Argument-Based Mathematical Inquiry: Teacher Strategies for Supporting Young Students' Collective Argumentation

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Development of students' argumentative capability in mathematics supports deeper conceptual understanding and reasoning. However, young students often lack the prerequisite communicative competency. This study examines how one teacher supported students in building collective argumentation through an extended mathematical inquiry. Analysis of classroom video highlights key practices that enabled this process. When enacted coherently, these allowed students to engage authentically in disciplinary reasoning and dialogue central to mathematical communities.

Introduction

Mathematics and argumentation are innately linked, as stating and justifying claims, and exemplifying, developing, communicating and evaluating arguments are core components of mathematical reasoning (Lannin et al., 2011). Argumentation in mathematics learning supports development of students' deeper conceptual understanding and critical thinking in mathematics through the need to justify solutions and explore the validity of different approaches (Hasançebi et al., 2021). This solidifies understanding, encourages a critical thinking approach, and engages students with different perspectives (Chinn et al., 2000). The critical thinking developed has been shown to be transferrable to other disciplines (Mercer, 2000). Argumentation also develops both generalised and discipline specific competency in communication, supporting students to improve their ability to express mathematical ideas through discourse (NCTM, 2020). As students explain their reasoning, they improve their mathematical vocabulary and gain confidence in discussing complex ideas. Further, students who argue about their reasoning are more likely to retain information long-term (Hattie & Timperley, 2007).

Challenges to the teaching and learning of argumentation for both teachers and students influence its uptake. Teachers require opportunities to themselves become proficient in argumentation and this can be challenging (Francisco, 2024). Young students on the other hand, tend to find it difficult to consider the viewpoints of others (Rapanta et al., 2023). Furthermore, argumentation is both a specific genre and a discursive practice that they are likely unfamiliar with, given the emphasis in the English curriculum on persuasive genres as incorporating expressions of opinion, having the goal of 'winning', rather than building collective knowledge.

Given these challenges, an investigation of how primary teachers can integrate collective argumentation into the mathematics classroom is needed. In this paper, we focus on the practices of one primary mathematics teacher as she introduces her students to argumentation practices embedded within a guided mathematical inquiry. In response to the identified difficulties above, we ask: *How does one teacher's strategies support students' development of collective argumentation in the context of an argument-based mathematical inquiry sequence?*

Literature Review

Argumentation is a practice comprised of the two forms of argument: structural and functional. A simplified argument structure for younger students is the Claim-Evidence-

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Reasoning (CER) model (Zembal-Saul, et al., 2013), which incorporates a position statement (*claim*), data that supports the claim (*evidence*), and logic that enables the evidence to be used to establish the claim (*reasoning*). *Rebuttals* are also incorporated into the framework to provide reasoning for why alternative explanations are not appropriate. The functional aspect of argument addresses the delivery of the argument, or 'arguing'. However, unlike debate, the purpose of the delivery is to achieve consensus or agreement or to advance knowledge.

Collective argumentation can be considered "any instance where students and teachers make a mathematical claim and provide evidence to support it" (Conner et al., 2014, p. 404). Collective argumentation recognises the discursive nature of argumentation and the constituent practices of developing, communicating and evaluating arguments as a social practice. Brown and Renshaw (2000) enumerate five key principles of collective argumentation: the necessity to communicate individual thinking about a task and may do this through use of representations (*generalisability principle*); the necessity to accept or reject ideas through logical argument and/or evidence (*objectivity principle*); the expectation that contradictory ideas or thoughts are resolved through argument (*consistency principle*); developing an agreed approach to a task as a class (*consensus principle*); and that individual and group ideas are presented to the class for discussion and evaluation (*recontextualization principle*) (Brown & Renshaw, 2000).

While young children demonstrate an inherent ability to argue and counterargue in various settings (Bubikova-Moan & Sandvik, 2022), their argumentative engagement often follows an egocentric pattern (Muller Mirza et al., 2009). Rather than aiming to enhance the plausibility of their arguments or reach mutually beneficial agreements, their primary focus is on defending personal interests and values (Rapanta et al., 2023). This cognitive egocentrism limits their ability to genuinely participate in argumentation dialogues where a shared goal is established.

A fundamental challenge in early argumentation is achieving intersubjectivity, where argumentation participants consciously pursue a common understanding of the discussion's objective (Perret-Clermont et al., 2004). Nonetheless, early informal debates may act as precursors to more structured argumentation, developing into more sophisticated argumentative reasoning over time (Iordanou & Rapanta, 2021). This suggests that fostering argumentation in young learners can be improved by scaffolding structured educational environments that encourage cooperative reasoning and challenge self-centred discourse.

Many argumentation frameworks focus strongly on cognitive and structural aspects at the expense of socio-cultural dimensions and there is more need to emphasise the social and discursive practices that occur (Francisco, 2024). Makar et al. (2015) suggest that supporting the development of argumentation practices includes: fostering a classroom in which peer collaboration, feedback and critique are encouraged; promoting the collective sharing of evidence to refine arguments; and, setting clear expectations that ideas would be examined.

Method

This study was part of a larger design experiment and was guided by the principles of Design-Based Research (Cobb et al., 2003), incorporating an iterative and reflective nature of cycles of instruction with a pragmatic focus. The first author taught the unit. The study received human research ethics clearance from The University of Queensland (clearance number 11-017) and consent from both parent and student was obtained for 22 of the 25 students. The data of the remaining three students is not included in this study.

The class was comprised of 9-10 years-old students, including five boys who were ascertained with autistic spectrum disorder and/or significant learning difficulties. The school was situated in a middle socio-economic suburb of a capital city. The class had remained intact with the same two co-teachers for two school years. These students had engaged in guided mathematical inquiry for various periods of time depending on their class placements prior to

Year 4 but with a minimum of one and a half years under the same teachers. While students had prior experience with inquiry-based learning, they had not yet been introduced to argumentation beyond the generic study of persuasive texts under the English curriculum.

The lesson sequence is centred on a geometry investigation. The class undertook a geometry unit spanning the previous week, focussing on the properties of pyramids and prisms. During this time, a student queried whether pyramids could have a scalene face. The teacher suggested the question as the basis of their next class inquiry and received enthusiastic agreement.

Data comprised video recordings of ~10 hours of learning across five days. Each video was transcribed in full, and the transcripts were examined with a view to identifying teacher supports and the associated impact on students' development of collective argumentation.

Findings and Discussion

In this section, we provide illustrations of classroom practice of each of the key principles of collective argumentation. We also incorporate a number of key practices that the researchers identified as pivotal to class involvement in collective argumentation. To facilitate the narrative for our audience, we provide an (almost) sequenced approach to addressing the principles. We argue that, in practice, the principles were consistently demonstrated across the inquiry.

Consistency Principle

This principle provides that contradictory ideas or thoughts are resolved through argument. At the outset of the lesson sequence, the teacher introduced the students to argumentation practices through a guided discussion, linking argument structure of claim-evidence-reasoning (Zembal-Saul, et al., 2013) to an inquiry framework familiar to her students (refer author, 2014), as well as to their existing knowledge of persuasive genres covered in English lessons Through this process, the students were introduced to the notion of argumentation structure and purpose as a way of informing, shaping and supporting their conclusions, and as fundamentally different than using opinion or emotion to justify their claims. At the commencement of the lesson sequence, the opening discussion indicates the students' preparedness to bring argumentation practices into a mathematics inquiry task.

Teacher: OK. So, you need the evidence to do what?

Lucy: To convince

Connor: To persuade

Shana: With evidence you can back up, support your conclusion.

Oliver: You have to have evidence because a claim is like trying to get someone to believe what you are saying you make it stronger by giving it more evidence. You give it evidence which will make your claim better. You can make your conclusion better.

Resolving contradictory ideas through argument was also an overlaying principle throughout the lesson sequence with the teacher ushering students towards a collective argumentation practice in which all students contribute evidence and share their experiences to negotiate a common claim. Midway through the lesson sequence, each group presented their claim to the class, supported by evidence and reasoning. The resultant class critique prompted further refinement of their arguments. Through this process, students came to understand argumentation not as a final product, but as an evolving, inquiry-driven process. This empowered them to recognise their capacity to engage in disciplinary argumentation to explore and resolve questions about the world. In this instance, serving as a springboard for investigating geometric relationships, thereby deepening their conceptual understanding.

Teacher: So, in terms of regular shapes, we could put forward a theory, just a theory, we don't know if we are right or not, that four or less sides and we can make a scalene pyramid. So, what is special about a 5-sided figure that we don't see on a four or less-sided figure? …

Leticia: Could it be, …the pentagon has one line of symmetry but a square and a triangle have 2 (sic).

Teacher: What is different about a pentagon, a heptagon, an octagon that is different from a square or triangle? And don't tell me the number of sides because that is fairly obvious.

Delmar: On the heptagonal base and the hexagonal base and on the octagonal base aren't like all the angles the same?

Teacher: Well, if they are regular, yes …

Leticia: I think if you umm ... If it is a right angle or smaller it works. If it is obtuse ...

The classroom enactment of the *consistency principle* demonstrated how students' prior experiences with persuasive texts and the inquiry framework were leveraged to build a foundation for collective argumentation. The teacher's deliberate juxtaposition of claim-evidence-reasoning (Zembal-Saul et. al., 2013) with mathematical inquiry practices enabled students to reconceptualise evidence, not merely as a means of justification, but as a tool for constructing and shaping claims. Students in this study progressively learned to move beyond evidentiary assertions as static justifications toward an evolving engagement with uncertainty—a hallmark of authentic disciplinary argument (Osborne et al., 2004).

Objectivity Principle

The *objectivity principle* requires that ideas can be validated through reference to reasoning. This argumentation sequence was intended to focus students on evidence as a way of coming to know and to stress the importance of evidence quality. The purpose of the inquiry was to create evidence, and build knowledge to make a claim, and thus answer a novel question. To this end, the teacher used a balanced approach of challenge and support to deepen students' understanding of evidence. For example, she used a scenario with a series of follow-up prompts to challenge students' concepts of evidence and emphasise the role of evidence in collective mathematical argumentation. The teacher links the students' previous experience writing persuasive texts to mathematical argumentation practices, highlighting the emphasis on using elements of logical arguments and quality evidence.

Teacher: So, when I make a conclusion, when I decide whether or not a pyramid can have a face which is scalene, what's going to be in my conclusion?

Connor: A claim

Teacher: So, what's a claim?

Connor: Something that you ... [tailed off]

Teacher: Think about the persuasive arguments that you have been writing for [co-teacher].

Connor: Something that you say and then you give evidence.

Teacher: Ah. So, we have a claim which is something that we believe, something that we think, something that we have concluded - from our inquiry. … From our claim, what was the next thing that you said? [pause then prompting] For your claim you have to have?

Connor: Evidence

Teacher: Evidence. Why do I have to have evidence? Why can I just not say, "Can a pyramid have a face which is scalene? Yes!" …Ahh...no someone different - Konrad?

Konrad: How can we believe you? … Teachers aren't always right.

The environment of collaboration and acceptance of risk-taking when sharing ideas is evident in the students' discussions concerning the acceptance or rejection of quality evidence.

In the following excerpt, Connor shows that he is open to the affordances of evidence that provide positive instances to support of the claim ("the net of a pyramid that works"), and those that provide negative instances to support the claim ("nets that didn't work") to formulate the logical argument. The excerpt also provides an example of teacher probing to facilitate sharing of the mathematical ideas that form the basis of students' decisions around evidence selection.

Connor: If you were making evidence saying that it does work, you would need the net of the pyramid that works, you would need the measurements of each scalene face, and you would need the net actually built so that they know that it works. …

Teacher: Why would you want the measurements?

Connor: If you just show the triangle, you wouldn't know that it is scalene unless it is really wonky and all of that. But it could be like 6.9 and 7 or something like that. … For the evidence that [the scalene pyramid] doesn't work, you would need to show a big range of different nets that didn't work, and we'd have to show each measurement that you tried that didn't work, each face your tried that didn't work and each net that didn't work.

Teacher: It sounds like it would be a lot harder to prove that you can't than it would be that you can.

Throughout the lesson sequence, teacher prompts were directed in such a way to challenge students' conceptualisation of what counts as "quality" evidence in relation to:

- The nature of evidence, being an act of judgment as opposed to mere opinion,
- The notion of sufficiency of data in relation to the claim,
- Validity of the source of data, notably that authority does not ensure validity.

These prompts became an anchor for the teacher to which she constantly referred throughout the sequence. The teacher utilised repetitive modelling of these notions which contributed to the students becoming themselves versed in the practices of argumentation.

Consensus Principle

This principle requires that approaches to a task are agreed by the class and that all members can articulate the approach taken. The teacher ensured that, through discussion, all students understood both the problem and the need to gather evidence to address the problem. The teacher's role was facilitative rather than directive. Students were offered choice and therefore ownership of both mode of working, and ways of progressing. The teacher encouraged collaborative work around a shared objective, and this allowed for rich interactions and cross-fertilisation of ideas. This helped students improve their openness to other people's ways of knowing and finding out. The students moved beyond collaborative agreement of task processes to collaborative understanding of what would constitute an acceptable conclusion.

The findings highlight the importance of *consensus* as a motivating force within collective inquiry. That students co-constructed the inquiry question and chose their investigative approaches supports the view that authentic engagement arises when learners are invested in the epistemic aims of the task. This sense of ownership not only deepened their persistence but also fostered openness to multiple perspectives. Such openness is critical in developing an understanding that, while multiple interpretations may exist, they can be adjudicated through evidence (Chandler et al., 2002). Here, collective argumentation was not merely a pedagogical device but a means of cultivating what Sandoval et al. (2014) describe as epistemic cognition: an awareness of how knowledge is generated, justified, and contested.

Generalisability Principle

This principle requires that students attempt to communicate individual thinking about a task. Through this lesson sequence, the students worked predominantly in group settings in which all students were expected to contribute their ideas and understanding. The teacher introduced expectations that students would not only communicate their understandings but also determine their own forms of representations to support this communication. For instance, the teacher asked students to envisage evidence to determine whether a pyramid might be able to have a scalene face. The students worked in groups and were encouraged to select their own mode (*consensus principle*) for articulating their evidence. All groups elected to create representations consisting of a combination of a built pyramid and/or a net. After determining the evidence, they required, and sharing their group plans in a whole class discussion (*recontextualization principle* below), students commenced creating their representations.

Teacher: Your first task is to work out …what evidence you will need. …I don't mind how you do it, whether you draw pictures or write words, but what evidence will we need to provide?

Salome: So, what would count as evidence?

Geneva: A model could. If you get a model with at least one scalene side, then it would be evidence because obviously it would be possible.

Lee: Maybe a diagram

Sadie: A model because it actually does show us.

Salome: [talking aloud as she writes] A model of a pyramid with one face that is scalene. And I like Lee's idea about a diagram. A diagram of a pyramid.

Teacher: OK a couple more minutes and I am going to ask each group to share what they have put down.

Salome: And a diagram of a pyramid with one face that is scalene.

Geneva: A net

Salome: But isn't the net the diagram?

Geneva: A measurement - a measurement on the diagram

Lee: A net of a scalene pyramid… A testable net

Salome: No, an already tested net.

From the findings, the *generalisability principle* was reflected in students' ability to apply discursive argumentation practices to novel problems, such as investigating whether a pyramid could possess a scalene face. This required students to envision and operationalise appropriate forms of evidence. The shift from general geometric knowledge to task-specific representation generation illustrates a refined capacity to apply learned structures in new contexts.

Recontextualisation Principle

This principle addresses the requirement for group members to present ideas to members outside the group for discussion and validation. The mathematical ideas the students were considering were quite complex. Children at this stage of the curriculum would normally identify pyramids by properties, including the shape of the base, the triangular faces and the apex. Building pyramids would normally be done from a provided net and these are universally equilateral or isosceles. Designing a functional net proved challenging. The teacher supported the students through convening whole class discussions to support group sharing and enable students to overcome hurdles that other groups had addressed successfully. For instance, the students, in groups, presented their ideas to the class; as a result, they realised their pyramid models weren't convincing evidence because the feedback suggested they were being forced. Students eventually became more rigorous about the design and production, producing quality nets to overcome original critiques. The enhanced evidence quality was driven by peer scrutiny.

The challenges students encountered in producing viable pyramid representations further activated the *recontextualisation principle*, with the teacher leveraging this difficulty as a productive site for learning. Rather than intervening to correct student efforts, she facilitated peer critique as a central mechanism for refining evidence. Through these exchanges, students came to recognise the inadequacy of initial models and iteratively improved them in response–mirroring the communal validation mechanisms of scientific inquiry (Osborne et al., 2004).

Other Observations

Evident in the data was the role the teacher played in the development of students shared language of both the discipline and argumentation to support communication. By doing so, she facilitated a common language to support students to effectively communicate, formulate and deliver the argument. The necessity to repurpose their informal language (and learning) and develop and use formal mathematical discourse was a prerequisite for the development and support of collective mathematical argument. This was established at the outset and conclusion with whole class discussions of argumentation terms and ideas, and through consistent use of the terminology throughout. The use of argumentation and mathematical language was present throughout, with the teacher often revoicing student comments, such as when a student referred to faces meeting at the 'top' and the teacher repeating but reframing 'the top' as 'apex'. The teacher drew the students' attention to specific vocabulary on many occasions (e.g., when discussing properties of triangles and pyramids). By adopting discipline and argumentation specific language, the students were supported in their communicative competence by having the language needed to articulate their ideas specifically. We have tentatively named this the *Discursive Knowledge Principle.* The teacher's approach exemplifies how epistemic and discursive practices are mutually reinforcing: as students acquired the disciplinary and argumentation language, their capacity to engage in collective reasoning also deepened.

Implications and Conclusions

Despite the many affordances of mathematical argumentation, there are still limited studies of argument-based learning practices in primary mathematics (Krummenhauer, et al., 2022). Specifically, there are few studies on teachers' instructional approaches and ways in which teachers can support development of student argumentation practices (Campbell et al., 2020).

Our findings affirm the transformative potential of collective argumentation when intentionally scaffolded within a rich disciplinary context. Through the implementation of collective argumentation principles, this research illuminates how students can develop epistemic agency in mathematics, fostering not only conceptual understanding but also the communicative competencies central to authentic argumentation. We further proposed the discursive knowledge principle as foundational in enabling this development, particularly in bridging everyday language with disciplinary and argumentation language. Our findings support that argumentation is not only a cognitive or structural task, but also a socially situated practice mediated by language. Thus, implications for teaching underscore the need for teachers to explicitly scaffold both the epistemic processes and the discursive tools required for constructing, evaluating, and communicating arguments.

Future research is warranted to investigate how students' discursive and epistemic practices co-develop over time, particularly in classrooms that value student agency and collaborative reasoning. Specifically, studies could examine how the development of disciplinary language and argumentation practices evolve in students across time and tasks. Longitudinal studies might further explore how students learn to internalise argumentation-specific language (e.g., claim, evidence, reasoning, rebuttal, qualifier) in relation to their capacity to engage in argument evaluation and construction. Such research could illuminate how discursive fluency supports deeper disciplinary argumentation mastery. In addition, future work could explore the multilingual and multimodal dimensions of discursive knowledge to investigate how representations, material artefacts, and translanguaging practices might contribute to students' capacity to engage in collective mathematical argumentation.

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