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Children's multimodal dialogue in a pattern activity

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This paper integrates dialogic and embodied theories of learning to investigate how multimodal dialogue unfolds as three 4-year-olds translate an AABCC block-tower pattern (blue, blue, white, red, red) into a pattern dance within a colour matrix. Drawing on data from an embodied design study, four interrelated aspects of the children's multimodal dialogue (flexibility, rhythm, gaps, and revoicing) were examined using synchronic and diachronic analyses. The findings show how flexibility functioned as an adaptive resource through which the children attuned to one another's actions, negotiated emerging meanings, and sustained collective understanding by dynamically coordinating speech, gesture, stepping, and sound. Rhythm supported anticipation and collective flow, while dialogic gaps, moments of hesitation or disruption, created openings for negotiation and meaning-making. Revoicing bridged these gaps through alignment of rhythm, speech, and movement into shared understanding. The study demonstrates how mathematical meaning emerges through multimodal voices, thereby foregrounding multimodality as a central dimension of early mathematical learning.

KEYWORDS
dialogical theories, early years mathematics, embodied learning, multimodal dialogue, repeating patterns

1 Introduction

Research in mathematics education has shown a growing interest in exploring the role of bodily movement and multimodality as resources for learning (e.g., Abrahamson et al., 2020; Ferrara, 2014; Lim 2020). Multimodal bodily experiences have been recognised as beneficial for cooperative learning in mathematics (Davidsen and Ryberg, 2017) and for enhancing mathematical performance (Shoval et al., 2018). Children's use of embodied multimodal resources can facilitate productive dialogues in mathematics, reveal misunderstanding, and result in changes in their mathematical expressions (Abdu et al., 2021). Similarly, collaborative embodied activities can promote communication and extend mathematical understanding (Walkington et al., 2019).

However, despite these promising results, research on embodiment in mathematics education has been criticised for a biased focus on individual processes, overlooking the relational, dialogic, and social dimensions of learning (Danish and Gresalfi, 2018; Shvarts and Abrahamson, 2019). At the same time, relatively little attention has been given to how children use multimodal resources to argue, reason, and communicate mathematically (Breive and Carlsen, 2021). Moreover, studies adopting dialogic perspectives have tended to emphasise verbal exchanges, giving less attention to how bodily, spatial, and material resources contribute to dialogue-based learning (Hetherington et al., 2018).

To address these limitations, this paper brings together embodied learning theories and dialogical perspectives, highlighting their shared emphasis on learning as social, situated and multimodal. Within this theoretical framework, we investigate how young children engage in multimodal dialogue during an embodied mathematics activity. Specifically, we chose the topic of patterns, as research highlights the need for deeper insight into early patterning abilities (Lüken, 2023; Wijns et al., 2019), and, in particular, how children explain and communicate repeating patterns (Lüken and Tiedemann, 2019). Based on this, we ask: What characterises children's multimodal dialogue in an embodied activity concerning repeating patterns? Specifically, we examine how children use and integrate speech, movement, and other modal resources to communicate and reason about patterns in peer interactions, focusing on four key aspects of multimodal dialogue: flexibility, rhythm, gaps, and revoicing. While our primary approach is qualitative, we complement it with quantitative measures to analyse multimodal flexibility, where children's coordination of verbal, movement-based, auditory, iconic, and concrete modalities are combined into multimodal bundles (Abdu et al., 2021; Arzarello, 2006). This integrated analysis provides a comprehensive understanding of how children express and negotiate mathematical meaning through embodied multimodal dialogue.

2 Theoretical background

This section first reviews research on multimodality in mathematics education, followed by an introduction to embodied and dialogical perspectives on learning. It then discusses multimodal rhythm and its relevance for repeating patterns, which form the mathematical focus of the study.

2.1 Multimodality in mathematics education research

Multimodality refers to the use and coordination of diverse modalities to convey meaning, such as visual, verbal, kinaesthetic, haptic-tactile and aural resources, to construct and convey meaning and is considered fundamental in human dialogue (Kress, 2010). From this perspective, mathematical learning is inherently multimodal (O'Halloran, 2015), and mathematical meaning-making can therefore be understood as a multimodal activity through which learners interpret, represent, and engage with their environment (Kress, 2010).

Based on a cultural-historical perspective on learning, Radford (2010, 2012, 2015) shows how speech and non-verbal semiotic means (e.g., physical action, gestures, movement, rhythm, tools and symbols) advances students' pre-symbolic knowledge of patterns towards abstraction. In one study, Radford (2012) examined an 8-year-old's development of abilities in pattern generalisation across grades 2–4. The findings revealed that gestures and physical actions, initially used to describe algebraic patterns, were not replaced by more abstract representations but rather underwent refinement: they became more integrated, deliberate, and conceptually charged. In another study, Radford (2015) showed how a combination of rhythmic grouping gestures, speech and visual and symbolic representations supported grade 9 students' generalisation of patterns. For much younger students, Lüken and Kampmann (2018) designed 13 lesson interventions in which first graders could create, recognise, use, describe and explain patterns and structures. Compared to the control group receiving normal teaching, the intervention had a transfer effect on the first graders' mathematical abilities, and this effect was particularly significant for low-achieving students. Wijns et al. (2020) found that 4- and 5-year-olds who spontaneously created a pattern when building a tower demonstrated better patterning and mathematical abilities than those who constructed randomly.

More recent research confirms that multimodal coordination and rhythm are integral to young children's early patterning and reasoning. In a comparative multimodal study of grade 1 students with high and low number-sense proficiency, Junker et al. (2024) found that both groups employed recursive strategies, yet students with higher number sense were more likely to use relational strategies grounded in multimodal awareness. Their analyses revealed that children frequently accompanied their patterning with verbal utterances such as "big, small, big, small," aligning the alternation of adjectives with rhythmic intonation and finger-pointing to visual elements in the pattern. Research also highlights the multimodal nature of children's learning and communication in other mathematical domains. In a comprehensive review of 24 studies, Ekowati et al. (2024) show how learners flexibly coordinate gestures, speech, symbols, drawings, artefacts, and digital media when reasoning mathematically. Their review identifies flexibility as a quality of creative mathematically founded reasoning, contrasting with imitative or algorithmic forms and enabling learners to shift fluidly between modalities to construct meaning. Ekowati et al. (2024) further report that oral and gestural resources often dominated these processes, highlighting reasoning as both embodied and communicative, while multimodal coordination strengthened conceptual understanding and supported transitions between contextual and abstract reasoning. This aligns with Nergård (2021) analysis of five-year-olds' play-based arguments, where multimodal interactions were integral to all reasoning stages, and with Johansson et al. (2014), who showed that 4–5-year-olds integrated gestures, peer collaboration, and tool use in their mathematical explanations. Comparable patterns appear in Schwarz and Prusak (2016) study of talented Grade 3 pupils, where gestures and material actions (drawing, folding, cutting) intertwined with verbal argumentation, and in Breive and Carlsen (2021) work on kindergarteners' collaborative geometry inquiries, marked by the interplay of speech, artefacts, and gesture. Extending into embodied contexts, Shoval (2011) found that full-body, mindful movement enhanced pupils' understanding of angles, while other embodied design studies link rhythmic bodily tempo to fluency in number sense (e.g., Bjørnebye, 2022). Nevertheless, multimodality may also poses cognitive challenge. Mayer and Moreno (2003) caution that simultaneous multimodal input may cause cognitive overload, a concern echoed in studies reporting adverse learning effects in mathematics among children (Posid and Cordes, 2019; Ruiter et al., 2015).

2.2 Conceptual framework: embodied and dialogical perspectives of learning

Embodied learning, grounded in interactionist traditions of embodied cognition (Stevens, 2012), views learning, thinking, and communication as relational processes enacted through bodily and multimodal actions situated in cultural and material contexts (Cresswell and Teucher, 2011; Flood, 2018; Nathan and Alibali, 2021; Newen et al., 2018; Wilson and Golonka, 2013). Within mathematics education, this view foregrounds how bodies, artefacts, and environments mediate collaborative meaning-making and participation in mathematical activity (Hall and Nemirovsky, 2012; Ma, 2017; Nemirovsky et al., 2013; Roth, 2011). Lim (2020) highlights the pedagogical implication of this perspective, observing that such an embodied teaching practice entails translating insights from multimodal communication into classroom practice. Researchers have further examined how embodied and dialogical participation intertwine in collective reasoning processes, revealing the temporal and rhythmic organisation of interaction (Bamberger and diSessa, 2003; Bautista and Roth, 2012; Kelton and Ma, 2018; Palatnik and Abrahamson, 2018). Rhythm in interaction, in particular, has been shown to structure joint attention and coordination in mathematical activity, functioning as a temporal resource for synchronising gesture, speech, and material engagement (Bautista and Roth, 2012; Milner et al., 2019). These embodied processes of coordination and multimodal meaning-making are inherently dialogical, as they unfold through the exchange of perspectives and the co-construction of understanding among participants.

Complementing embodied perspectives, dialogical theories conceptualise learning as emerging through the interaction of *voices*, socially and materially mediated perspectives situated within cultural and historical contexts (Asterhan et al., 2020; Bakhtin, 1987). A voice expresses an individual's position yet is shaped by the artefacts, tools, and semiotic systems through which it is enacted (Wegerif, 2006, 2011). When voices meet, their encounter constitutes *dialogue*, a dynamic exchange of meanings in which difference, rather than similarity, drives understanding (Asterhan et al., 2020). Through dialogue, voices become responsive and transformed, generating new perspectives and opening what Wegerif (2011) calls the *dialogic gap*, a space of potential learning that arises between differing understandings.

Within multimodal activity, these dialogical processes take embodied forms. When semiotic resources such as speech, gesture, gaze, posture, spatial positioning, and material engagement co-occur, they enact a multimodal voice (Abdu et al., 2021; Arzarello, 2006). The interaction between multimodal voices gives rise to *multimodal dialogue*, where alignment, tension, and responsiveness unfold not only through spoken language but also through bodily and material modalities. Each modality contributes a distinct layer of information, and meaning emerges through their orchestration and interplay (Radford, 2010). Extending Wegerif's (2011) concept, a *multimodal dialogic gap* refers to a moment of dissonance or misalignment within or between modalities, such as conflicting gestures, rhythms, or gazes, and signals the potential for new understanding. Rather than representing communicative failure, such gaps prompt participants to explore, clarify, or reconfigure their shared understanding. Within multimodal dialogue, multimodal revoicing functions as a central mechanism for bridging multimodal gaps (Flood, 2018). Revoicing describes the embodied uptake and reflexive transformation of one's own or another's contribution across modalities, such as reproducing or varying a gesture or rhythm. It makes prior understanding visible and re-negotiable through talk and bodily and material alignment. Drawing on Bakhtin's (1987) conception of dialogue as a responsive chain of utterances, revoicing exemplifies how learning emerges through iterative embodied reinterpretation, where each response both echoes and transforms what has come before.

A learner's ability to coordinate and shift between modalities to construct and communicate mathematical understanding is captured by the concept of multimodal flexibility (Abdu et al., 2021; Heinze et al., 2009). From an embodied learning perspective, such flexibility reflects children's capacity to extend thinking and co-construct meaning by mobilising the body as a communicative resource, enabling participation in collective activity through bodily, spatial, and material interaction. From a dialogical standpoint, it signifies the openness of one's multimodal voice to transformation through encounters with others (Bakhtin, 1984; Wegerif and Major, 2019). While multimodal revoicing denotes the interactional mechanism through which participants take up, transform, and respond to others' contributions, multimodal flexibility refers to the broader capacity that makes such uptake possible.

2.3 Translating patterns and multimodal rhythm

Mathematical patterns are sequences that follow a rule, exhibiting regularity in numerical, spatial, or logical relationships (Mulligan and Mitchelmore, 2009; Zippert et al., 2020). Repeating patterns, specifically, are defined by their cyclical structure, composed of smaller repeating units (e.g., ABBABBABB…), where the repeating segment (ABB) is known as the unit of repeat. The ability to create, copy, duplicate and extend repeating patterns and communicate their relationships is fundamental to developing an understanding of their structural regularities (Lüken and Sauzet, 2021). In translating repeating patterns, the unit of repeat remains invariant, while its modal and material properties may vary. The complexity of this translation ranges from exact copying or pattern extensions (maintaining full invariance) to pattern unit identification and the replication of its cyclical structure with full variance of modal or material properties. This deeper level of understanding requires multimodal flexibility and enables multimodal revoicing of a pattern, such as translating a cube tower of coloured blocks into spoken sequences ("Blue, red, red, blue, red, red, …"), iconic sequences (e.g., ⊿◯◯⊿◯◯ …), auditory sequences ("High tone, medium tone, medium tone, …"), or movement-based patterns ("Right foot, parallel jump, parallel jump, …").

The cyclical nature of repeating patterns is also visible in rhythm, the temporal production of form at regular intervals (Roth, 2011). Radford (2015) highlights rhythm's pivotal role in mathematical thinking, serving as a bridge from memory to imagination and fostering a sense of continuity that aids in anticipating future events. Within a multimodal context, rhythm encompasses the synchronised interplay of various modalities created by individual multimodal voices. For example, in the act of verbally counting steps (e.g., "One, two, one, two, …"), the body engages in rhythmic contact and separation from the ground, while the verbal and auditory modalities alternate between silence and sound in a coordinated temporal manner. According to Threlfall (1999), the unit of repeat can be articulated through rhythmic verbalisation, such as chanting the sequence (e.g., "Blue, red, red, blue, red, red, …"), or by explicitly describing its structure (e.g., "One blue and two reds"). The latter, involving a more analytical articulation of the repeating unit, is considered a higher level of abstraction.

2.4 The current study

Building on the theoretical perspectives outlined above, this study examines how multimodal dialogue unfolds when three four-year-olds translate a block-tower pattern into a full-body pattern dance within a colour matrix. Guided by embodied and dialogical perspectives, the analysis focuses on four aspects of multimodal dialogue: flexibility, rhythm, gaps, and revoicing. This enables us to explore how children coordinate modalities and develop shared mathematical understanding through embodied interaction.

3 Method

3.1 Embodied design study of early learning of patterns

With the written permission of their legal guardians, ten 4- and 5-year-olds were enrolled in an embodied design study on pattern learning, conducted in accordance with Norwegian ethical guidelines (NESH, 2016). This study involved five intervention sessions with pattern activities in a designed environment on asphalt, located nearby the kindergarten, facilitated by a kindergarten teacher and a researcher. In addition, individual and group-based post-testing were conducted. All sessions and tests were recorded on video. Based on our unified framework of embodied and dialogical theories of learning, four design principles (DPs) were selected to guide the design, evaluation and redesign of the activities: (DP1) Extensions of pattern knowledge in full-body performance and multimodal interaction (Nathan and Alibali, 2021; O'Halloran, 2015); (DP2) Aesthetic and expressive qualities of full-body performance (Bjørnebye et al., 2023; Bjørnebye and van Bommel, 2025); (DP3) Collaboration and multimodal dialogue (Abdu et al., 2021; Wegerif, 2006); and (DP4) Guided play.

As part of the study, Bjørnebye (2026) addressed DP1 by examining the case of a 5-year-old, focusing on the multimodal transformation of pattern knowledge across linear and non-linear arrangements of pattern elements. Drawing on variation theory of learning, the case study demonstrated how rhythmic, verbalised full-body movements and spatial interactions with dispersed and structured visual elements (see matrices in Figure 1 below) supported the discernment of the repeating unit in a self-created AABBC model pattern. The data excerpt analysed in the present paper stems from the group-based post-testing sessions, featuring the 4-year-olds Idar, Eline, and Mary (pseudonyms). In line with our research objective, we focus on DP3, with emphasis on the multimodal dialogue within the collaborative pattern activity described below.

3.2 Settings and context of the pattern activity

A key principle for the design of multimodal learning environments is the facilitation of transitions between different representations and modalities (Ainsworth et al., 2002). Following this, the mathematical learning objective of the activity was translating a pattern using different modalities while preserving its repeating unit (DP1). The research facilitator introduced the activity by using coloured blocks (10 cm·10 cm·5 cm), arranged in the AABC pattern (i.e., a "blue, blue, white, red" tower). The children, in groups of three, were guided through the process of translating this concrete pattern into a dance on a colour matrix painted on the ground, featuring two blue, two red and two white dots (DP1). Next, the children used blocks to design their own pattern and then transformed it into a dance (DP1 & 2). Each child then guided their peers in learning the dance (DP3). To foster multimodal dialogue, they could freely draw on available modal resources (e.g., blocks, the matrix, gestures, speech and movement).

3.3 Data selection, coding and reduction

Following a deviant case selection strategy (Seawright and Gerring, 2008), the excerpt examined in this paper was chosen because the children assumed a dominant role in driving the multimodal dialogue, thereby highlighting the comparatively passive involvement of the facilitator (the first author). The excerpt consists of 3:57 min of video data, initially transcribed and analysed in Norwegian and subsequently translated into English. The transcription is structured into numbered segments, each corresponding to an individual's voice. The formation of segments assumes the inclusion of the verbal modality. From the full dataset, we excluded segments involving non-mathematical utterances or actions, instructional prompts, and instances of speech unaccompanied by mathematical activity. The remaining material thus consisted of multimodal episodes in which mathematical meaning was expressed through coordinated bodily, material, and verbal modes. To support our qualitative analysis, we conducted basic quantitative counts of modality frequency and co-occurrence patterns, allowing us to triangulate the prevalence and combinations of modal resources used. Table 1 builds on and adapts Kress's (2010) semiotic framework of multimodality, illustrating the modalities considered in our analysis and providing a signature description of each modality coded.

TABLE 1 Overview of modalities with signature descriptions.

Modality	Description
Verbal	Spoken articulation of pattern elements (e.g., "*blue, blue, red, red*").
Movement (bodily action)	Stepping: Feet moving onto dots to mark pattern elements. Touching gestures: Fingers or feet briefly tapping/touching dots or blocks. Pointing gestures: Fingers or feet indicating pattern elements without contact.
Auditory	Distinct sounds generated by stepping on pattern elements.
Iconic	Engagement with the six-dotted matrix either directly, through stepping or touch-pointing with the feet or hands, or indirectly, through gestures referencing the dots without physical contact.
Concrete	Concrete–tangible: Physical interaction with the block tower (e.g., touching blocks to represent pattern elements).

Building on the categorisation in Table 1, a pattern-related unit was defined as any verbal, bodily, auditory, iconic, or concrete action indexing a pattern element, for example naming a colour, or producing a sound through stepping. Visual input was not included in the coding. The following segment illustrates the identification of pattern-related units:

> *Blue, blue, white, red, red* [Stepping (on corresponding colour dots)—slow tempo (6 s), with a brief glance at the block tower before stepping on the white dot]

In this segment, ten pattern-related units were identified: five verbal units (colour naming) and five movement units (stepping actions), while the visual action of glancing at the block tower was excluded from the coding. To capture how these units coordinate within a multimodal voice, the analysis applies the concept of the multimodal bundle (Abdu et al., 2021; Arzarello, 2006). Bundles are identified only when the verbal modality is present through colour naming. Accordingly, the segment is coded as five Verbal–Movement (stepping)–Auditory–Iconic (matrix) bundles. These bundles constitute the empirical units through which multimodal dialogue is analysed.

3.4 From theory to analytical concepts

The analytical approach operationalises the integration of embodied and dialogical perspectives by examining how mathematical understanding emerges through multimodal dialogue, as children's voices interact, diverge, and realign across bodily, verbal, and material modes. The identified bundles are analysed through both synchronic and diachronic lenses (Arzarello et al., 2009). The synchronic lens captures how modalities are coordinated within a bundle at a given moment, whereas the diachronic lens traces how successive bundles unfold and transform over time, revealing the temporal organisation of children's multimodal activity. Through this dual perspective, the analysis focuses on four interrelated aspects of multimodal dialogue: flexibility, rhythm, gaps, and revoicing.

Multimodal flexibility refers to how children coordinate and shift between semiotic resources to construct mathematical understanding. Synchronic analysis examines the flexibility and orchestration of modalities within each bundle, while diachronic analysis traces how these configurations evolve over time. Quantitatively, flexibility is reflected in the frequency and diversity of modal combinations (bundles); qualitatively, it is interpreted through the responsiveness of multimodal coordination in the expression of mathematical ideas.

Multimodal rhythm focuses on the temporal structuring of children's dialogue by capturing how recurring patterns of gesture, movement, and speech sustain anticipation, flow, and the transformation of meaning (Bautista and Roth, 2012; Kelton and Ma, 2018; Palatnik and Abrahamson, 2018; Radford, 2015). Tempo is analytically classified as slow, medium, or fast according to the time span between the first and last coded bundle in a segment (rounded to the nearest whole second). A slow tempo denotes fewer than one bundle per second, a medium tempo approximates one per second, and a fast tempo exceeds this rate, including transitions under one second (marked as <1).

Multimodal dialogic gaps refer to moments of discontinuity or tension between multimodal voices (Wegerif, 2011). Synchronic analysis identifies these as disruptions in ongoing coordination, while diachronic analysis traces how the children respond to such dissonances and adjust, clarify, or reformulate, revealing how meaning is reorganised across time.

Multimodal revoicing captures how children respond to either their own or others' prior expressions to sustain, refine, or transform shared understanding (Flood, 2018). Instances are identified when a child mirrors, adjusts, or integrates aspects of a previous multimodal expression, whether drawn from a peer's or from their own earlier multimodal voice. Synchronically, revoicing appears in moments of embodied alignment where coordination is enacted; diachronically, it becomes visible as the re-enactment and transformation of earlier expressions in later interactions.

Taken together, these analytical dimensions illuminate how coordination within bundles and their temporal development across interaction shape the emergence of multimodal dialogue in children's collaborative mathematical activity, revealing how mathematical understanding develops through the evolving interplay of their multimodal voices.

4 Results

In the following a full excerpt is provided to increase transparency of our data and analysis.

4.1 The episode: children's multimodal dialogue of repeating patterns

The transcription approach follows semiotic principles of multimodal transcription (Bezemer and Mavers, 2011), in which written conventions are used to represent the orchestration of multiple modalities within interaction. In the transcribed episode, text in brackets [ ] indicate tone and mode of speech, gaze, movement tempo, body orientation, and other non-verbal actions conveying information on the children's multimodal dialogue. Speech is presented in italics. The episode is based on Eline's tower design, which consist of a blue block at the bottom, followed by another blue, then white, red and red, forming an AABCC pattern. The episode begins when the research facilitator invites Eline to guide Mary and Idar in learning the pattern dance.

1. Eline: [Casting a glance at the tower, enters the 6-dotted matrix; Figure 1] *Blue, blue, white, red, red* [Stepping on corresponding dots, looking at the tower after each of the three first steps (slow tempo; 6 s)]. *Now, it is your turn* [looks at Mary and then at Idar]
2. Mary: [Casting a glance at the tower] *Blue, blue* [Steps on two blue dots (fast tempo; 1 s). Halts and twists her body to examine the dots behind her]
3. Eline: [Looking at Mary's dance] W*hite* [While glancing at the tower (medium tempo; 1 s)]
4. Mary: [Turns towards Eline] *No, don't do that* [Holding a frustrated tone]
5. Mary: [Looking at the tower] *Blue, blue, white, red, red.* [Stepping on corresponding dots, glancing at the tower after each of the three first steps (slow tempo; 9 s)]
6. Eline: *Now it's Idar* [Turning towards Idar's matrix]
7. Mary: *I think it's a very nice dance*.
8. Idar: *Blue, blue, white, red* [Stepping on corresponding dots (slow tempo; 5 s), not looking at the tower]
9. Eline: [Observing Idar's dance and then making eye contact with him] *Two more red. No, I mean one red more. It is one red more, Idar*.
10. Eline: [Enters Idar's matrix] *Blue, blue, white, red, red* [Using her right foot to touch corresponding dots in conjunction with her verbal explanation (fast tempo; 3 s); Figure 2]
11. Idar: [Casting a glance at the tower] *Blue, blue, red, red, white* [Stepping on corresponding dots, looking at the tower after the second and fourth step (slow tempo; 6 s)]
12. Facilitator: *Eline, can you show Idar how to do it in the right order?*
13. Eline: *Blue, blue, white, red, red.* [Clear articulation while stepping (fast tempo; 4 s)]
14. Idar: [Looks at Eline's first two steps] *Blue, blue, red, red, white* [Stepping on corresponding dots; Figure 3, looking at the tower before the final step (fast tempo; 4 s)]
15. Eline: *Uhm* [Frustrating tone] *Blue, blue, white, red, red.* [Stepping (fast tempo; 4 s)]
16. Idar: [Observing Eline's dance] *Blue, blue, red, red, white, white.* [Stepping (medium tempo; 6 s); Figure 4]
17. Facilitator: *Was it correct, Eline?*
18. Eline: [Shakes her head] *It is blue, blue, white, red, red* [Finger pointing at the tower (fast tempo; 3 s), Idar is observing Eline's action; Figure 5]
19. Idar: [Casting a glance at the tower] *Blue, blue, red, red.* [Stepping (slow tempo; 5 s)]
20. Eline: [Interrupting] *No, it's not correct. Look there* [Pointing at the tower, moves towards it]. *It is blue, blue, white, red and red* [Finger touching blocks (fast tempo; 3 s), Idar is observing; Figure 6]
21. Eline: [Looking up at Idar] *Blue, blue* [short pause], *white* [short pause], *red, red.* [Three-parted finger touching on blocks (fast tempo; 4 s), Idar is observing; Figure 7]
22. Eline: [Looking at Idar] *Do it like that now. Blue, blue* [Finger touching blocks (medium tempo; 2 s), looks at Idar]
23. Idar: *Blue, blue.* [Stepping (fast tempo; 1 s), halts. Not looking at Eline]
24. Eline: *White* [Finger touching white block (fast tempo; <1 s), looks up at Idar]
25. Idar: [Glances behind] *White* [Stepping (fast tempo; <1 s), halts. Not looking at Eline]
26. Eline: *Red, red.* [Finger touching two red blocks (medium tempo; 2 s). Looks at Idar]
27. Idar: *Red, red.* [Stepping (fast tempo; 1 s)]
28. Facilitator: *Nice, how good you are at teaching, Eline*.
29. Eline: *I pointed at them so he would remember them. That's what's clever [lurt in Norwegian]*
30. Facilitator: *Now, you are all going to dance, in turn.*
31. Eline: *Me first. Blue, blue, white, red, red* [Stepping (fast tempo; 3 s)]
32. Facilitator: *And then you, Mary*.
33. Eline: [Walks to the tower] *Blue, blue, white, red and red* [Finger touching blocks (fast tempo; 2 s)]
34. Eline: *Blue, blue* [Short pause], *white* [short pause], *red, red* [Three-parted touch, looking at Mary in between each part (slow tempo; 6 s)]
35. Mary: *No, not Eline*.

FIGURE 1
Eline's first attempt to dance the AABCC-pattern.

FIGURE 2
Rhythmic use of the foot in conjunction with speech.

FIGURE 4
The emergence of a multimodal gap.

FIGURE 3
Idar guided by eline's multimodal voice.

FIGURE 5
Rhythmic pointing gestures.

36. Facilitator: *Okay. Then you can take it first, Mary. Come on.*
37. Mary: *Blue, blue, red, red.* [Stepping (slow tempo; 6 s). Looks at tower] *No.*
38. Facilitator: Now, how is it?
39. Mary: *Blue, blue, white, red, red.* [Stepping. looks at the tower after the fourth step (slow tempo; 6 s)]
40. Facilitator: *Yes, and then it is Idar's turn.*
41. Eline: *Blue, blue* [Touch-pointing at blocks (medium tempo; 2 s). Looking at Idar]
42. Idar: *Blue, blue* [Stepping (fast tempo; 1 s)]
43. Eline: *White* [Touch-pointing (fast tempo; <1 s). Looking at Idar]
44. Idar: [Twist to glance back] *White* [Stepping (fast tempo; <1 s)]

FIGURE 6
Rhythmic touching gestures.

FIGURE 7
Three-parted multimodal revoicing.

45. Eline: *Red, red.* [Touch-pointing (fast tempo; 1 s). Looking at Idar]
46. Idar: *Red, red.* [Stepping (fast tempo; 1 s)]
47. Facilitator: *Yes!*
48. Eline: *That's why I pointed at them.*
49. Facilitator: *And then it's Eline's turn.*
50. Eline: *Blue, blue, white, red, red.* [Stepping (fast tempo; 3 s)]

4.2 Synchronic analysis: multimodal flexibility

The synchronic analysis highlights the children's flexibility in using and communicating pattern information through multimodal bundles. It also provides insights into intermodal consistency or inconsistency, with the latter potentially resulting in gaps in the multimodal dialogues. Within the 50 transcribed segments, 16 included instructional prompts or verbal responses without pattern integration (#4, 6, 7, 12, 17, 28, 29, 30, 32, 35, 36, 38, 40, 47, 48, 49). Segment #9 was unique, including unimodal communication of pattern knowledge through speech. Table 2 summarises the multimodal bundles identified in the 33 remaining segments, forming the foundation of the children's multimodal voices.

The dominant combination (i.e., Verbal–Movement–Auditory–Iconic) occurred in 20 segments, illustrating how synchronisation across speech, sound, and movement structured the multimodal voices in which patterns were enacted and negotiated. A second cluster, Verbal–Movement (finger touching)–Concrete–tangible (tower), anchored verbal expressions in tactile exploration. Less frequent bundles reflected variations in modality use rather than fundamentally different forms of multimodal interaction. The few segments without pattern integration were mainly driven by instructional prompts or evaluative comments, marking temporary shifts away from collective multimodal engagement. Overall, the multimodal bundles reveal a consistent alignment between verbal and embodied modalities, indicating that pattern understanding was enacted through flexible coordination of multimodal voices.

TABLE 2 Appearance of multimodal bundles (number of segments, segment references and frequency).

Multimodal bundle	Number of segments	Segment reference number	Frequency
Verbal—Movement (stepping)—Auditory—Iconic (matrix)	20	1, 2, 5, 8, 11, 13, 14, 15, 16, 19, 23, 25, 27, 31, 37, 39, 42, 44, 46, 50	75
Verbal—Movement (finger touching)—Concrete–tangible (tower)	10	20, 21, 22, 24, 26, 33, 34, 41, 43, 45	30
Verbal—Movement (pointing)—Concrete–visual (tower)	1	18	5
Verbal—Movement (feet touching)—Iconic (matrix)	1	10	5
Verbal—Concrete–visual (tower)	1	3	1

4.3 Diachronic analysis: temporal organisation of multimodal bundles

While the synchronic analysis captured momentary configurations of modalities, the diachronic analysis traces how children's multimodal voices evolve over the course of the interaction. This temporal perspective highlights how rhythm, tempo, and revoicing shape participation over time and how dialogic gaps create opportunities for renegotiating meaning.

Figure 8 visualises the distribution of multimodal bundles across the 33 analysed segments. This distribution reveals a dynamic alternation between fast, medium, and slow multimodal rhythms. Segments with tightly aligned bundles (e.g., #14) displayed rapid transitions and synchronised timing between modalities, forming sequences coded as *fast*. In contrast, slower segments often coincided with dialogical gaps, moments when one participant paused or hesitated, prompting adjustment in the collective tempo.

These rhythmic variations mark shifts between individual and collective multimodal voices. For instance, in segment #14, Idar's brief misalignment with Eline's embodied rhythm constituted a multimodal gap rather than a coordination error, illustrating how difference and temporal dissonance generated opportunities for renewed alignment. Overall, the diachronic organisation of multimodal bundles reveals rhythm as a generative mechanism through which the children maintained coordination, adapted to one another's timing, and transformed hesitation into shared mathematical meaning.

4.3.1 Multimodal rhythm

Rhythm here refers to the recurrence and transformation of the AABCC pattern across modalities, revealing how temporal

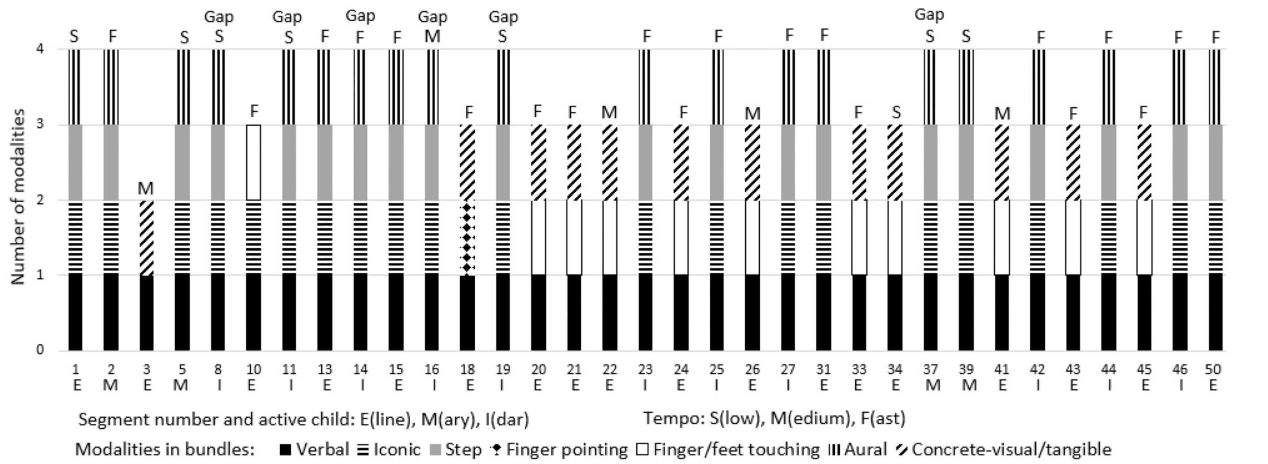

FIGURE 8
Multimodal bundles in the children's voices by segment.

organisation structured multimodal dialogue. Mary and Idar each reproduced the pattern twice, relying respectively on visual cues from the tower (#5, 39) and on Eline's verbal and embodied guidance (#22–27, 41–46). In contrast, Eline enacted thirteen repetitions, displaying flexibility in shifting between movement forms, dancing, foot or finger touching, and pointing, while maintaining rhythmic coherence (Figures 1, 2, 5–7).

Tempo introduced a further dimension to this rhythmic multimodal dialogue. Both Eline and Mary began with slow, segmented pacing guided by the tower's visual structure (#1, 5). As Eline internalised the pattern, her tempo became increasingly fluid, alternating between fast, medium, and slow phases across bundles (#20–23, 33–34). A key instance occurs in her three-part revoicing of "Blue, blue/white/red, red," where vocal modulation aligned precisely with embodied rhythm (#22–27). This progression exemplifies how rhythmic variation sustained the dialogic flow, transforming repetition into prediction and linking the children's multimodal voices within a shared temporal frame of collective dialogue.

4.3.2 Multimodal gaps and revoicing

The diachronic lens also revealed moments of temporary misalignment in the children's multimodal voices, here termed multimodal gaps. Six such gaps were identified, five in Idar's segment (#8, 11, 14, 16, 19) and one in Mary's (#37), each prompting adaptive responses in Eline's voice. These gaps activated diverse multimodal strategies, including shifts in body movement (#15), verbal explanation (#3), finger-pointing (#18), and tactile engagement with the tower. In the final observed gap (#19), for instance, Eline responded to Idar's error with a multimodal revoicing: "No, it's not correct. Look there…", followed by rhythmic finger-touching and verbal repetition of "blue, blue, white, red, red". Her modulation from a fast to a slower tempo (#20–26) exemplifies how revoicing bridged the dialogic gap by combining embodied and verbal modalities to re-establish shared understanding. Rather than signalling breakdown, these multimodal gaps functioned as productive spaces for negotiation, allowing rhythm and revoicing to realign voices and sustain the flow of multimodal dialogue.

5 Discussion

To characterise children's multimodal dialogue during a pattern activity, this paper focused on four interrelated aspects of multimodal interaction: flexibility, rhythm, gaps, and revoicing, that together reveal how mathematical meaning emerged through embodied and dialogic coordination.

5.1 Multimodal flexibility in children's voices

Prior research demonstrates that multimodal flexibility enables learners to coordinate and shift across multiple modalities and representations, thereby deepening mathematical understanding (Abdu et al., 2021; Heinze et al., 2009). The present analysis extends this insight by showing how flexibility supported children's capacity to sustain shared understanding within collective dialogue. Across 33 segments, over 100 multimodal bundles were identified (Table 2). These bundles captured how children dynamically adapted to one another's voices, adjusting bodily, verbal, and spatial modalities in response to peers' actions. Consistent with dialogic perspectives on learning as co-constructed and responsive (Wegerif and Major, 2019), flexibility functioned as a condition for maintaining participation and coherence. While oral and gestural (finger touching/pointing) modes dominated, as in Ekowati et al. (2024), our findings reveal that stepping, in synchrony with colour naming, served as a distinctive embodied resource for pattern learning, linking rhythm, perception, and coordination within the children's multimodal dialogue.

5.2 Rhythm as shared temporality

Rhythm, understood as the temporal structuring of multimodal activity, proved decisive for sustaining joint attention and collective flow. Consistent rhythmic beats produced by footsteps on the coloured dots, accompanied by verbal cues such as "blue, blue, white, red, red," synchronised auditory, verbal, and spatial modalities (Radford, 2010). Eline's division of the pattern into three parts using touching gestures exemplified how rhythm enabled her and Idar to coordinate attention and sustain mutual engagement, demonstrating how rhythmic structuring supported collaborative focus. Building on research identifying rhythm as a temporal resource for coordinating gesture, speech, and material engagement (Bamberger and diSessa, 2003; Bautista and Roth, 2012; Kelton and Ma, 2018; Milner et al., 2019; Palatnik and Abrahamson, 2018), our findings show how rhythmic regularities scaffolded expectation, alignment, and collective coherence. Rhythm thus functioned not merely as repetition but as shared temporality, structuring how multimodal dialogue evolved. In line with Radford (2015) notion of rhythm as bridging memory and imagination, rhythmic synchrony transformed repetition into prediction, enabling participants to anticipate one another's actions and sustain flow. While earlier studies often framed rhythm as an individual expressive resource (Bjørnebye, 2026; Junker et al., 2024; Threlfall, 1999), this analysis foregrounds its dialogic and relational role, a shared temporal frame through which multimodal voices were coordinated into collective dialogue.

5.3 Multimodal dialogic gaps as openings for co-construction

Multimodal dialogical gaps, defined as moments of disruption or hesitation (Wegerif, 2011), were found to play a generative role in shaping the unfolding of the children's multimodal dialogue. Rather than signalling communicative breakdowns or failures, these moments functioned as potential learning spaces in which responsive engagement was invited. They can thus be understood as productive spaces of difference that opened opportunities for renewed negotiation of meaning. Eline's response exemplified learning between voices: rather than instructing, she slowed her tempo and shifted from stepping to pointing and touching gestures to sustain mutual engagement. Such responsiveness demonstrates how embodied coordination enacts dialogic meaning-making, where tension and contrast become drivers of collective understanding (Bakhtin, 1984; Wegerif, 2011). This interpretation aligns with research showing that multimodal activity, compared to speech alone, supports semiotic refinement as embodied and dialogical resources are progressively recombined and re-coordinated in more sophisticated ways (Arzarello and Sabena, 2014; Bridges et al., 2020; Radford et al., 2017). The observed multimodal gaps also reveal the cognitive demands of integrating multiple modalities simultaneously (Mayer and Moreno, 2003), underscoring the importance of rhythmic support in maintaining shared understanding.

5.4 Multimodal revoicing as dialogic alignment

Multimodal revoicing emerged as the mechanism through which dialogic gaps were bridged and dialogue re-aligned. By synchronising her rhythm, speech, and movement with Idar's tempo, Eline recontextualised his hesitant contributions within the shared flow of the activity. This process resonates with the view of revoicing as a responsive re-articulation that both acknowledges and reshapes meaning (Flood, 2018). In aligning her embodied tempo and verbal cues, Eline reduced cognitive load, strengthened temporal contiguity (Mayer and Moreno, 2003), and reinforced Idar's multimodal understanding of the AABCC pattern. As coordination stabilised, Idar's participation became increasingly synchronised and responsive, marking a shift towards collective contribution. In this sense, revoicing acted as embodied alignment, sustaining rhythm and coherence in the face of difference. Consistent with prior work showing that multimodal dialogue integrates speech, gesture, and artefacts into shared explanation (Breive and Carlsen, 2021; Johansson et al., 2014; Nergård, 2021; Schwarz and Prusak, 2016), our findings further demonstrate how rhythmic synchronisation and revoicing transform dialogic gaps into moments of shared insight.

5.5 Summary and contributions

Both dialogical and embodied learning theories emphasise that learning is culturally embedded and situated in multimodal activity (Cresswell and Teucher, 2011; Flood, 2018). By integrating these perspectives, this paper advances the growing research base connecting embodied and dialogical frameworks in mathematics education (e.g., Bridges et al., 2020). Framing multimodal interaction as a dialogic process, unfolding through rhythmic negotiation, responsive alignment, and revoicing, the analysis shows that mathematical understanding is co-constructed between voices through the embodied orchestration of multiple modalities in dialogue. The findings reaffirm the central role of embodied and multimodal resources in mathematical learning (Davidsen and Ryberg, 2017; Walkington et al., 2019) while supporting calls to move beyond speech-centred views of communication (Flood, 2018; Hetherington et al., 2018). Multimodality thus emerges as a key condition for dialogic participation and shared meaning-making.

Methodologically, the study contributes to multimodal research by combining synchronic and diachronic analyses to trace both micro-level coordination and the temporal unfolding of dialogue. While the close analysis of a brief interaction necessarily provides a partial view, it offers fine-grained insight into the embodied mechanisms underpinning collective mathematical dialogue. Responding to calls for a deeper understanding of how young learners communicate and reason about repeating pattern (Lüken, 2023; Lüken and Tiedemann, 2019; Wijns et al., 2019), the study also answers Lim (2020) call to translate multimodal insights into embodied teaching practice. Extending previous research on gesture and tool use (e.g., Walkington et al., 2019), it foregrounds the rhythmic, bodily, material, and relational dimensions of children's multimodal dialogue. In doing so, the study contributes a nuanced account of how embodied coordination and multimodal revoicing transform collective activity into shared mathematical insight, pointing towards new directions for both research and pedagogical practice in early mathematics learning.

Designing for embodied and multimodal dialogue supports more equitable participation as it widens what "counts" as mathematical competence and allows learners with diverse strengths to engage meaningfully in patterning activities. Regarding the mathematical content, the paper shows that by coordinating modalities to repeat the AABCC pattern, children learned to stabilize and preserve the unit of repeat, translate structure across modalities, and use rhythm to anticipate and predict rather than merely copy. These processes reveal early mathematical learning as fundamentally embodied, rhythmic, and dialogic, structured through joint attention, temporal coordination, and peer responsiveness.

The case highlights conditions that enabled particularly rich multimodal coordination: an activity design requiring modal translation, materials that afford rhythm, space for peer-led guidance, and a facilitation style that allowed dialogic gaps to become productive. These conditions can guide implementation in other settings where multimodal dialogue and embodied learning are central.

Data availability statement

The datasets presented in this article are not readily available because the data supporting the findings of this study consist of video recordings of young children and cannot be shared publicly due to privacy and ethical restrictions. Data are stored securely at Inland Norway University of Applied Sciences in accordance with NSD and NESH guidelines. De-identified excerpts may be made available from the corresponding author upon reasonable request and within ethical constraints. Requests to access the datasets should be directed to morten.bjornebye@inn.no.

Ethics statement

The project was approved by the Norwegian Centre for Research Data (NSD) and was conducted in accordance with the ethical guidelines of the National Committee for Research Ethics in the Social Sciences and the Humanities (NESH). The project received institutional ethical guidance at Inland Norway University of Applied Sciences and was conducted in accordance with established procedures, local legislation, and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin. Written informed consent was obtained from the minor(s)' legal guardian/next of kin for the publication of any potentially identifiable images or data included in this article.

Author contributions

MB: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. JvB: Conceptualization, Formal analysis, Methodology, Validation, Writing – review & editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declared that generative AI was used in the creation of this manuscript. Generative AI (ChatGPT) was used solely for language editing and proofreading. All intellectual content, analysis, argumentation, and interpretations are the author's own.

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