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Students' dialogic and justifying moves during dialogic argumentation in mathematics and physics

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ABSTRACT

In this study, we focus on dialogic argumentation among students in a whole class setting in mathematics and physics in lower secondary school. By drawing on previous studies on the structure of argumentation and dialogic interactions, we suggest that transparency of student reasoning and students' engagement with each other's ideas are two key aspects in dialogic argumentation. We examine what levels might exist in these key aspects and how they can exist simultaneously. We collected data by video recording mathematics and physics lessons in lower secondary school, and created a coding scheme for students' dialogic and justifying moves. By using the coding scheme, we recognized different kinds of argumentation with respect to how dialogic student–student interaction is and how transparently student reasoning is expressed. Furthermore, we found different ways how students can provide justifications as a dialogic re-action to others' ideas.

1. Introduction

Argumentation is one of the most important skills valued by educators of different subjects worldwide as a means and goal of learning (e.g., Asterhan and Schwarz, 2016). Dialogic interactions in which diverse ideas are considered in connection to each other (e.g., Mercer, 1996; O'Connor and Michaels, 2007; Wells, 2007) are also emphasised, and studies have provided evidence for the benefits of such interactions (e.g., Mercer and Howe, 2012). Argumentation and dialogic interactions have common aspects, yet they are not the same thing. Argumentation does not necessarily happen in direct interaction with other people and even when it does, the interaction does not necessarily contain dialogic interanimation of ideas. Similarly, not all dialogic interactions are argumentation as, for example, different viewpoints may be compared without justifying them. Yet, argumentation studies in the context of classroom interactions often consider dialogic aspects such as a student challenging another student's idea (e.g., Asterhan and Schwarz, 2016; Erduran et al., 2004; Osborne et al., 2004). In a similar manner, studies focusing on dialogic interactions often pay attention to students giving reasons for their opinions (e.g., Hennessy et al., 2016; Mercer, 1996), thus dealing with argumentation.

In mathematics and science education, argumentation is considered as one of the key processes of the subjects. Mathematics and science education research often focus on the structure of the argument by examining the components of an argument and how the teacher facilitates argumentation (e.g., Conner et al., 2014). However, considering dialogic interactions among students can provide

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new insights into argumentation. Even in the whole class setting, focus on student–student dialogic interactions may contribute to understanding different kinds of argumentation.

In this study, we draw on the literature on argumentation structure and on dialogic interactions to conceptualise dialogic argumentation. Using the ideas from both of the research strands, we seek to understand and characterize ways in which dialogic argumentation among students may play out in whole class discussion in mathematics and physics.

2. Theoretical background for dialogic argumentation

2.1. Argumentation structures

Several mathematics and science education researchers have based their analysis methods of whole class argumentation on the Toulmin model (1958). According to the Toulmin model, arguments consist of claims (conclusion), data (supporting evidence), warrants (connects the data to the claim), backing (justifies warrant), rebuttals (circumstances under which the claim or warrant would not hold), and qualifiers (degree of certainty). Particularly in mathematics education research, the Toulmin model is used to study collective argumentation in which students and the teacher justify mathematical claims together. For example, Conner et al. (2014) expanded the Toulmin model to construct diagrams of whole class collective argumentation in mathematics. The diagrams show the interpreted elements of the Toulmin model and indicate whether an element was explicit or implicit and whether students or the teacher articulated the element. The study by Conner et al. (2014) shows how the whole class collectively built an argument as orchestrated by the teacher. It seems that in this kind of collective argumentation, the teacher has an important role, particularly in posing questions and connecting students' ideas as a coherent argument. Similarly, Ayalon and Even (2016), although not using the Toulmin model, constructed argumentation diagrams in which they indicated whether students or the teacher produced the elements. These studies draw our attention to the importance of considering who produces which elements during the whole class argumentation. If the teacher is the only one who produces warrants, students have limited access to argumentation.

In science education research, Erduran et al. (2004) and Osborne et al. (2004) developed an analysis method based on the Toulmin model. They focussed on instances in which students opposed each other and considered the quality of rebuttals. They argued that the existence and quality of rebuttals are signs of the quality of argumentation. According to them, the lowest level of argumentation consists of simple disagreement. In the second level, at least one of the opposing claims is supported. In the third level, occasional weak rebuttal occurs. Level 4 argument contains a clearly identifiable rebuttal, and Level 5 argument contains several rebuttals. This framework emphasises the importance of opposing and responding to opposing arguments. In addition, it also focuses on justification as the higher-level argumentation contains supported opposition. This framework moves away from interpreting all the components of the argument by characterising the whole argumentation episode.

Studies have also characterised different kinds of argumentation with respect to considering opposing views and justification without the Toulmin model. In their literature review, Asterhan and Schwarz (2016) characterised three kinds of argumentation: disputative argumentation, consensual co-construction, and deliberative argumentation that echo Mercer's (1996) three more general talk types (see the next section). In terms of the consideration of opposing views, disputative argumentation includes efforts to persuade others in a competitive manner, consensual co-construction does not contain opposing views, and deliberative argumentation includes constructive exploration of opposing views. With regards to justification, disputative argumentation focuses on rhetoric instead of justifying, consensual co-construction develops a justification for one view, and deliberative argumentation considers justifications for several views. Asterhan and Schwarz (2016) argued for the benefits of the deliberative argumentation over the two other types. However, they also stated that research has shown consensual co-construction predicting learning gains.

2.2. Dialogic interactions

Often all communication between two or more participants is considered as dialogue. However, the attribute "dialogic" in expressions such as dialogic interactions and dialogic teaching signifies a particular kind of communication in which diverse ideas are welcomed, ideas are juxtaposed, and participants build on each other (e.g., Mercer, 1996; O'Connor and Michaels, 2007; Wells, 2007). Thus, not all dialogue is dialogic in this sense. In the following we unpack dialogic interactions in different contexts.

In a whole class setting, dialogic interactions are often considered by focusing on the teacher–students interaction. In science education, Mortimer and Scott (2003) differentiate between the authoritative and dialogic communicative approach. In the authoritative approach, the teacher focuses only on the scientific perspective, whereas in the dialogic approach, the teacher is open to various perspectives. Researchers using Mortimer and Scott's (2003) ideas have elaborated how teachers can use different communicative approaches for various purposes and promote cumulativity in the flow of ideas (e.g., Bossér and Lindahl, 2021; Lehesvuori et al., 2019).

Studies of peer discussion have focused on student–student dialogic interactions. Mercer (1996) characterised three kinds of peer discussion: disputational talk, cumulative talk, and exploratory talk. Characteristic features of disputational talk are disagreement and individual decision making. In cumulative talk, students build positively but uncritically on each other. In exploratory talk, students engage critically but constructively with each other's ideas and reasoning is visible in the talk. Thus, in exploratory talk, interaction is dialogic as students engage with each other's ideas. In addition, exploratory talk contains argumentation as it focuses on reasoning and justifying. The idea of making reasoning visible in the talk can be compared to argumentation structures in which data and warrants are explicitly stated. Furthermore, Mercer's three types of talk seem to correspond to disputative argumentation, consensual co-construction, and deliberative argumentation (Asterhan and Schwarz, 2016) as both frameworks describe how opposing views, if existing, are considered.

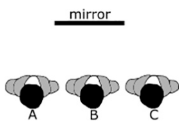
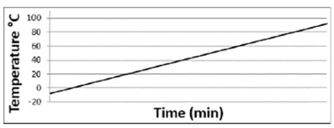
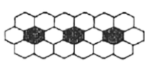
In the whole class discussion, the teacher usually orchestrates the discussion. A necessary condition for dialogic interactions among students is that the teacher is open to various ideas. In addition to cumulatively collecting students' ideas, the ideas can be discussed as in exploratory talk. Scott et al. (2006) differentiate between students only presenting various ideas and students exploring and working on different ideas. In the latter case the interanimation of students' ideas is higher (Scott et al., 2006) and thus can be considered more dialogic. Similarly, Webb et al. (2014) consider two aspects of productive dialogue: students voicing their own ideas and engaging with other students' ideas. According to Webb et al., engagement may be high (adding details to a peer's idea), medium (referencing details of a peer's idea), or low (acknowledging a peer's idea). They also presented evidence that students' engagement with other students' ideas was related to student achievement. In summary, dialogic interactions among students in whole class discussion involves students not only presenting ideas but also engaging with others' ideas.

Previous studies suggest that students' dialogic engagement with each other's ideas may be captured by identifying specific student moves. The SEDA coding scheme developed by Hennessy et al. (2016) includes several categories of communicative acts that indicate dialogic interactions in the above referred sense. These communicative acts (e.g., build on/clarify others' contribution, challenge viewpoint, and invite elaboration or reasoning), when done by a student as a reaction to peers' ideas, suggest that the student engages with other students' ideas. Howe et al. (2019) used a modified SEDA for teacher and student moves and additionally coded the whole lesson holistically for levels of student participation (opportunities to express ideas and engage with the ideas of others). When students participated extensively, Howe et al. found that particularly elaboration and querying (doubting and challenging) were statistically significantly positively associated with mathematics test scores but not with science test scores. Thus, at least for mathematics, their results support the importance of dialogic interactions among the students.

2.3. Summarising two key aspects for dialogic argumentation

Based on literature on argumentation structure and dialogic interactions, two key aspects seem to be important when considering dialogic argumentation in a whole class setting. First, it is important to consider the extent to which student reasoning is made transparent within justification. Studies focusing on argumentation structure have accounted for this by examining whether students produce data and warrant for claims, and studies of dialogic interactions have examined whether reasoning is made visible in talk.

Table 1
Sample argumentation lessons.

Topic	Task	Lesson structure
Divisibility	Is the statement true or false? E.g., the sum of two odd numbers is even.	Group work – Whole class discussion
Fractions	Which of the two fractions is the largest? E.g., 11/24 or 7/16.	Individual thinking and voting – Group work – Whole class discussion (repeated 5 times)
Reflection of the light	Select an option that is true. a) A sees only himself. b) Only B sees all the people. c) A and C see only each other. d) B is the only one who sees himself.  	Group work – Whole class discussion
Geometric construction	Construct geometrically a quadrangle with four equal sides. Prepare to explain why the construction is valid.	Group work – Commenting posters – Whole class discussion
Change of state	Use the given fact cards to argue whether the graph describes the heating of water from ice to steam. E.g., Fact card F: If on a temperature graph there is a horizontal segment, the temperature of the substance does not change. E.g., Graph 1:  	Group work – Whole class discussion
Function	1. How many white tiles are needed if there are 100 black tiles? Justify.  2. Construct a rule that can be used to calculate the number of white tiles if the number of black tiles is known. Justify.	Group work – Commenting posters – Whole class discussion

Second, it is important that there exist dialogic interactions among students. Studies in dialogic interactions suggest that this may be accounted for by considering whether multiple ideas are brought to the discussion and the extent to which students engage with each other's ideas. In addition, studies of argumentation structure support this as considering opposing arguments in a constructive manner requires engaging with each other's ideas.

3. The present study

3.1. Research questions

As conceptualised in the preceding section, dialogic argumentation among students in a whole class setting includes students engaging with other students' ideas (dialogic interactions) and students making their reasoning visible (transparency of reasoning within a justification). Notably, there can also be differences in degrees of engagement and visibility of reasoning. To increase understanding of these two dimensions we set three research questions:

1. What levels exist in dialogic interactions among students in whole class discussion?
2. What levels exist in transparency of student reasoning within a justification in whole class discussion?
3. How do dialogic interactions and transparency of student reasoning exist simultaneously in whole class discussion?

3.2. Context and data collection

This study is part of the DARLING (Dialogic Argumentation for Learning) research project. Six Finnish lower secondary school classes participated in the project. We followed these classes in 7th grade (age 13) and in 8th grade in mathematics and physics. Each class had the same teacher for both subjects. The classes devoted 9–17 mathematics and 6–9 physics lessons for the project. The number of students in the classes varied from 18 to 25. The teacher of each class participated in a professional development programme in which they had meetings with the researchers before and after each lesson. In the meetings, the previous lesson was reflected on with the help of selected video clips, and the next lesson was planned. The meetings focused on dialogic interactions and justification.

Data from the lessons were collected by video recording. One hand-held camera was used to record a teacher from the back of the classroom. The teacher wore a wireless microphone that was connected to the video camera. In addition, all the student groups had small wide-angle cameras attached to their desks. Students' written work was collected.

The basic structure of an argumentation lesson had three phases: introduction, group work, and whole class discussion. The format of group work varied. For example, sometimes the students worked in approximately three-person groups whereas sometimes students first worked in pairs and then two pairs joined together. Table 1 gives an overview of some of the lessons.

3.3. Data analysis

We developed a coding scheme that has two dimensions: students' dialogic moves and justifying moves. The coding scheme was developed in interaction between reviewing literature and observing data. Particularly, the first lessons of the 2-year project impacted the development of the coding scheme. While first observing the lessons, we started to notice how students reacted differently to each other's ideas and that their reasoning was more or less explicit. By comparison to literature, we started to formalise these ideas. The

Table 2
Dialogic argumentation coding scheme.

Student move	Description	Examples from the data
Dialogic moves		
Questioning	Student asks a question about an idea presented by someone else.	Why there is a circle?/What is the reflection angle?/How did you get it exactly 90°?
Challenging	Student points out a deficiency in another student's idea.	It is smaller than 40°./It increases all the time and if you would continue the line, it would reach 100 °C.
Elaborating	Student analyses, develops or clarifies another student's idea.	I suppose you mean one and a half squares from these, and then if you move this, it would be two squares./Yes, he has to turn eyes more.
Commenting	Student comments or takes a stand on another student's idea without questioning, challenging or elaborating.	It is not./I change my opinion./We had similar./Pretty nice.
Responding	Student responds to another student's question without questioning, challenging, elaborating or commenting.	We used a ruler./It has no horizontal part because the line goes above 100 °C.
Justifying moves		
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.	If they would be separately, for one black tile you need 6. Then, when you put them together, 6 becomes 5. So it is 5×100 and then you add 1 for the last one.
Describing support (DS)	Student presents facts, calculations, observations, figures, etc. to support the claim without articulating reasoning. The support has to be related to the content of the lesson.	I don't see half of myself from here (pointing to a glass surface).

coding scheme was then developed, used to analyse, and redeveloped. A new lesson was selected to be analysed whenever the coding scheme was adjusted until the coding scheme was stabilized. The dialogic moves were composed to indicate engagement with other's ideas. The justifying moves were designed to capture whether students produce justification and whether reasoning is explicitly explained. The two dimensions are coded independently so that a student move may be a dialogic move and a justifying move. Within a dimension, the coding categories are mutually exclusive. Table 2 presents the codes with descriptions and examples from the data.

The unit of analysis is a student turn but, when coding, a turn is considered in relation to preceding turns (e.g., what does a turn add to previous turns). We consider there being only one turn when a student continues talking about the same topic after being interrupted by the teacher. For example, when a student begins to justify and continues because the teacher asks a follow-up question, we consider that there is only one justifying move. On the other hand, if another student poses the follow-up question, we consider that there are two justifying moves. The reason for this is that it allows capturing the question –respond pair that indicates students engaging with each other's ideas. If a turn contains a dialogic move and a justifying move, which are not related to each other, the turn is divided into two parts. This is important in order to recognize those justifying moves that are simultaneously dialogic moves.

To help discern between articulated reasoning (AR) and describing support (DS), we composed specific criteria for AR in typical forms of reasoning. For example, when a student refers to a counter example, the move includes AR if the student explains how the example illustrates a case that refutes a claim. When a student argues by citing a known theory that directly justifies the claim, the move includes AR if the student explains how the theory can be applied to the case in which the claim is posed. When a student describes steps that lead to a claim, it is considered AR if the steps lay out a chain of reasoning in which each step directly follows from the previous step. These three forms of reasoning have been the most typical in our data, but we have AR criteria (see Hiltunen et al., 2017) for several other forms of reasoning that are described in literature (e.g., Reid and Knipping, 2010).

In the analysis process, the transcript and video were used in parallel so that the transcript allowed consideration of how a turn was related to a previous turn, while the video allowed us to observe the turns in context. Both the transcript and the video were used through Atlas.ti analysis software. The codes were marked on the transcript. In most cases, only the video following the teacher was observed, but occasionally complex moments were checked on the student group videos.

3.4. Inter-rater reliability

The inter-rater reliability of coding was controlled by applying the recommendations of Seelandt (2018). Two researchers coded several lessons, compared their coding and negotiated differences of opinion. In some cases, the coding manual was refined to help achieve consensus. The agreement on which turns were dialogic and justifying moves was consistently high from the beginning. The agreement about the type of dialogic or justifying move varied and finally increased to an appropriate level. Finally, after negotiations and adjusting the coding manual, we coded two more lessons separately and calculated the Cohen's kappa coefficient. Table 3 provides the Cohen's kappa coefficient for the elements of the scheme.

According to Table 3, the reliability is very good (above 0.80) or substantial (above 0.60) for identifying dialogic and justifying moves as well as differentiating between types of dialogic and justifying moves (Landis and Koch, 1977 in Seelandt, 2018).

4. Results

4.1. Levels of transparency of student reasoning within a justification

We found three levels that describe how transparent student reasoning within a justification was: students explicitly articulated the reasoning leading to the claim (explicit student reasoning), students described support for the claim (implicit student reasoning), and students produced factual statements that the teacher used to justify (teacher reasoning using students' statements). In the highest level, when explicitly articulating reasoning, students themselves gave not only evidence for the claim but also explained how the evidence is used to conclude the claim. For example, in the Fractions lesson (Table 1), a student explained how he knows that 11/24 is larger than 7/16:

> They both are a little less than a half. But, a bit like in the previous task, in 11/24, the pieces are smaller in the half, because there are more of those pieces, so there is less to fill.
>
> [AR]

Table 3
Inter-rater reliability (Cohen's kappa coefficient) of dialogic argumentation coding scheme.

	Cohen's kappa
Identifying whether a move is a dialogic move	0.86
Identifying whether a move is a justifying move	0.85
Identifying the type of dialogic move	0.77
Identifying the type of justifying move	0.84

In the above turn, the reasoning is articulated by the following steps: The fraction 11/24 is divided into more pieces than 7/16. Thus, the pieces in 11/24 are smaller than in 7/16. Therefore, the one piece missing from ½ is smaller in 11/24 than in 7/16. The student's explanation is not as clear as it could be, but the line of reasoning is made visible.

In the second level, students provided statements that support a claim without articulating reasoning. For example, another student provided support that 11/24 is larger than 7/16:

> If you divide 7/16 by 2, you will get 3½ eighths and then you have to multiply 8 by 3. No. Yes. Then 3, 3½ has to be divided, I mean multiplied by 3. Then it will be 10.5. Thus, it is smaller than that [11/24].
>
> [DS]

In this turn, the student explained how 7/16 can be transformed first into 3.5/8 and then into 10.5/24. However, the student only explained what is done to the fraction 7/16 instead of explicating the reasoning. In both of the above instances, the students justified and obviously the justification was based on reasoning. However, the instances are different as in the first instance, the student made reasoning explicit, whereas in the second case the reasoning is implicit.

In the above excerpts from mathematics, students' justifications were composed of chains of steps. Sometimes, particularly in physics, students draw on scientific facts or theories. In doing so, they may articulate reasoning from the facts to the claim or just describe the supporting facts. For example, in the Reflection of the light lesson (Table 1), a student argued that person C does not see himself in the mirror:

> I look from the side at the mirror, then the mirror doesn't reflect the light at an angle back at me [gestures from notebook representing a mirror to eyes], but it reflects it at an angle in that direction [gestures from eyes to notebook and away].
>
> [AR]

In this turn, the student drew on the fact that light reflects from a plane mirror. He explicated by using gestures that light is not reflected towards person C but away from him. In addition to talk, gestures are part of the communication and can be used to make the reasoning within the justification visible. In the same lesson, another student supported the claim that persons A and C see only each other:

> If A looks at the mirror, he does not see B because he looks from the side. So, he would see only C because the light comes in a way in 90° angle and he cannot see B.
>
> [DS]

In this case, the student drew on the fact that person A is on the side and light forms an angle of 90°. However, the student did not use gestures or otherwise explain how this leads to the claim.

In the lowest level of transparency of student reasoning, the students produced statements that the teacher used in justifying. In these cases, students did not make justifying moves, but nevertheless, the teacher used students' statements to justify. For example, the following excerpt from the Divisibility lesson (Table 1) started when a student evaluated the statement 'the sum of two odd numbers is even':

Student 1: False.

Teacher A: False. Aha! Now it is interesting. All the other groups thought that it is true, but you think that it is false. Great. Now we will get a discussion. Would you have an example that does not work?

Student 1: What did we try? I can't remember.

Teacher A: Well, say an odd number.

Student 1: For example, five.

Teacher A: Five. Another odd number?

Student 2: Three.

Teacher A: Three. Five plus three equals?

Student 2: Seven. […] No, so, eight.

Teacher A: Eight. And eight. Is eight divisible by two?

Student 1: Yes.

Teacher A: Well, now others should, or the groups should prove that, this time, majority is right.

In this excerpt, students were not justifying a claim but just responding to the teacher's questions. The students did not produce the facts to support a claim as in the above excerpt from the Reflection of the light lesson, nor did they chain together the facts in steps leading to the claim as in the excerpts from the Fractions lesson. Instead, the teacher connected the students' statements to support that the divisibility statement is false (although $3 + 5 = 8$ actually supports that the statement may be true). Thus, collectively the teacher and the students produced a justification, and finally students might have even understood the justification. Nevertheless, at the time of producing the statements, the students were not necessarily aware of the reasoning in which the statements are used.

4.2. Levels of dialogic interactions among students

We identified three levels of dialogic interactions among students based on how students engaged with each other's ideas: students analysed an idea, students commented on surface features of the idea, and students presented separately several ideas. The highest level, students analysing another student's idea, was found when students were questioning, elaborating, or challenging. The following excerpt from the Geometric construction lesson (Table 1) is an example of such an episode. The students were discussing the solution of Student 2 and his group mates. The solution was projected on the wall (see Fig. 1).

Turn	Speaker	Transcript	Dialogic moves
1	Student 1	How did you get this segment? I mean, if you did the perpendicular bisectors, then how did you get it to the right point?	Questioning
2	Student 2	Well, look, here in the top right vertex we have the perpendicular thing that is used to get the line into a 90-degree angle.	Responding
3	Student 1	Yeah, yeah…	
4	Student 2	Which we then draw.	
5	Student 1	I don't get that.	Commenting
6	Student 3	So somehow in a different direction.	Commenting
7	Student 4	Like so that they are in the same line.	Commenting
8	Student 5	If there is the perpendicular bisector at the bottom right vertex, why is there not one in the bottom left vertex, too?	Questioning
9	Student 6	It must have been the last vertex.	Elaborating
10	Student 5	Because then the bottom left vertex, it is, it is only drawn from the top left vertex. Then, if there is the perpendicular bisector in the bottom right vertex, it should also be in the left, too.	Challenging

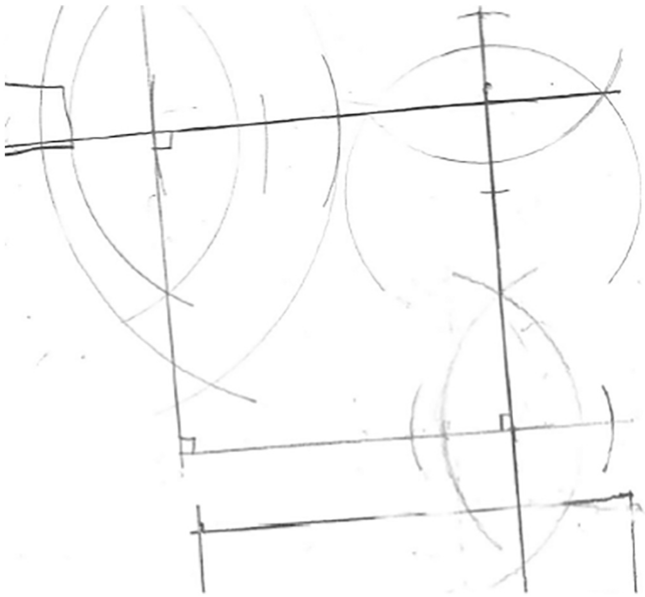


Fig. 1. The geometric construction of a rectangle.

This excerpt includes several student turns that are raised in relation to other students' ideas. The two questions (turns 1 and 8) are based on analysis of Student 2 and his group mates' work and thus indicate thorough engagement with the idea of the group. In turn 9, a student, who is not part of the group whose solution is discussed, engaged with the discussed work and with the preceding question (turn 8). The student suggested an explanation for the question based on the order in which the constructions might have been done. Thus, even this short elaboration indicates engagement with the other students' ideas. In turn 10, Student 5 reiterated his idea, but this time he did not ask a question but instead proposed that there was a deficiency in the solution. Even though the student did not take into account the preceding elaboration (turn 9), the student still analysed the ideas presented in the work under discussion. As natural, sometimes even so-called good ideas are bypassed, but still engaging with any of the ideas indicates dialogic interactions among the students.

The second level of dialogic interactions was found in instances where students only commented on each other's idea. For example, the following excerpt presents the whole class discussion on comparing fractions 12/23 and 11/24 in the Fraction lesson.

Turn	Speaker	Transcript	Dialogic moves
1	Teacher B	Why, in your opinion, is 12/23 bigger than 11/24?	
2	Student 1	Well, because it is bigger because 12 is half or over half of 23, whereas 11 is less than half of 24. So, 12 is more than one-half of 23.	
3	Teacher B	Yeah. How about here?	
4	Student 2	Same opinion.	Commenting
5	Teacher B	Is it exactly the same?	
6	Student 2	Same.	(cont.)
7	Teacher B	How about Student 3; do you agree?	
8	Student 3	I think about combining those previous right answers of the previous tasks. So, here, you need smaller amounts of numbers to fill it, and you also have less of those numbers. So, okay, I will explain better. You have a smaller amount of numbers in the denominator, and thus, you need a smaller number of numerators to make it one whole, and now, you have even more of the numerators. […]	
19	Teacher B	What do the other people say about a thing like that?	
20	Student 4	It is basically the same thing.	Commenting
21	Student 5	It is what we tried to explain.	Commenting

In this case, the first justification (turn 2) received only a comment about agreeing. The second justification (turn 8) was given as a separate justification without relating it with the first one. This justification was only said to be similar to what others were thinking (turns 20–21). These comments do not necessitate thorough analysis of the work and the difference between the two profoundly different justifications was not discussed. Nevertheless, even only this kind of commenting shows that students have recognized at least the similarity of the conclusion and are somehow reacting to each other's ideas.

Both of the two preceding excerpts include commenting. The difference between them is that the first excerpt also includes questioning, elaborating, and challenging while the second excerpt contain only commenting. It is only natural that there also exist more superficial comments in addition to ideas based on careful analysis. However, if only comments are given, it means that presented ideas are not thoroughly discussed and thought about together.

The lowest level of dialogic interactions, but still relevant for argumentation, was found when students presented ideas but did not engage with each other's ideas. For example, in the Divisibility lesson, students supported the claim that the sum of two numbers, that are divisible by five, is divisible by five:

Student 1: $5 + 10 = 15$ and 15 can be divided. […]

Teacher A: Is it enough to try, for example, with a million first pair of numbers? Does it prove that also the next million after works?

Student: No.

Teacher A: No, it does not prove. So, other justifications? Student 2 […]

Student 2: We put here that because the number always ends with 5 or 0.

Teacher A: You also had similar kind of justification, did you? Would you read your justification of the first [statement]?

Student 3: I changed it, but we had that all the numbers that end with 0 or 5 are divisible by 5.

In this excerpt, the students described three supports for the claim. However, the three supports were not related to each other. Thus, several ideas were presented but the ideas were not interanimated. The second justification was not stated to improve the first one but rather just to offer another justification as requested by the teacher. The third justification was almost the same as the second, but the students did not say that the third justification added some details to the second. Only the teacher commented that the second and the third justifications were the same. Thus, although these kinds of instances are rich in justification, they are at a low level in dialogic interactions.

4.3. Justifying as a dialogic move

We found that some student moves are simultaneously dialogic and justifying moves. There are three kinds of these instances: improving an argument, counterarguing, and justifying triggered by a question. In the first kind of instance, a student elaborates another student's idea and at the same time justifies (DS or AR). An example of such a turn is given in the following excerpt from the Change of state lesson (Table 1). Student 1's group claimed that Graph 1 was incorrect and supported it with fact card F (see Table 1). Then, the teacher asked what they had written as a reason for why fact card F justifies their answer.

Turn	Speaker	Transcript	Dialogic moves	Justifying moves
1	Teacher B	So, fact card F. [Reading] If on a temperature graph there is a horizontal segment, the temperature of the substance does not change. And here it says that. What does it say?		
2	Student 1	Well, that's maybe a little poorly written, but…		
3	Teacher B	[Interrupting other students talking over Student 1] Hey.		
4	Student 1	… it means that, when there isn't a horiz-, like it said there, that only on a horizontal segment, like, the temperature doesn't change, and only then can the state change. And there isn't at any		AR

(*continued on next page*)

(*continued*)

Turn	Speaker	Transcript	Dialogic moves	Justifying moves
		point a horizontal segment, so the temperature is changing the whole time, so the state can't change. Did that make sense?		
5	Student 2	Yeah, because then it wouldn't have originally been able to start from ice into water, because it doesn't show there, that it would be a straight line, or that the temperature wouldn't change. Because when the state changes then there has to be a straight line.	Elaborating	AR
6	Teacher B	What do you mean by a straight line?		
7	Student 2	By a straight line, I mean that the temperature doesn't change during that time when the state changes.		(cont.)

In turn 4, Student 1 articulated reasoning. Then in turns 5–7, Student 2 from a different group elaborated Student 1's justification by clarifying that the state changes only when there is a straight line. In addition, Student 2 articulated reasoning. It seems that turn 4 provided a basis for another student to continue reasoning along the same line. Despite this being a small improvement, it shows that another student participated in justifying through dialogic interactions.

A second kind of instance of simultaneously dialogic and justifying moves is challenging and AR/DS, which means that a student is producing a counterargument to another student's idea. For example, in the Function lesson (Table 1), a group including Student 2 and Student 3 solved the number of white tiles if there are 100 black tiles, as shown in Fig. 2.

The solution in Fig. 2 is most likely based on noticing that the number of white tiles increases by five when a new black tile is added. The students have listed the number of white tiles when there are no more than 50 black tiles. Then, the students have doubled the number of white tiles to reach the answer. This strategy caused their answer to be one tile too many. The following discussion was launched by Student 1's question.

Turn	Speaker	Transcript	Dialogic moves	Justifying moves
1	Student 1	Why did you get that kind of answer? […]	Questioning	
6	Student 2	It is multiplied by two. This, what you call it. The one that is 206, I mean 251 was multiplied by two. No, I mean we added (inaudible).	Responding	DS
7	Teacher C	Yeah, sorry. Here is 241, 246, 251 and then there is 502.		
8	Student 2	It was added, because [Student 3] calculated it somehow like here there were 50 of these and then he added it so that it would be the same if you would put 50 more. […]	(cont.)	(cont.)
12	Student 4	Either this is. I don't know if this is more like a comment or a question. Somewhere there has happened an 'oops' mistake when calculating until 50, I think, or the technique does not work.	Challenging	
13	Teacher C	[Student 5].		
14	Student 5	I think that it happened so that they have calculated it exactly correctly until that point (251), but they have multiplied it by two and then there will not be the last one, like when you have two of those 50-rods, but the one that has six is not there. That is where the mistake happened.	Challenging	AR

In turn 12, Student 4 points out without justifying that there is either a calculation mistake or the strategy does not work. However, another student continued challenging the presented solution and articulated reasoning for why there is a mistake. The difference to the previous excerpt from the Change of state lesson is that now the first justification created an opportunity for counterargument. However, in both cases the first justification created a basis for further justification through dialogic interactions.

A third kind of instance of simultaneously dialogic and justifying moves was found when justifying moves were given to respond to another student's question. For example, in the previous excerpt, in turns 6–8, Student 2 responded to Student 1's question. By doing so, Student 2 described their solution (DS). Thus, the student question triggered the justification. In this case, the dialogic move launched the justification, whereas in improving an argument or counterarguing, the first justification launched further justification. In all the three kinds of instances, dialogic interactions supported further justification. Furthermore, as in the previous excerpt, these instances can exist in a sequence where, for example, a first question triggers a justification which is continued by further analysis of it leading to another justification.

5. Discussion

In this study, we sought to understand and characterize ways in which dialogic argumentation among students may play out in whole class discussion. We found that dialogic interactions among students and transparency of student reasoning within a justification, two key aspects of dialogic argumentation, may exist independently of each other in different levels. Furthermore, these two aspects can also exist simultaneously when a student justifies by reacting dialogically to another student's idea. Therefore, the results show how differently dialogic argumentation may play out in whole class argumentation.

We characterised three levels of dialogic interactions (in ascending order): students presenting separately several ideas, students commenting on surface features of each others' ideas, and students analysing peers' ideas to ask questions, challenge, or elaborate.

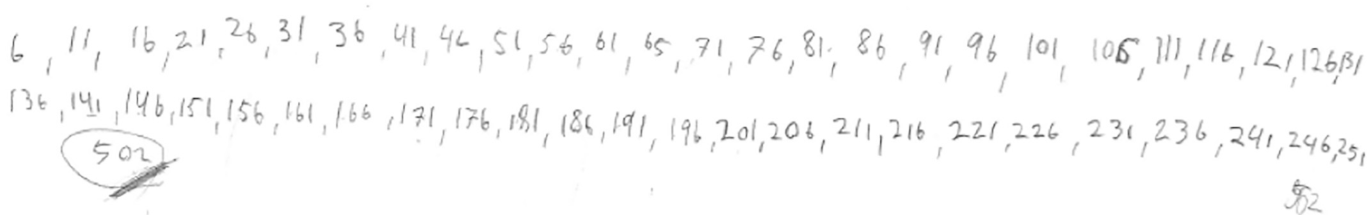


Fig. 2. The solution for the number of white tiles when there are 100 black tiles.

Often studies of whole class discussion consider dialogic interactions between the teacher and the students, for example, by considering how open the teacher is towards several viewpoints (e.g., Bossér and Lindahl, 2021; Lehesvuori et al., 2019; Mortimer and Scott, 2003). The important point here is that the discussion may well be dialogic in this sense, but not necessarily in the sense that students engage with each other's ideas. Even in the whole class discussion orchestrated by the teacher, considering dialogic interactions among students opens a new perspective. Particularly argumentation studies in mathematics and science often focus on the teacher and students collectively building arguments and analyse whether the students' produce the elements of the argument and how the teacher supports this (Ayalon and Even, 2016; Conner et al., 2014; Erduran et al., 2004; Osborne et al., 2004). Additional analysis of dialogic interactions helps to characterize how students use ideas in addition to providing them, and how this affects the process of argumentation. Furthermore, our results suggest that there are levels in dialogic interactions. Even students' comments about less important features of their colleagues' ideas show some engagement with others' ideas. When compared to the levels of engagement in Webb et al. (2014), our highest level of dialogic interactions is somewhat similar to adding details to or referencing details of a peer's idea, and our second level resembles acknowledging a peer's idea. In addition, we have used the levels in characterising different kinds of dialogic argumentation. For example, considering dialogic interactions together with justification helped to recognize the argumentation type where students do not engage with other's ideas but where different justifications are presented.

As regards to transparency of student reasoning when justifying, we found three levels (in ascending order). First, students may produce only factual statements that are used by the teacher to build an argument. In this case, the students may not be aware of the reasoning in which their statements are used and therefore the students are not actually justifying at that time. Second, students may describe support for a claim. In this case, the students probably are reasoning, but the reasoning is implicit in the talk. Third, students may articulate reasoning which means that they make reasoning explicit. To have students present their reasoning has been found to be an important feature of classroom interactions in previous studies (Hennessy et al., 2016; Mercer, 1996). This study contributes to the literature by characterising three levels in transparency of reasoning. In addition, the three levels offer an alternative to using the Toulmin model to consider justification. Argumentation studies that identify student utterances that are used as claims, data, or warrants usually consider those arguments where students produce warrants as more advanced (Erduran et al., 2004; Osborne et al., 2004). The three levels of transparency of student reasoning within a justification conceptualises this differently without breaking the argument into the interpreted elements and instead takes the argument as whole and examines how visible student reasoning is. Roughly compared, the first level of transparency of reasoning means students producing only claims, the second level means students producing data, and the third level means students producing data and warrants in a way that reasoning is visible.

An insightful finding of this study is that the student moves that are simultaneously dialogic and justifying moves further characterize dialogic argumentation. As shown in the results, simultaneously dialogic and justifying moves mean that a justification is presented as a dialogic reaction to a previously presented idea. These simultaneously dialogic and justifying moves occurred in three different types of instances: counterarguing, improving an argument, or responding to a question by justifying. Dialogic interactions and justifying mutually support each other as more (AR) or less (DS) explicitly described reasoning gives the opportunity to build on that and, on the other hand, student challenging, elaborating, or questioning may eventually lead to justifying.

The importance of argumentation that includes justifying through challenging is highlighted in argumentation studies (e.g., Asterhan and Schwarz, 2016; Erduran et al., 2004; Osborne et al., 2004) and in dialogic interactions studies (Howe et al., 2019; Mercer, 1996). The reason for this is that this kind of argumentation means consideration of alternative ideas and thorough negotiation. Because this kind of talk includes reasoning and critical examination of ideas, it can be described as exploratory talk (Mercer, 1996). This study proposes that somewhat similar yet different argumentation is concerned when students are not making counterarguments but rather develop the argument presented by another student by elaborating and justifying at the same time. Justifying through elaborating has some features of exploratory talk as the talk contains reasoning and careful analysis of the previous ideas and builds on it. According to Mercer (1996), elaborating is a feature of cumulative talk and challenging is a feature of exploratory talk. However, when elaborating is at the same time justifying, the talk resembles more of exploratory talk as students are reasoning together. Justifying by challenging and by elaborating both have desirable talk features. The course of events may naturally give rise to one of these. For example, as shown in the result, when a student justification has some shortcomings, it may give rise to challenging whereas, when a student justification already includes a productive basis, it may be natural to elaborate the justification by further developing it. This may be particularly relevant for argumentation in certain mathematics or physics topics where the aim is to have the discussion to converge towards the specific justified scientific viewpoint as opposed to a more controversial topic (e.g., socio-scientific issues, literature interpretation, ethical issues), where the aim may be to reach multiple justified standpoints.

The third instance of a simultaneously dialogic and justifying move highlights the role of student questions in promoting argumentation. From the perspective of dialogic argumentation, it is different to justify on a teacher's request or to justify as a response to a student question. The latter shows that students engage with each other's ideas and, furthermore, a student question triggers the justification. In all of the three instances of simultaneously dialogic and justifying moves, dialogic interactions focus on justification instead of, for example, claims or conceptions and thus are key moments in dialogic argumentation.

The analysis method used in this study offers some contributions to the research society's efforts in developing methods to analyse dialogic argumentation. The two dimensions, dialogic moves and justifying moves, allow identifying two key aspects of argumentation: dialogic interactions among students and students' justifications. Furthermore, as the two dimensions are coded independently, we can distinguish instances that contain either dialogic interactions or justification from those where dialogic interactions and justifying co-exist in a synergistic way. This may provide some future opportunities also for the users of other coding schemes of dialogic interactions. For example, the coding scheme of Hennessy et al. (2016) could be modified to capture transparency of student reasoning and to examine moves that are dialogic and include reasoning at the same time. The analysis method also provides an alternative to the application of the Toulmin model that is widely used in mathematics and science education research. The main benefit of the Toulmin model is that it enables describing the structure of argument in detail (see Conner et al., 2014) and differentiating simple arguments including only data and claim from those arguments that also include warrant and other elements (Erduran et al., 2004; Osborne et al., 2004). However, identifying which part of an argument is which element might be challenging (Erduran et al., 2004). We approached this issue by differentiating between articulating reasoning and describing support within the whole argument instead of identifying which part is which element in the argument.

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