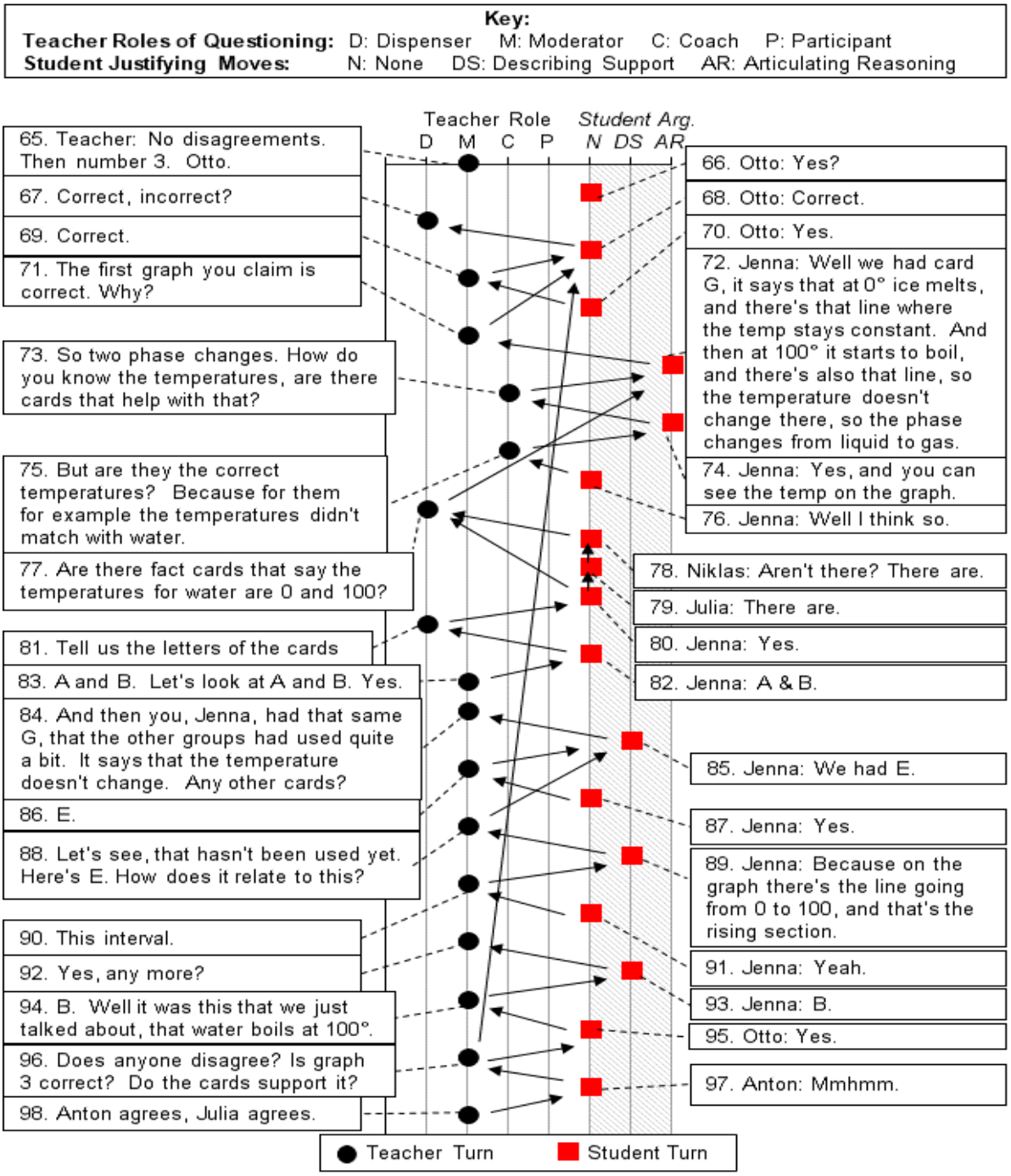


Figure 9. Maria episode 3 demonstrates a dialogic/interactive communicative approach. Arrows indicate instances in which turns refer to or respond to previous turns.

In turn 84, Maria returned to the moderator role, which supported Jenna in sharing more arguments. Maria's question at the end of the episode in turn 96 was again more of a token gesture, as she moved on

after receiving brief confirmation from students without waiting for further input. Similar to the first episode from Maria's lesson (Figure 8), the teacher engaged mainly with one student. Although this episode contained AR, indicating a higher level of argumentation, no other students further elaborated on or challenged Jenna's idea, revealing a low level of dialogicity between students in relation to the justifications or evidence used in Jenna's argument. Thus, this episode showed student argumentation but did not show a good example of dialogic argumentation because it was mostly one student constructing and justifying their claims. This serves to illustrate how student argumentation can occur in the broader context of a dialogic episode, but the argumentation itself may be more monologic rather than dialogic.

In this episode, Maria supported precise arguments using the roles of moderator and coach but shifted to the dispenser role and focused on having only one student participate in the discussion. The episode as a whole was considered dialogic because the teacher was mostly non-evaluative of the students' claims and used probing questioning in the role of moderator and coach to further open up a student's argumentation. This episode showed the teacher pursuing a deeper justification of a claim of an individual. By using a dialogic communicative approach in a purposeful manner, Maria invited student ideas and, more specifically, used the roles of moderator and coach to make these ideas more explicit. The teacher did not immediately confirm these ideas but remained neutral. This helped to elicit reasoning and supported the student in sharing their justifications. In summary, in this episode, we saw the roles of moderator and coach being used to help support one student to further justify their claims and share justifications with the class.

Figure 10 illustrates episode 4 of Johanna's lesson featuring a dialogic/interactive communicative approach. In this specific episode, Johanna avoided the dispenser role altogether and employed the moderator role frequently, directing turns from one student to another. The first instance of argumentation (turns 121–124) was supported by the teacher's open invitation to share (turn 120) and neutral tone when echoing Elias's ideas (turn 123). Leevi then shared a related claim with DS in turns 128, 136, and 138, partly supported by the teacher's use of the coach role. In turn 127, Johanna used the coach role to draw Elias's claim into question, inviting critical evaluation of the claim. This turn was coded as "coach", as the teacher's contribution was used to make Elias's implicit idea more explicit, exemplifying the "elicit" category of the coach role (refer to Table 1). In turn 137, Johanna used the coach role again to challenge Leevi's idea, prompting further DS. In turn 147, Johanna used the moderator role to draw out two contrasting student ideas. In Figure 10 we can visually see how Johanna created links between two students' statements. By juxtaposing opposing claims, Johanna created an opportunity for students to engage directly with each other's arguments, supporting dialogic argumentation through the examination of a counterargument. Throughout the episode, Johanna refrained from taking a stance in relation to any arguments, which may have encouraged more students to participate. Johanna frequently referred back to previous turns, creating an interconnected chain of argumentation and explicitly presenting links between student ideas. Students primarily maintained ownership of the ideas presented in this discussion, but Johanna inserted clarifying questions and corrections alongside the students to further connect their ideas. Johanna's use of the pronoun "we" in turn 127 (Figure 10) may indeed signify co-ownership of the ideas and frames this discussion as a joint venture in argumentation constructed by multiple participants. By combining multiple individual arguments together, Johanna was able to enrich the argumentation of the students by requiring them to further inspect the links between their claims and evidence. Adding this additional purposeful dialogic component onto their argumentation process created a genuine opportunity for students to exercise critical thinking and practice further explicating their arguments.

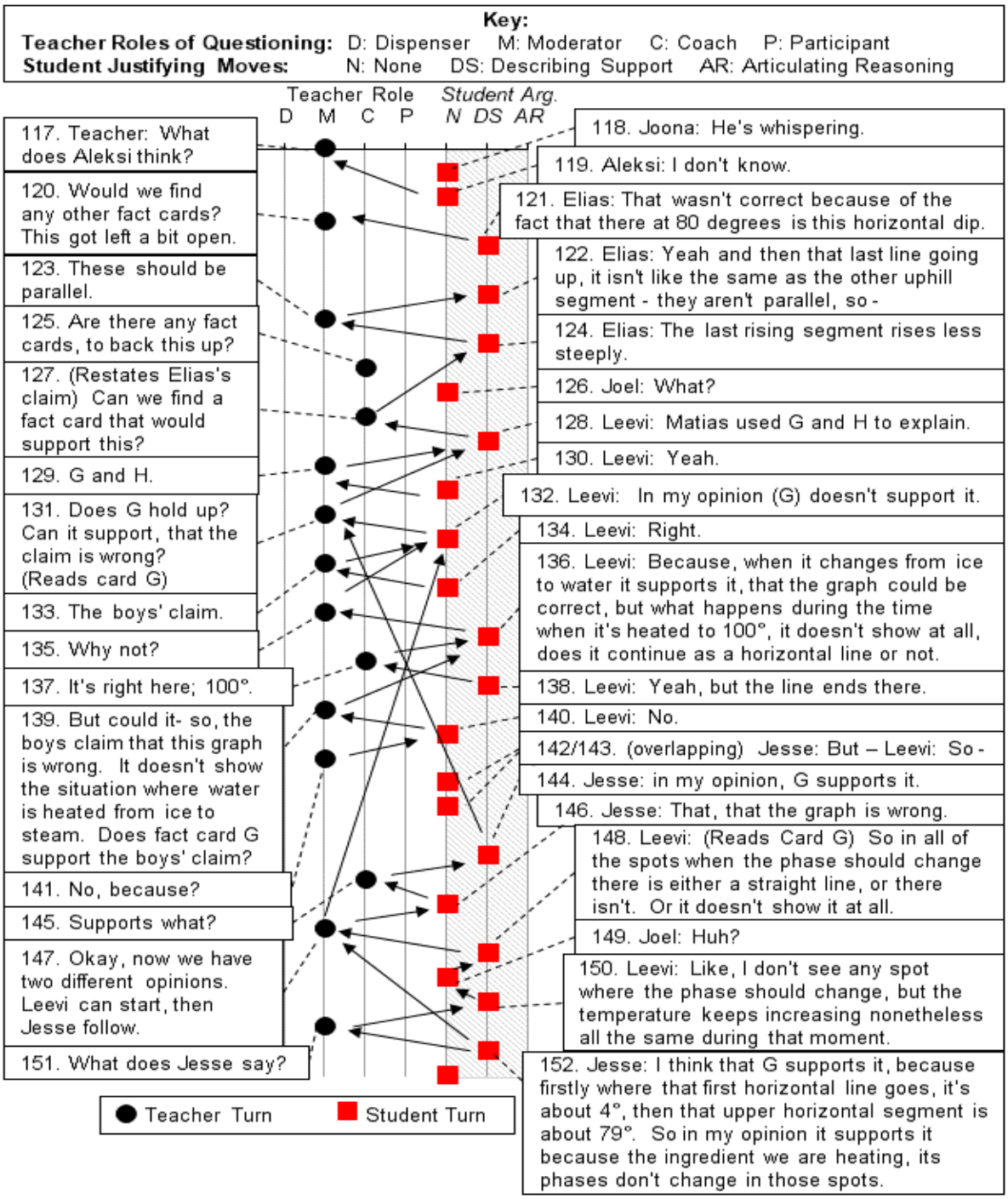


Figure 10. Johanna's episode 4 demonstrates a dialogic/interactive communicative approach. Arrows indicate instances in which turns refer to or respond to previous turns. Note: Turn 153, which features a brief confirmation from Leevi, is omitted to limit the size of the image.

This episode drew some similarities to Maria's episode 3 (Figure 9), in the sense that both teachers used the role of moderator to make student claims more explicit, and both episodes would be considered dialogic/interactive. However, in this episode, the moderator role was used to interanimate multiple student ideas rather than focusing on one justification of the claim. The moderator role was characterized by

teacher control of the activity, and in this case, we saw Johanna acting as an expert moderator by intentionally piecing together multiple contrasting student ideas. This created an opportunity for more dialogue between students and supported multiple students to contribute to dialogic argumentation.

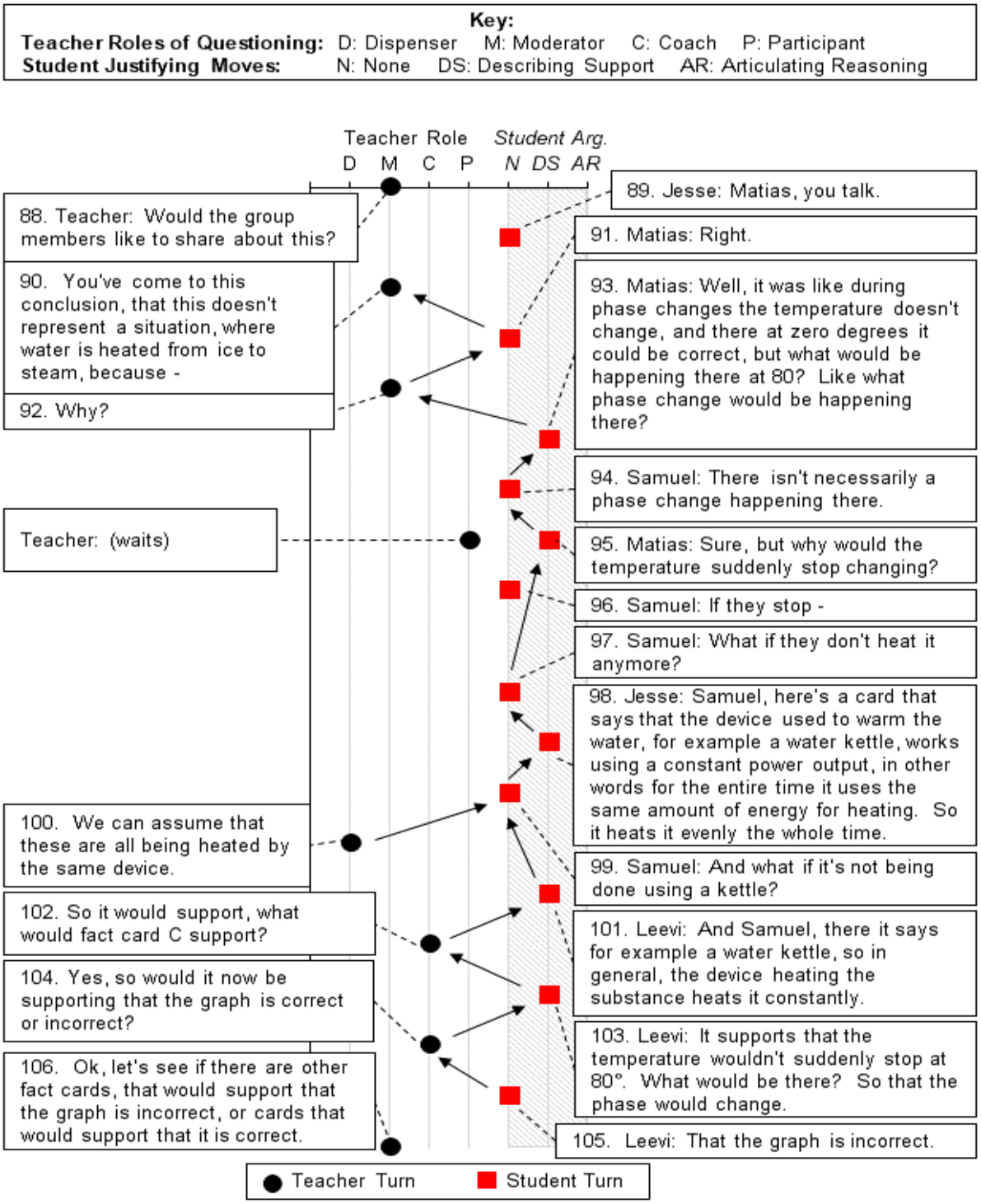


Figure 11. Johanna's episode 3 demonstrates a dialogic/interactive communicative approach. Arrows indicate instances in which turns refer to or respond to previous turns.

Figure 11, showing a portion of episode 3 of Johanna's lesson, depicts how the participant role can support students in engaging with each other's arguments. After Matias presented DS in support of his claim in turn 93, the teacher played the role of a silent participant, allowing students to carry the conversation for six turns. This unrehearsed argumentation included DS and a high level of student-student dialogicity, representing dialogic argumentation. In Figure 11, this unbroken chain of student-student discussion is represented by the arrows, which stay for several turns on the side of the students. Of note, the moderator role seems to have been required to initiate this sequence, but the participant role allowed it to continue. Johanna used the dispenser role (turn 100) to limit the scope of the discussion, but the students quickly regained ownership of the discussion. Johanna then used a 10-second period of wait time before asking a question (turn 102), giving students ample time to respond directly to each other and allowing students to retain ownership of the activity.

Of all of the episodes analyzed in these lessons, this episode (Johanna episode 3) showed perhaps the best example of students directly engaging each other in dialogic argumentation. Many structural elements of arguments were presented, including claims, evidence, and rebuttals. More importantly, students were engaged in critical assessment of the claims and evidence presented by their peers. Students in the class were motivated and willing to critique their classmates in a constructive manner, but the teacher also played a role in supporting this. In this episode, Johanna maintained a dialogic/interactive communicative approach and used the participant role to allow students to carry on the discussion without the need for further evaluation or direction from the teacher. As the teacher remained more of a passive participant in this episode, we can characterize some moments in this episode as examples of dialogue with authenticity, given the lack of explicit direction from the teacher at times. The absence of teacher evaluation or explicit teacher orchestration of this discussion gave ownership of the ideas and activity to the students. The students, in turn, used the opportunity to listen to each other and challenge the arguments presented by their peers.

Discussion

The first research question explores how the teacher roles of questioning and communicative approaches can be used to characterize different ways of orchestrating argumentative whole-class discussions. At the episode level, this analysis revealed some similarities to cycles of opening up and closing down classroom talk, as discussed by Scott and Ametller (2007). This is exemplified by episode-level analysis of Maria's lesson, which showed a period of opening up from authoritative/interactive talk to dialogic/interactive talk, followed by a period of closing down to authoritative/interactive and authoritative/noninteractive talk (see Figure 5). Similarly, Johanna used dialogic/interactive talk for the majority of the lesson and also closed down the lesson with authoritative/noninteractive talk. Transitions between types of communicative approach aligned with changes in teaching purpose (Lehesvuori et al., 2013), as dialogic discussions served argumentation-related objectives while closing explanations clarified content-related objectives.

By analyzing these episodes with multiple lenses, we were able to characterize some episodes as more clearly authoritative, featuring the role of dispenser, in which the teacher maintained ownership over classroom ideas and activities (e.g., Maria Episode 1, Figure 8). Using these frameworks also enabled us to characterize a variety of dialogic episodes. These included Maria Episode 3 (Figure 9), showing a dialogic episode in which the teacher used the moderator and coach roles primarily to pursue one justification in more depth, and Johanna Episode 4 (Figure 10), in which the teacher used the moderator role to bring together multiple opposing viewpoints to support dialogic argumentation. In both of these episodes, we have characterized the teacher using dialogue with a clear and sometimes limited purpose. In contrast, we have characterized Johanna Episode 3 (Figure 11) to represent dialogue with greater

authenticity, as Johanna used the role of participant to remain passive and allow a chain of student-student dialogic argumentation to develop. These different 'flavors' of dialogicity, in turn, supported different kinds of student-student interaction and argumentation. The interaction between the communicative approach and teacher roles of questioning in these episodes is also generalized below in Figures 12-13. These visualizations show the dominant teacher roles of questioning (circled), as well as movement from one role to another, represented by arrows between quadrants.

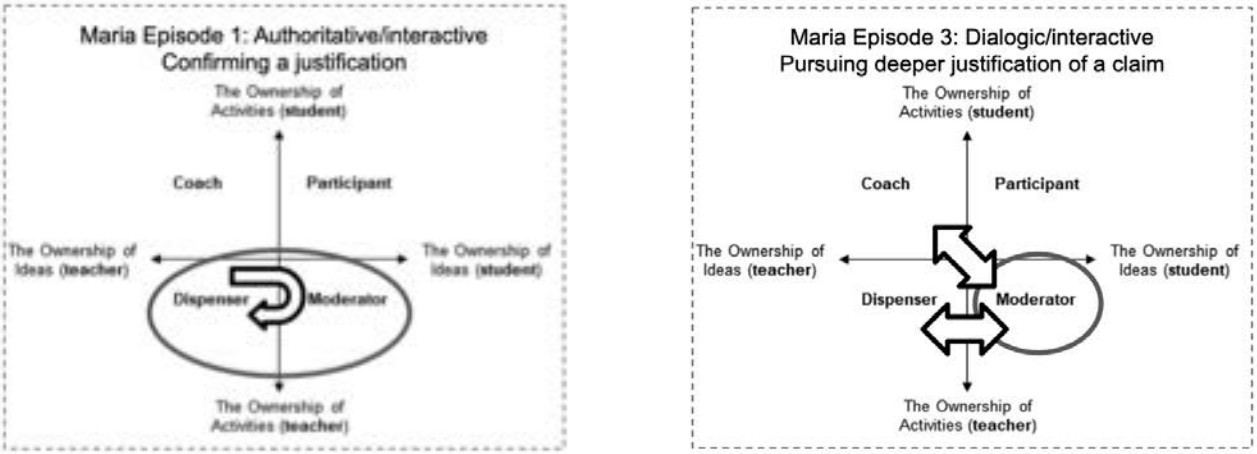


Figure 12. Communicative approach and teacher roles of questioning present in Maria Episodes 1 and 3.

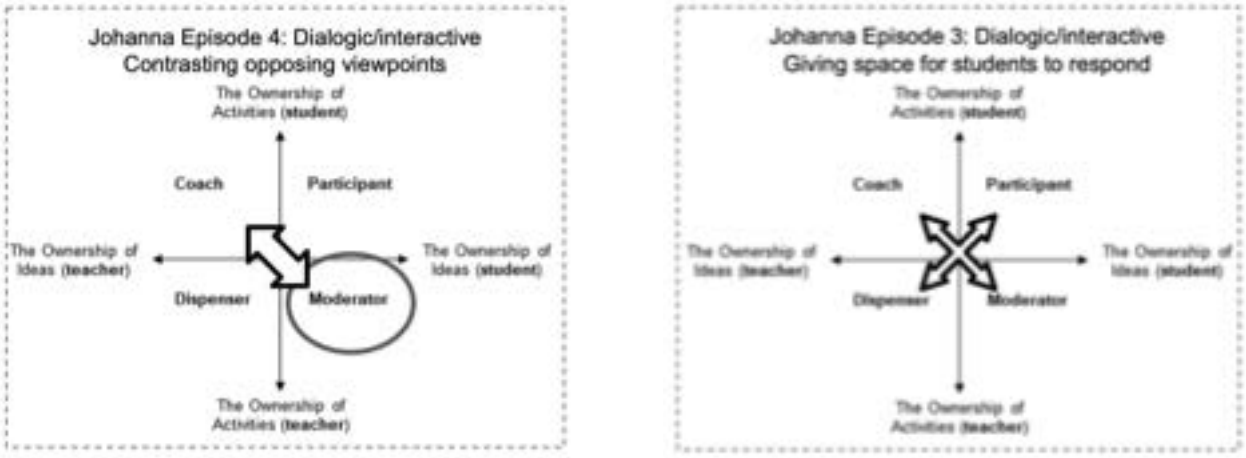


Figure 13. Communicative approach and teacher roles of questioning present in Johanna Episodes 4 and 3.

Analysis using the teacher roles of questioning framework revealed that teachers played multiple roles but used the moderator role most to orchestrate discussions. Teachers may see the moderator role as the safer alternative to the roles of coach or participant, which both entrust students with ownership of the activity. Thus, as also reported by Chen et al. (2017), the roles of coach and participant were less common than moderator. During authoritative episodes, teachers primarily used the dispenser role, but episodes included some dialogic moments supported by the moderator role.

The second research question focuses on how different roles of teacher questioning can affect students' contributions to argumentative discussions. Specifically, our main focus was on dialogic argumentation formulated by students and the questioning roles used by the teacher to support this. This study illustrated how teachers can support argumentation by using roles besides that of the authoritative

voice in the classroom (McNeill & Pimentel, 2010). The most authoritative dispenser role did very little to support students in elaborating on their justifications or engaging with one another's arguments, in fact, it stifled this (e.g., Maria episode 1, Figure 8). The moderator role allowed ideas to be shared and supported a basic level of student argumentation, in which students presented their claims and offered some justification (e.g., Maria episode 3, Figure 9).

In episodes that featured dialogic argumentation with students responding directly to elements of other students' oral arguments, teachers used the moderator role to allow students to make connections between their claims and the ideas of others and supported them in defending their ideas or scrutinizing the claims of others (e.g., turns 148-150 in Johanna episode 4, Figure 10). This created opportunities for dialogic argumentation, as opposed to a single student explaining their justification in isolation. When teachers used the role of coach to bring students' ideas up for scrutiny, students frequently responded by providing more evidence for their claims. Students also may have used the teacher's critique of a classmate's idea as an invitation for further exploration, but our analysis presented here cannot directly support that claim. Although uncommonly used in these episodes, the role of participant allowed students to engage freely with each other's ideas (Johanna, episode 3, Figure 11). As discussed by Davies et al. (2017), students have low motivation to share ideas if the teacher exercises power as the subject authority. In a study of the quality of students' oral arguments in small groups (Chin and Osborne, 2010), there were some moments when teachers intervened in students' small-group discussions, resulting in an oppressive effect on the quality of arguments created by students, as the students began simply responding to teacher questions and no longer carrying on their own discussion. Thus, students may lack some motivation to critically evaluate or respond to each other's arguments if the teacher controls the activity. By giving students ownership of the ideas and the classroom activity in the participant role, the onus is put on them to carry the discussion rather than simply filling gaps in a teacher's rhetorical sequence. Although we have very limited examples of the use of the participant role in this study, we observed it being used to allow dialogic argumentation to continue once a strand of discussion has already begun. However, this demands that students readily engage in discussion, requiring a classroom culture in which student-student interactions are encouraged (McNeill & Pimentel, 2010).

In summary, within authoritative episodes, the dispenser role was used to clarify and communicate the scientific perspective. The moderator role was also present in authoritative episodes but used in a limited amount and followed up by the dispenser role. This was interpreted to hinder dialogic argumentation. In dialogic episodes, the other three teacher questioning roles were used more frequently to encourage students to elaborate, compare, and continue challenging each other's ideas, which supported dialogic argumentation. However, due to a limited data set, generalizations should not extend beyond describing discourse in the episodes analyzed in this study. Specifically, the minimal occurrence of the role of participant leads to further questions of how teachers might use this questioning role in other settings other than whole-class discussions.

Analysis of discourse in this study also supplies insight into teachers' values, which in turn, affected student argumentation and dialogicity. Maria used questioning roles that frequently rephrased student contributions to create precise explanations, reflecting values of correctness. Johanna used questioning roles that allowed for the tension of uncertainty to build, placing value on student contributions and critical thinking. Due to her use of the dispenser role, students in Maria's class may have viewed the goal of discussing to be getting the right answer, as noted by McNeill and Pimentel (2010). Maria's rigid questioning routines placed high value on correctness, while Johanna's balance between dialogue with authenticity and dialogue with purpose placed value on sharing reasoning. Student argumentation reflected this foundational difference in values, as argumentation strands from Maria's lesson involved only a single

student sharing a refined argument, while Johanna's lesson included up to four students engaged in dialogic argumentation.

Our multi-layered analysis enabled broad interpretations of the whole-class discussion as a whole while also revealing the effects of individual speaking turns. Firstly, we characterized the overall communicative approach of episodes within the discussion. This allowed us to see the flow of the discussion as a whole and highlighted the overall differences between the two teachers. Using the teacher roles of questioning framework revealed that even within episodes that had the same communicative approach, the ownership of ideas and the activity traded between the students and teacher to varying degrees. This allowed us to further characterize episodes on the basis of questioning roles. For example, both Maria Episode 3 and Johanna Episode 3 were categorized as dialogic/interactive, but Maria predominantly used dialogue with more of a clear purpose (Alexander, 2006), shifting mostly between moderator and dispenser, while students in Johanna's class were afforded a greater opportunity to follow up on each other's claims. Specifically, Johanna's use of the role of participant may serve as a useful indicator to characterize moments of dialogue with more authenticity and equal consideration of ideas (Bakhtin, 1986). Analyzing the justifying moves that students used in their arguments further revealed that individual turns by the teacher sometimes further supported individual students in explicitly sharing the reasoning leading to a justification. Lastly, considering student justifications in the context of other student turns showed how teacher roles of questioning could support students in challenging or elaborating on justifications that had already been shared, revealing some instances of dialogic argumentation.

A major limitation of this study is a small set of data, limited to only 2 whole-class discussions from 2 teachers. The teacher roles of questioning framework could specifically be utilized further with a greater variety of lessons, including lessons where the teacher works alongside students in practical learning tasks or student investigations rather than analyzing whole-class discussions only. In our data set, the teachers frequently maintained ownership of the activity in whole-class discussions, and the roles of coach and participant were quite rare. However, it seems likely that teachers would use the roles of coach and participant more frequently when supporting students in individual tasks or group work when students inherently possess more ownership of the activity. These more informal exchanges could provide opportunities to analyze further how ownership of the activity is negotiated between students and teachers, and its effect on dialogic argumentation.

References

Alexander, R. (2006). *Towards dialogic teaching* (3rd ed.). York: Dialogos.

Asterhan, C. S. C., & Schwarz, B. B. (2016). Argumentation for learning: Well-trodden paths and unexplored territories. *Educational Psychologist 51*(2), 164–187. https://doi.org/10.1080/00461520.2016.1155458

Bakhtin, M. (1986). *Speech genres and other late essays*. Austin: University of Texas Press.

Barreto, L.P., Rodrigues, A.A.D., de Oliveira, G.C. et al. (2021). The Use of Different Translation Devices to Analyze Knowledge-Building in a University Chemistry Classroom. *Research in Science Education, 51*, 135–152. https://doi.org/10.1007/s11165-020-09969-z

Berland, L., & McNeill, K. (2010). A learning progression for scientific argumentation: Understanding student work and designing supportive instructional contexts. *Science Education, 94*(5), 765–793. https://doi.org/10.1002/sce.20402

Chen, Y., Hand, B., & Norton-Meier, L. (2017). Teacher roles of questioning in early elementary science classrooms: A framework promoting student cognitive complexities in argumentation. *Research in Science Education, 47*(2), 373–405. https://doi.org/10.1007/s11165-015-9506-6

Chen, Y., Hand, B., & Park, S. (2016). Examining Elementary Students' Development of Oral and Written Argumentation Practices Through Argument-Based Inquiry. *Science & Education, 25*(3), 277–320. https://doi.org/10.1007/s11191-016-9811-0

Chen, Y., & Steenhoek, J. (2014). Arguing like a scientist: Engaging students in core scientific practices. *The American Biology Teacher, 76*(4), 231–237. https://doi.org/10.1525/abt.2014.76.4.3

Chin, C. (2007). Teacher questioning in science classrooms: Approaches that stimulate productive thinking. *Journal of Research in Science Teaching, 44*(6), 815–843. https://doi.org/10.1002/tea.20171

Chin, C., & Osborne, J. (2008). Students' questions: a potential resource for teaching and learning science. *Studies in Science Education, 44*(1), 1-39. https://doi.org/10.1080/03057260701828101

Chin, C., & Osborne, J. (2010). Students' questions and discursive interaction: Their impact on argumentation during collaborative group discussions in science. *Journal of Research in Science Teaching, 47*(7), 883-908. https://doi.org/10.1002/tea.20385

Davies M., Kiemer, K., & Meissel K. (2017). Quality talk and dialogic teaching—An examination of a professional development programme on secondary teachers' facilitation of student talk. *British Educational Research Journal, 43*(5), 968–987. https://doi.org/10.1002/berj.3293

Donnelly, D., McGarr, O., & O'Reilly, J. (2014). 'Just be quiet and listen to exactly what he's saying': Conceptualising power relations in inquiry oriented classrooms. *International Journal of Science Education, 36*(12), 2029–2054. https://doi.org/10.1080/09500693.2014.889867

Finnish National Agency for Education. (2016). *National core curriculum for basic education 2014.* Helsinki: Finnish National Board of Education.

Ford, M., & Forman, E. (2015). Uncertainty and scientific progress in classroom dialogue. In L. B. Resnick, C. S. C. Asterhan, & S. N. Clarke (Eds.), *Socializing intelligence through academic talk and dialogue* (pp. 143–155). Washington, DC: American Educational Research Association.

Hähkiöniemi, M., Hiltunen., J, Jokiranta, K., Kilpelä, J., Lehesvuori, S., & Nieminen, P. (2022). Students' dialogic and justifying moves during dialogic argumentation in mathematics and physics. *Learning, Culture and Social Interaction, 33.* https://doi.org/10.1016/j.lcsi.2022.100608

Hiltunen, M., Kärkkäinen, S., Keinonen, T., Hähkiöniemi M., Lehesvuori, S., & Tikkanen, P. (2016). Primary school student teachers' classroom talk during inquiry-based biology lessons. *Problems of Education in the 21st Century, 69,* 37–54. https://erepo.uef.fi/handle/123456789/128

Kennedy, M. M. (2005). *Inside teaching: How classroom life undermines reform*. Cambridge, MA: Harvard University Press.

Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics, 33*(1), 159–174. https://doi.org/10.2307/2529310

Lehesvuori, S., Hähkiöniemi, M., Jokiranta, K., Nieminen, P., Hiltunen, J., & Viiri, J. (2017). Enhancing dialogic argumentation in mathematics and science. *Studia Paedagogica, 22*(4), 55–76. https://doi.org/10.5817/SP2017-4-4

Lehesvuori, S., Ramnarain, U., & Viiri, J. (2018). Challenging transmission modes of teaching in science classrooms: Enhancing learner-centredness through dialogicity. *Research in Science Education, 48*(5), 1049–1069. https://doi.org/10.1007/s11165-016-9598-7

Lehesvuori, S., Viiri, J., Rasku-Puttonen, H., Moate, J., & Helaakoski, J. (2013). Visualizing communication structures in science classrooms: Tracing cumulativity in teacher-led whole class discussions. *Journal of Research in Science Teaching, 50*(8), 912–939. https://doi.org/10.1002/tea.21100

Lemke, J. L. (1990). *Talking science: Language, learning and values*. Norwood: Ablex Publishing Company.

Matusov, E. (2009). *Journey into Dialogic Pedagogy*. Hauppauge, NY: Nova Publishers. 147-206.

Matusov, E., & von Duyke, K. (2010). Bakhtin's notion of the internally persuasive discourse in education: Internal to what?: A case of discussion of issues of foul language in teacher education. In K. Junefelt & P. Nordin (Eds.), *Proceedings of the Second International Interdisciplinary Conference on Perspectives and Limits of Dialogism in Mikhail Bakhtin* (pp. 174-199). Stockholm, Sweden: Stockholm University

McNeill, K. L., & Pimentel, D. S. (2010). Scientific discourse in three urban classrooms: The role of the teacher in engaging high school students in argumentation. *Science Education, 94*(2), 203–229. https://doi.org/10.1002/sce.20364

Mercer, N. (2008). The seeds of time: Why classroom dialogue needs a temporal analysis. *The Journal of the Learning Sciences, 17*(1), 33–59. https://doi.org/10.1080/10508400701793182

Mercer, N. (2009). Developing argumentation: Lessons learned in the primary school. In N. Muller Mirza & A. Perret-Clermont (Eds.), *Argumentation and education: Theoretical foundations and practices* (pp. 177–194). Berlin: Springer.

Mercer, N., Dawes, L., & Staarman, K. (2009). Dialogic teaching in the primary science classroom. *Language and Education, 23*(4), 353-369. https://doi.org/10.1080/09500780902954273

Mortimer, E., & Scott, P. (2003). *Meaning making in secondary science classrooms.* Philadelphia: Open University Press.

Nielsen, J. (2013). Dialectical features of students' argumentation: A critical review of argumentation studies in science education. *Research in Science Education, 43*(1), 371–393. https://doi.org/10.1007/s11165-011-9266-x

NGSS Lead States. (2013). *Next generation science standards: For states, by states.* Washington, DC: The National Academies Press.

Nurkka, N., Mäkynen, A., Viiri, J., Savinainen, A., & Nieminen, P. (2012). Classroom discourse types and students' learning of an interaction diagram and Newton's third law. In C. Bruguière, A. Tiberghien, & P. Clément (Eds.), *E-Book proceedings of the ESERA 2011 conference: Science learning and citizenship.* Part six (Coeds. Manuela Wenzel-Breuer and Conxita Marquez), (pp. 58–64). Lyon, France: European Science Education Research Association.

Osborne, J. (2010). Arguing to learn in science: The role of collaborative, critical discourse. *Science, 328*(5977), 463–466. https://doi.org/10.1126/science.1183944

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/10.1002/tea.20035

Scott, P. (1998). Teacher talk and meaning making in science classrooms: a Vygotskian analysis and review. *Studies in Science Education, 32*(1), 45-80. https://doi.org/10.1080/03057269808560127

Scott, P., & Ametller, J. (2007). Teaching science in a meaningful way: Striking a balance between 'opening up' and 'closing down' classroom talk. *School Science Review, 88*(324), 77–83.

Scott, P. H., Mortimer, E. F., & Aguiar, O. G. (2006). The tension between authoritative and dialogic discourse: A fundamental characteristic of meaning making interactions in high school science lessons. *Science Education, 90*(4), 605–631. https://doi.org/10.1002/sce.20131

Simon, S., Erduran, S., & Osborne, J. (2006). Learning to Teach Argumentation: Research and development in the science classroom. *International Journal of Science Education, 28*(2–3), 235–260. https://doi.org/10.1080/09500690500336957

Sinclair, J., & Coulthard, R. M. (1975) *Towards an analysis of discourse*. Oxford: Oxford University Press.

Soysal, Y. (2018). Determining the mechanics of classroom discourse in Vygotskian sense: Teacher discursive moves reconsidered. *Research in Science Education*. https://doi.org/10.1007/s11165-018-9747-2

Toulmin, S. (1958). *The uses of argument.* Cambridge, UK: Cambridge University Press.

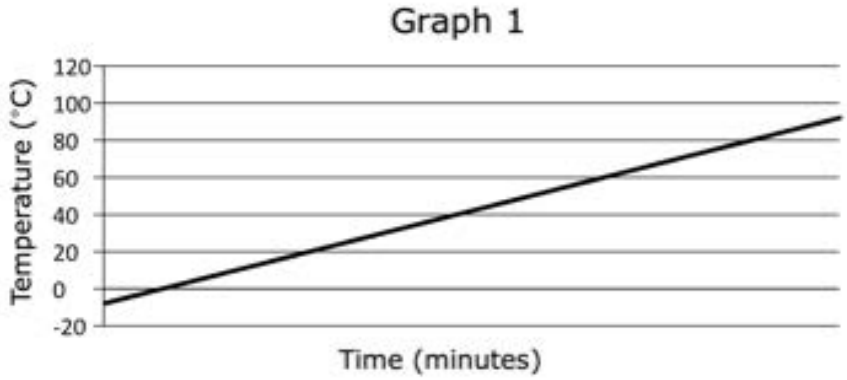
Vrikki, M., Wheatley, L., Howe, C., Hennessy, S., & Mercer, N. (2019). Dialogic practices in primary school classrooms. *Language and Education, 33*(1), 85–100. https://doi.org/10.1080/09500782.2018.1509988

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes.* Cambridge, MA: Harvard University Press.

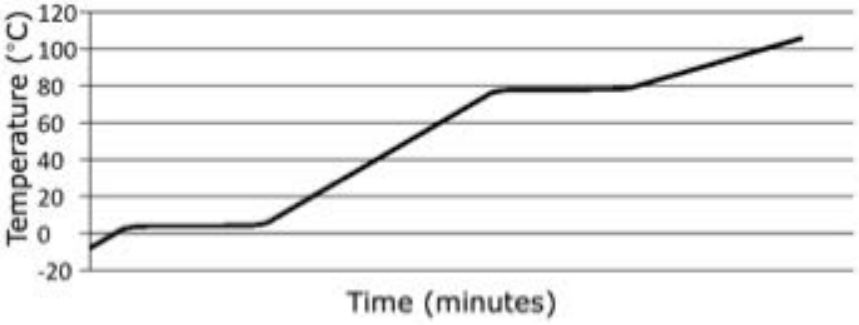
Watson, J. R., Swain, J. R. L., & McRobbie, C. (2004). Research Report: Students' discussions in practical scientific inquiries. *International Journal of Science Education, 26*(1), 25–45. https://doi.org/10.1080/0950069032000072764

Appendix A. Graphs and fact cards used in the lesson activity

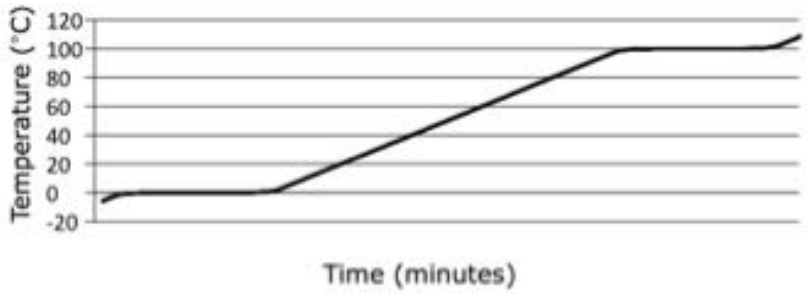
Graphs analyzed by students:



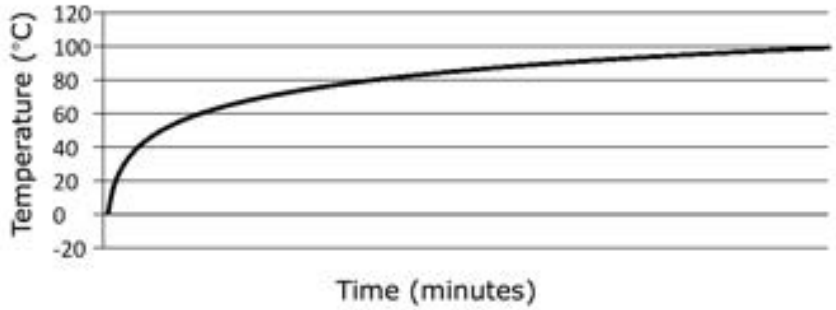
Graph 2



Graph 3



Graph 4



Statements written on fact cards:

- Fact Card A: At a temperature of 0 °C, the solid structure of ice breaks down and ice melts into water.
- Fact Card B: At a temperature of 100 °C, the bonds between water molecules are broken, and water boils into steam.
- Fact Card C: The device used to warm water, for example, a water kettle, works using a constant power output, in other words, for the entire time, it uses the same amount of energy for heating.

- Fact Card D: Energy is required in order to break the bonds between molecules.
- Fact Card E: If there is a rising section on a graph, the temperature of the substance increases.
- Fact Card F: If there is a horizontal section on a graph, the temperature of the substance does not change.
- Fact Card G: During the time of a phase change, the temperature does not change.
- Fact Card H: When the bonds between molecules are formed or broken, the thermal energy is not left over to change the temperature.
- Fact Card I: During the time of a phase change, the bonds between molecules are broken or are formed.
- Fact Card J: When a substance is heated, its molecules begin to move faster.
- Fact Card J*: The density of water is greatest when water is at a temperature of 4°C.
- Fact Card K: The boiling point of water is 78 °C.

*The lesson materials supplied to teachers accidentally included two fact cards labeled "J."