

Research Article

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Expressive Extensions of Number Sense in Embodied Task Design Through Full-Body Performance

Morten Bjørnebye , Jorryt van Bommel

Abstract

Background/purpose. STEAM (Science, Technology, Engineering, Arts, Mathematics) research and embodied design research have explored the role of full-body movement and multimodal actions in mathematical learning. However, the expressive and dynamic aspects of embodied mathematics learning remain underexplored. This paper aims to address this gap by investigating the expressive dimensions of six- to nine-year-olds' extensions of number sense through full-body performances.

Materials/methods. This paper explores two outdoor mathematical activities developed as part of an embodied design study. Using an adapted version of the Laban/Bartenieff movement framework, our descriptive analysis focused on the following expressive themes: (i) pace, (ii) weight, (iii) bodily coordination and spatial interaction, (iv) body shape and improvisation, and (v) the phrasing of these themes and their alignment with number sense.

Results. The findings highlight the dynamic and flexible interconnections among these expressive themes of bodily performance, demonstrating varying degrees of correlation with students' number sense. This dynamic interplay of expressive themes fosters an artistic and creative approach to mathematical experiences, encouraging personal interpretation and deepening student engagement.

Conclusion. Theoretically, this paper enriches our understanding of the notion of expressiveness within the embodied perspective of learning. It also underscores the potential of embodied learning designs, offering insights for educators to integrate expressive dimensions of full-body movement into their teaching practices.

1. Introduction

STEAM (Science, Technology, Engineering, Arts, Mathematics) research emphasises interdisciplinary and creative approaches to mathematics learning (e.g., Chalmers et al., 2017; Colucci-Gray et al., 2017). Among these approaches, the embodied perspective of learning stands out for its emphasis on creativity, expression, emotion, and aesthetic experience, offering students meaningful ways to connect with mathematical ideas (Sinclair, 2004). This perspective places less emphasis on the separation of representations into external and internal, instead favouring an extended and relational view in which cognitive processes are seen as intertwined with bodily actions and the environment (Newen et al., 2018). Embodied learning is recognised as a vital approach to student-centred and innovative educational interventions, supporting the development of core mathematical competencies that is essential for the twenty-first century (Paniagua & Istance, 2018).

Previous embodied research has shown how gestures, finger tracing and arm movements might support students' mathematical learning (Novack et al., 2014; Radford et al., 2017). Other studies have explored the connection between full-body movement and students' mathematical learning within digital learning environments (e.g., Dackermann et al., 2016; Ruiter et al., 2015). The incorporation of full-body movement is also recognised in STEAM research, which demonstrates how creative dance (e.g., Leandro et al., 2018) and physical activity can enhance learning (e.g., Hraste et al., 2018; Mavilidi et al., 2018; Mullender-Wijnsma et al., 2016) and foster engagement in mathematics (e.g., Riley et al., 2017). However, with some notable exceptions (Bjørnebye & van Bommel, 2025; Leandro et al., 2018), there is limited understanding of the dynamic movement qualities that underpin embodied learning in mathematics, particularly in cases involving full-body performance.

To address this gap, we present findings from an outdoor embodied design project conducted at a Norwegian primary school, examining the expressive dimensions of students' extensions of number sense through full-body performance. Specifically, we ask: What characterises the expressive dimensions of students' extensions of number sense in full-body performance? Our aim is twofold: firstly, to contribute to embodied design and STEAM research by exploring the integration of mathematics and the arts through bodily expressiveness; and secondly, to advance the theoretical understanding of expressiveness within embodied mathematics learning.

2. Literature Review

2.1. Review of STEAM and embodied design studies in mathematics involving full-body movement

The integration of arts and mathematics within STEAM research is supported by several studies. For instance, Parsley and Soriano (2009) demonstrated how geometric concepts can be embodied through static dance postures, such as depicting the edges and vertices of Platonic solids. In a more dynamic vein, Leandro et al. (2018) showed that 7- and 8-year-olds achieved better mathematical outcomes through creative dance activities compared to traditional instruction. These activities encouraged exploration of numbers, operations, quantities, and measurements through movement and physical expression. Similarly, Wood (2008) used rhythmic square dancing to enhance students' number sense.

Other projects, like Budinski et al. (2022), extended mathematical concepts into expressive embodied movements, including angles, vertices, and theorems like the sum of angles in a triangle. Fenyvesi et al. (2019) presented Maths in Motion, a multisensory, STEAM-based embodied learning programme that enables creative and imaginative exploration of the structural, spatial, rhythmic, and symbolic aspects of mathematics through the integration of body movement and kinaesthetic learning. Using a design-based approach, the programme developed five modules: symmetry,

geometric shapes, patterning, problem-solving, and number discrimination (including positive and negative numbers). In one module developed for kindergarten, children stepped in rhythm to elephant and monkey footprints, engaging with patterning through contrasting tempos. In another module designed for lower-secondary students, they embodied positive and negative numbers, physically experiencing the structure of the number line to support abstraction.

Within embodied design studies, Duijzer et al.'s (2019) review of learning environments focused on graphing motion found that real-world contexts and representations were two common factors mediating students' learning. The study showed that embodied learning environments that immediately linked students' own movements to their representations were most effective in terms of learning outcomes. The following two studies, both of which modelled the mental number line and utilised digital learning environments, exemplify this. On study, by Ruiter et al. (2015), compared two non-movement conditions to two full-body movement conditions (one including self-observation in a mirror) in the investigation of 7-year-olds' learning of two-digit numbers. In the movement conditions, the students were instructed to verbalise/speak out loud while taking small, medium, and large sideways steps for the representation of the numbers 1, 5 and 10, respectively. The results showed significantly better performance among students who engaged in full-body movement with a high degree of task integration, compared to those under the two non-movement conditions (Ruiter et al., 2015). In contrast to the studies by Leandro et al. (2018) and Fenyvesi et al. (2019), which integrated similar mathematical concepts into rhythmic embodied activities, Ruiter et al.'s (2015) approach restricted movement to linear, sideways steps.

A similar restriction of embodied engagement was observed in the study by Dackermann et al. (2016), who compared two representational formats in investigating 6- and 7-year-olds' abilities in the equidistant spacing of numbers. Students under the control condition used an electronic pen to segment a line displayed on a computer by drawing equally spaced dashes. The embodied condition involved walking with equally spaced steps in the representation of numbers. The results showed that students in the bodily movement condition outperformed those in the computer-based condition.

Regarding embodied design studies in outdoor contexts, there exists some sparse evidence that dynamic movement qualities such as pace and rhythm can serve as embodied extensions of mathematical ideas. An example can be found in Bjørnebye's study (2022), which showed that 4- and 5-year-olds' use of coordinated and timed bodily movements, such as rhythm, force, and tempo, was associated with the degree of fluency in counting-on strategies. Bjørnebye and Sigurjonsson (2020) also examined 3- and 4-year-olds' use of their body in navigation from A to B across a circle of multiple dots in their physical mapping of the numbers 1 to 4 on the ground. They showed that the ability to spontaneously perceive numerosity in the spatial environment influenced both navigation abilities and tempo in embodied interactions with numbers.

In summary, prior research shows that static and dynamic bodily actions can support students' mathematical learning. However, many of these studies focus on constrained forms of movement, such as low-tempo sideways gait in digital learning environments (Dackermann et al., 2016; Ruiter et al., 2015), which may limit opportunities for creative bodily engagement. As a result, the expressive and dynamic dimensions of bodily extensions of mathematical understanding remain underexplored. To address this gap, this paper focuses on the expressive aspects of students' full-body performances as they extend their number sense within an outdoor embodied design.

2.2. From representations to an extended embodied view of mathematical learning

Traditional models of representational and computational cognition propose a separation between internal mental processes and external representations that stand for mathematical ideas or relationships (e.g., symbols, words, diagrams, number lines, arrays of objects, physical models).

However, the embodied perspective challenges the division between internal and external representations. Instead, it views mathematical thinking as a relational phenomenon that extends beyond the brain to include the sensorimotor system and the surrounding environment (Newen et al., 2018).

Newen et al. (2018) introduced two key extensions to cognition. The first extension is extracranial processes, which involve brain-body units such as body postures. The second is extrabodily processes, which incorporate the surrounding environment such as using body movements to manipulate objects or dancing on a squared matrix on the ground (Newen et al., 2018). In this view, mathematical learning is situated in multimodal experiences, emphasising gestures, body shape, movement, manipulation of objects, and multimodal interaction with the environment (Nathan & Alibali, 2021; Shapiro & Stolz, 2019). Given this extended perspective, it becomes challenging to pinpoint where cognition begins and ends – a boundary problem that is addressed through the concept of expressiveness. Consistent with the situated and extended view of the embodied perspective of learning, Whitacre et al. (2009) argued that expressions are inherently partial in description, intrinsically tied to what they represent and characterised by their distinct specifics. Building on this, they introduced the metaphor of “the student as artist” to describe mathematical learning. This metaphor highlights the expressive dimensions of learning mathematics through embodied activities, emphasising the creative, imaginative and sensory-rich experiences that underpin mathematical understanding. However, as noted by Whitacre et al. (2009), capturing the nuances of expressive movement qualities presents a significant challenge.

2.3. Theoretical background of the methodological approach

Different frameworks have been used to capture the inherent complexity of movement and nonverbal behaviour in research (Bryl, 2021). These include the Kestenberg Movement Profile (KMP), which explores developmental and emotional rhythms in movement, and the Movement Psychodiagnostic Inventory (MPI), which assesses personality traits through structured movement analysis. In line with other STEAM researchers in mathematics education (Leandro et al., 2018), we adopt the Laban/Bartenieff Movement Analysis (L/BMA) as our analytical framework. L/BMA provides a methodological lens for both designing and analysing movement, encompassing four elements – body, effort, shape, and space (BESS) – and the concept of phrasing (Wahl, 2019). Phrases are made up of interconnected and discernible movement units, which are typically marked by a beginning, middle and end (Hackney, 2002), and capture both commonalities and individual variations in how movement is interpreted. The sequencing and arrangement of BESS elements within phrases reflects both the functional and expressive qualities of bodily movement (Wahl, 2019).

Body in L/BMA is primarily associated with the functional aspects of movement but also encompasses expressive qualities, including body creativity and the personally meaningful phrasing of body parts (Wahl, 2019). It concerns physical characteristics such as postures and gestures. Postures involve full-body movement, whereas gestures are limb-specific motions that do not affect the entire body (Wahl, 2019). Both serve functional and expressive purposes: communicating mathematical meaning, enhancing movement expressiveness, and forming dynamic and static shapes.

Phrasing of body parts can be simultaneous or sequential (Wahl, 2019). In simultaneous phrasing, all active body parts move together (Hackney, 2002), such as raising four fingers while jumping over four stones, where the posture enhances expressiveness and the jump serves a functional purpose. Sequential phrasing involves movement transitions between body parts (Hackney, 2002), as seen in a four-step rhythm: “right foot forwards, left foot forwards, right foot backwards, left foot backwards”, where pauses between cycles define its structure.

Shape in L/BMA concerns the body's structure and silhouette, and how it transforms in relation to itself and its environment (Wahl, 2019). Shapes can be static and dynamic, capturing variations in body positions and movement patterns.

Space in L/BMA refers to the physical dimensions and movement pathways, emphasising how the body navigates and interacts with its spatial surroundings (Wahl, 2019). It encompasses spatial organisation, including positioning, pathways and movement patterns. Take for instance a four-step rhythmic sequence, "right foot forwards, left foot forwards, right foot backwards, left foot backwards". Here space considers the spatial pattern, foot placement and directional shifts (e.g., forwards/backwards, lateral or vertical movement), forming a structured spatial organisation. Although this analysis captures body-spatial interactions, it does not account for the movement's qualitative dynamics (e.g., whether the rhythm is jerky or smooth).

Effort in L/BMA, which was originally termed Eukinetics by Laban, captures the expressive and dynamic qualities of movement, including force, tempo, and fluency (Wahl, 2019). A defining characteristic of effort is the continuous fluctuation of movement energy, which is analysed through four dimensions, each spanning a spectrum between two opposing qualities:

- *Weight (Light – Strong)*: The degree of active engagement with gravity, ranging from delicate and feathery to powerful and condensed. For instance, in the four-step rhythmic sequence, steps can be executed lightly, barely touching the ground, or with a strong, grounded impact.
- *Time (Quick – Sustained)*: The tempo of movement, where sustained movement feels prolonged and lingering, whilst quick movement is urgent and hasty. In the rhythmic sequence, steps can be slow and deliberate or performed with a rapid, accelerating pace.
- *Space (Direct – Indirect)*: The level of spatial focus, where movement can be precise and channelled (direct) or broad and encompassing (indirect). Steps in a rhythmic sequence may be aimed at specific points or more freely distributed.
- *Flow (Bound – Free)*: The continuity and control of movement, where bound movement is contained and deliberate, whilst free movement is easeful and expansive. The four-step rhythmic sequence can be tightly controlled or fluid and unrestricted.

Effort variations influence how movement is perceived and performed, and they shape both the expressive and functional qualities of bodily phrasing.

3. Methodology

3.1. Participants

This paper reports from an embodied design study conducted outdoors at a primary school in Norway. The school was selected based on its expressed interest in exploring innovative, outdoor approaches to mathematics education, aligning with the study's aim to examine embodied learning in non-traditional settings. The study included three teachers and all their 42 students aged 6 to 9 years (13 first-graders, 14 second-graders and 15 third-graders). The teachers were actively involved in the school's pedagogical development work but had limited experience in embodied outdoor mathematics learning environments. Similarly, the students had not previously engaged in mathematics learning through embodied activities outdoors. After informed written consent was collected from the students' caregivers, the students were given the choice to participate voluntarily, which all students did. The study adhered to the Norwegian ethical guidelines (NESH, 2016).

3.2. Embodied design research

Educational design research encompasses the theory-driven cycle of developing, testing, evaluating and refining learning environments (McKenney & Reeves, 2014). To integrate these

iterative stages in our embodied design study, we conducted five cycles of testing the activities in collaboration with teachers. During the intervention, the role of the first author was to function as a facilitator in cooperation with the teachers. Each intervention consisted of 45 minutes of outdoor activities in each of the participating classes, with all sessions being videotaped for analysis. Each activity was implemented in the respective grade, followed by an evaluation by the first author and the teachers, who then redesigned the subsequent activities. Informed by an embodied perspective, the development process was guided by the following design principles: (i) consistency between bodily performance and number sense (see Skulmowski & Rey, 2018), (ii) integration of aesthetic and expressive qualities of bodily performance, (iii) incorporation of play and cooperation, and (iv) a central role for speech and dialogue.

As part of the study, we previously discussed the aesthetic aspects of first-graders' full-body performances in number sense activities (Bjørnebye et al., 2023) and the expressive extensions of second-graders' ideas of addition in their bodily engagement (Bjørnebye & van Bommel, 2025). In this paper, two other activities are presented to examine expressiveness in the 6- to 9-year-olds' extension of number sense in their embodied action, focusing on the first design principle and the expressive aspects of the second principle. The third design principle acknowledges the central role of play in early-grades mathematics in Norway, which shapes both the setting and context of the embodied design. However, this principle, together with the fourth, is not discussed further in this paper. The mathematical content and progression of the activities were guided by learning trajectories regarding number sense (Björklund et al., 2020; Sarama & Clements, 2009). The following aspects were found to be relevant for this age group: ordinality, cardinality, number relations, addition, and subtraction. Below, we present the two activities discussed in this paper.

3.3. Two embodied mathematics activities



Figure 1. Closed number lines

Figure 2. Empty number lines

Figure 3. Number lines 0–30

Activity 1 (A1): The “jumping number relations” activity took place on painted number lines (marked 5, 10 and 20; Figure 1) and on empty lines (Figure 2), and with lengths from 0.5 m to 2 m. The mathematical learning object focused on cardinality and number relations, including both addition and subtraction. The research facilitator invited the students to explore how these concepts could be extended through bodily movement. For example, students were encouraged to experiment with how different number pairs (e.g., 3 and 7) could be embodied through jumping sequences, and to creatively express combinations that make ten (referred to as “ten-friends”) in aesthetically pleasing or expressive ways. The students were asked to shout out loud the numbers they were jumping. For example, jump saying “three”, one more jump to ten saying “seven”, ending with a posture or movement to state the sum (i.e., $3+7=10$). In the closed number lines, the sum (for addition) or the difference (for subtraction) was set, while the empty number lines allowed different answers. The number pairs aligned with the level of number sense for each age group. For the

younger students (age 6), this meant that the activity began with mastering simple number pairs (e.g., $1 + 4$, $5 + 5$) as anchors for solving more complex combinations (e.g., $7 + 3$, $4 + 6$).

Activity 2 (A2): The “dancing numbers” activity was conducted on multiple number lines drawn on the asphalt, featuring numerals at each metre from 0 to 30 and icons for numbers 1 to 12 (Figure 3). The iconic modality was displayed in a square format with layers of different colours; for instance, the number 5 was depicted with a full 4-layer in blue and an extra red layer in the upper right corner (i.e., $1 \cdot 4 + 1$). The students were asked to toss a beanbag, move to where it landed, and then perform a dance matching the respective number. For instance, to dance the number 4, a student would start with the right foot on the upper right dot, then the left foot on the parallel dot, move the right foot to the bottom-right dot, and place the left foot on the opposite dot to finish a 4-cycle. To dance numbers above 12, the students had to use the same square structure without iconic support. The mathematical focus of this activity was on cardinality and part-whole relationships of numbers. As an adaptation, dice were introduced, and students performed dances based on the number dictated by given rules, such as dancing the number two/three more than the dice roll.

3.4. Analysis, selection of examples and data reconstruction

Our methodological approach builds on the idea that movement data analysis should adopt a narrative form that captures the wholeness of the situated learning experience and be supplemented with visual representations (Sinclair, 2024; Tantia, 2021). To ensure a comprehensive analysis, we first reviewed the video data multiple times, identifying critical events (episodes) and key moments in the activities where expressiveness emerged. These episodes were then transcribed, linking the students’ utterances with sequences of embodied actions, thereby integrating verbal and non-verbal information from the recorded material. Given the challenges of conveying movement data solely through text, we used video clips alongside the transcriptions to enhance the credibility and transparency of our analysis (Moore & Yamamoto, 2012). We then used themes of expressiveness (see next section) as a basis for coding the data and composing narrative accounts of each expressive element (see Powell et al., 2003). Finally, we contextualised the narratives and data extracts by linking them to relevant theoretical and empirical literature.

3.5. Operationalisation of expressive themes

In our descriptive analysis, we used five themes of expressiveness, which were adapted from the L/BMA framework: (i) pace, (ii) weight, (iii) bodily coordination and spatial interaction, (iv) body shape and improvisation, and (v) phrasing of expressive themes and their alignment with number sense. We consider the expressive themes on a continuum – for instance, pace can range from slow to fast movement. In line with the movement analyst Bradley (2021), we recognise that the descriptive terminology used for movement parameters may create perceived overlaps between themes. However, we maintain that, when considered collectively, these themes offer a comprehensive picture of expressiveness within the perspective of embodied learning. Below, we outline how these expressive themes align with the L/BMA and detail the analytical approach applied to each theme.

Pace: Captures movement pace, ranging from stillness to rotating, and transitioning between slow, sustained, fast and quick movements. Pace corresponds to effort through the time dimension (Hackney, 2002). A quick pace signifies dynamic, energetic movement, whilst a sustained pace conveys control and measured execution in embodied mathematics. Our analysis employs descriptors such as slow, fast, forceful and dynamic to examine how variations in pace shape students’ extensions of number sense.

Weight: Captures contrasts between light and strong body weight. The expressive dimension is demonstrated through lightly or heavily weighted motor actions, such as tiptoeing versus stomping in dancing, or gentle versus forceful throwing and jumping. Movements may involve the body being

directed upwards to extend lightness or grounded to emphasise heaviness and stability. As a dimension of effort, weight captures the force and intensity of movement (Hackney, 2002). Observing the contrast between light and strong exertion provides insight into the level of effort a student applies, where strong use of weight suggests assertive, forceful extensions of number sense, while light weight effort reflects more tentative or gentle extensions.

Bodily coordination and spatial interaction: Captures the flow and coordination between body parts in physical spatial interaction. It highlights the maintaining of balance, rhythm, timing and smooth transitions, with movement patterns structured by spatial interaction and body alignment. Movements such as high and low jumps, rotations, throws, walking, running, stepping and dancing span from irregular and imbalanced to fluent and well-coordinated actions. These movements often involve synchronisation between body parts and controlled transitions between static balance and fluid, dynamic motion. This theme integrates the BESS elements body and space, focusing on the physical execution of coordination and the body's engagement with its spatial surroundings (Hackney, 2002; Wahl, 2019). It also aligns with the flow factor within effort, capturing the degree of fluidity in movement. The theme examines a continuum from irregular, imbalanced movements to fluid, well-coordinated actions, emphasising rhythm, timing, and spatial structuring. Key movement patterns, jumps (high/low, long/short), twists, turns and rotations, extend number sense through repeated spatial interactions. By analysing rhythmic patterns and transitions between fluidity and rigidity, this theme illustrates how bodily coordination and spatial engagement contribute to mathematical understanding within the designed environment.

Body shape and improvisation: Captures the body's capacity for static and dynamic shape formation and spontaneous movement. It encompasses both static and dynamic postures, which may be improvised or elegantly constructed during movement. These movements involve transitions through creative forms, including bodily shapes and postures seen in jumps, rotations, throws, steps and balancing in frozen positions. Rooted in the BESS element shape, this theme focuses on the body's adaptability in forming static and dynamic configurations (Hackney, 2002). Improvisation reflects the body's capacity for fluid, creative transitions between shapes, capturing the spontaneous generation and natural flow of movement. This theme emphasises how students dynamically shape and reshape their bodies, coding creative, improvised and aesthetically expressive movements as they extend their number sense.

Phrasing and alignment with number sense: Captures the degree to which these expressive elements of cohesive movement sequences serve as extensions of mathematical ideas in the number sense activities. Rooted in phrasing (Hackney, 2002), this theme captures the integration and sequencing of expressive movement elements in relation to number sense. It highlights how coordinated movement sequences contribute to mathematical understanding, aligning with what Skulmowski and Rey (2018) refers to as mathematical task integration of movement. By examining the interplay between pace, weight, bodily coordination and spatial interaction, and body shape and improvisation, this theme reveals how these expressive elements merge into fluid, structured actions that extend mathematical ideas.

4. Results

We present episodes from the intervention, highlighting key moments of expressiveness in the two embodied activities.

4.1. Activity 1: "Jumping number relations"

A1E1 (Activity1, Episode1) This episode is drawn from the first intervention session with the third-graders, showcasing their initial experiences with jumping number relations. The activity began with the facilitator demonstrating a $5+5=10$ jump on a number line (0–10), incorporating a 180-

degree mid-air rotation both before and after landing at the intermediate point of 5. This introduction encouraged students to explore how they could integrate expressive elements, such as rotation, tempo, and body shape, into complex movement sequences to support their embodied extensions of number relations.



Figure 4. The integration of dynamic and static bodily shapes in the extension of number relations

The students experimented with rotations ranging from single 180-degree twists to executing two or three 360-degree rotations throughout the number relation. These rotations took place mid-air or upon landing at the part or the whole (Figure 4).



Figure 5. Embodied extensions of $25-5=20$, transitioning from a fast pace to frozen postures at the difference

Interestingly, three students began exploring more advanced concepts, incorporating subtractions such as $25-5=20$. However, it was observed that the initial jump to 25 (i.e., 2.5 metres) limited their ability to integrate rotation into their physical extension of the concept (Figure 5). Pausing and balancing at 25, followed by a 180-degree turn and a jump back to 20, presented a complex motor coordination challenge. Additionally, this activity encouraged the creation of distinct dynamic body postures during the part-whole relations and elegant static body shapes in the students' embodied extension of the whole (Figures 4 and 5).

A1E2 This episode originates from the third intervention session with the third-graders, where the facilitator challenged the students to enhance the aesthetic quality of their number relations.



Figure 6. High jump



Figure 7. Sideways movement



Figure 8. The first mid-air rotation in $10+10=20$



Figure 9. Balancing after rotation



Figure 10. Static and dynamic body postures in extensions of the whole in number relations

During this session, students demonstrated an expressive range of number relations through high jumps (Figure 6), inventive dynamic shapes (Figure 7) and intricate movement patterns (Figure 8). This included executing rotations while maintaining motor balance at the cardinal value (Figure 9) and embellishing the final position with aesthetically creative static and dynamic body shapes (Figure 10). On the 0–20 number line, students explored various combinations summing to 20, such as $15+5$, $19+1$, and $17+3$, as well as their inverse pairs, such as $5+15$ and $1+19$. Interestingly, students adjusted their verbalisation to align with their movements – for instance, one self-corrected from “thirteen plus three” to “thirteen plus seven”. In this session, the students’ joy and engagement in their aesthetic and expressive explorations dominated over the complexity of the mathematical task and the pace of their movements.

A1E3 This episode presents observations from the fifth and fourth intervention sessions with the second and third-graders, respectively, focusing on their use of one-metre empty number lines. This variation aimed to foster creative exploration of number relations while also supporting students who faced motor coordination challenges when navigating the longer two-metre 0–20 number line (cf. previous episodes). For the second-graders, the facilitator set 17 as the target total. Students performed various jumping sequences to extend number relations, including $17+0$, $15+2$, $20-3$, and $18-1$. Subtraction tasks proved more demanding than addition, requiring students to turn back along the number line while maintaining balance and motor control, highlighting their coordination of spatial orientation with mathematical reasoning. As the students were required to vocalise their jumps, we noticed occasional errors in addition, such as $5+15=17$, as well as moments of directional confusion in subtraction, where students mistakenly jumped forwards instead of jumping backwards.

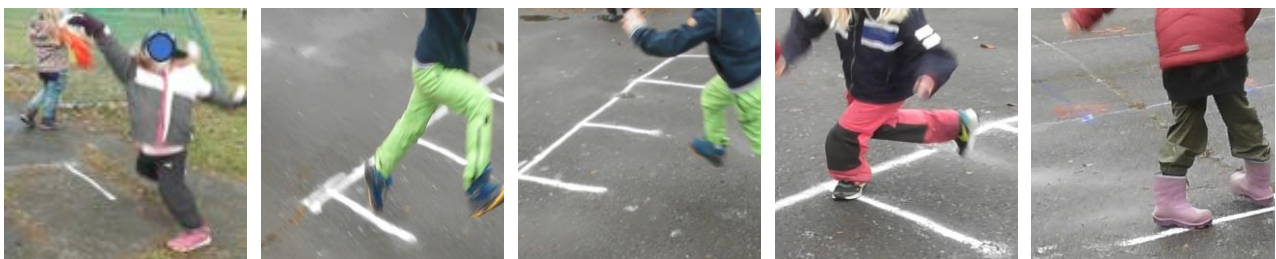


Figure 11. Turning in 20–10=10

Figure 12. Jump to “Hundred ...”

Figure 13. “... minus ninety is ten”

Figure 14. Forceful rotation during $1+9=10$

Figure 15. Gentle rotation during $5+5=10$

The third-graders began with the facilitator encouraging them to create beautiful number pairs. However, some opted for physically demanding tasks, such as $20-10$ (Figure 11; jump to 20 – one-foot balancing – rotate 180° – jump back 10 – rotate 360° – perform an aesthetic posture), $30-10=20$ and $100-90=10$ (Figures 12 and 13), incorporating a lengthy initial leap and a 180-degree twist. Even standard pairs summing to ten, such as $4+6=10$, $1+9=10$ (forceful rotations in “one”, “nine” (mid-air) and “ten”; Figure 14) and $5+5=10$ (Figure 15), introduced motor challenges, requiring controlled

backwards movements and integrating either rapid or sustained rotations at different points in the number relation.

4.2. Activity 2: “Dancing numbers” (along a number line)

Below, we present two episodes from Activity 2, along with one variation.

A2E1 These episodes stem from the third and fifth sessions with the first-graders.



Figure 16. Stiff legs, steady rhythm



Figure 17. Moderate tempo in heavy stomps



Figure 18. Fast, light-weighted interaction



Figure 19. Rotating jump in “nine”

The number dance, performed at the point where the beanbag landed along the number line, exhibited a spectrum of variations in rhythm, pace and weight, ranging from stiff-legged, steady-paced movements (Figure 16), through moderate tempo in heavy stomps (Figure 17), to fast, fluid light-weighted rhythmic interactions (Figure 18). However, some students struggled to determine the nearest number to the beanbag’s landing site, particularly when it landed between two numbers, leading to moments of frustration, expressed through remarks such as “I got nothing”. Others sought guidance, articulating their uncertainties with phrases such as “I got this!” or asking, “What number is that?”, particularly for larger numbers. In response, the facilitator encouraged the use of a known number as a reference point to count-on to the correct number. For instance, one student, who had counted from 10 to begin her dance at the site of the number 14 without iconic matrix support, first performed rapid stomps, deviating from the expected squared pattern. However, with encouragement to begin the sequence by stepping forward with her right foot, she completed the number dance at a slower, more controlled tempo, accompanied by verbal counting. The length of her throw, combined with performing the number dance without iconic support, captured the interest of several other 6-year-olds, suggesting that the activity encouraged them to engage in new and exploratory learning experiences. We observed discrepancies between verbal counting, physical steps and the iconic modality. For example, one student counted “One, two, ..., nine, ten” while engaging in the iconic 8-dotted matrix, aligning multiple number words with several steps and iconic units. Despite occasional multimodal misalignments, clear articulation appeared beneficial, regardless of whether the dance followed a rigid or fluid rhythm.



Figure 20. Heavy weight on lead foot during a forceful throw



Figure 21. Moving to the beanbag



Figure 22. Rapid tiptoeing dance with iconic support



Figure 23. Rapid counting in English (not Norwegian)

During the beanbag toss, students demonstrated varied techniques, ranging from gentle underarm throws to forceful, full-effort launches (Figure 20). Their movement to the landing spot also differed, with some walking whilst others sprinted (Figure 21). Whilst second-graders were allowed to use their dominant hand, third-graders were to throw with their non-dominant hand. One third-grader remarked, “I managed to throw this far [14] using my weaker hand”. When the facilitator asked for the number, the student did not respond but began a well-rhythmed dance, initially stopping at “eighteen”. Upon noticing the mistake, the facilitator pointed it out, prompting the student to redo the dance and accurately reach 14. However, such errors were rare, as most students exhibited rhythmic speech and fluent dancing, both with (Figure 22) and without iconic support. Interestingly, two students began counting in English instead of Norwegian, adopting a quick, rhythmic counting style without iconic reinforcement (Figure 23). Eventually, a third-grader inquired about using their preferred arm, suggesting an eagerness to engage with larger numbers through dance.

A2E3 This episode, from the fifth session with first-graders, introduces a variation of the activity. Instead of using a beanbag, students rolled a die and then ran to a number two or three greater than the value shown.



Figure 24. Walking during counting-on from 6



Figure 25. Slow dance of 9, forceful rotation at “eight” (back)



Figure 26. Forceful rotation at “nine”



Figure 27. Run to “three more than five”



Figure 28. Transitioning between modalities



Figure 29. Rapid dance of a part-whole relation



Figure 30. Rotating jump in “seven”



Figure 31. Light-weighted body posture

The students employed various strategies to reach the sum: some moved directly to it, whilst others referenced the die’s value and counted sequentially. Their pace also varied – some walked, others ran and several adjusted their speed throughout the activity. For instance, one student moved slowly to 6 (Figure 24), paused briefly, then counted “seven, eight, nine” at a steady pace while advancing to the total of $6+3$. This was followed by a slow dance on the iconic matrix of 9, with brief pauses after every four-count cycle (Figure 25), culminating in a forceful rotation while stepping the sum (Figure 26). In contrast, another student relied on the symbolic number line for a direct sprint to the sum of $5+3$ (Figure 27), then shifted sideways into the matrix (Figure 28), executing a rapid dance (Figure 29) followed by a forceful rotation (Figure 25). Similarly, the final rotations displayed a range

of speed, body postures and motor complexity, ranging from cautious 180-degree turns to multiple, powerful 360-degree rotations, often paired with jumps (Figure 30) and creative body shapes (Figure 31). Additionally, moments of self-correction emerged. For example, one student aiming for “two more than the die”, initially moved to 9, then recognised the mistake, returned to 6 and correctly counted to 8.

5. Analysis of results using the expressive themes

Table 1 presents instances of expressive elements identified in our transcripts of the episodes from the two investigated activities.

Table 1. Observations of expressive themes in the two embodied mathematical activities

Expressive themes	Examples
Pace	A1E1: In $25-5=20$, a rapid jump to 25, continued motion in the turn, followed by a controlled step back to 20, culminating in a static posture at the difference (Figure 5). A1E2: A fast-paced rotation, followed by balancing at the sum (20) in the embodied extension of a part-whole relation (Figure 9). A1E2: Static and dynamic bodily postures in the sum of part-whole relations (Figure 10). A1E3: In $100-90=10$, a quick jump to 100, immediate turn, then a fast-paced return jump to land at 10 (Figures 12 and 13). A1E3: Forceful ground and mid-air rotations in $1+9=10$ (Figure 14), with continued rotation in $5+5=10$ (Figure 15). A2E1: A forceful beanbag throw to produce a number to run to and dance (Figure 20). A2E1: Dancing 9 at a steady pace (Figure 16), stomping 8 at a moderate pace (Figure 17), and tiptoeing 12 with a fast and precise articulation (Figure 18). A2E3: Walking (Figure 24) or running (Figure 27) along the number line to perform addition. A2E3: A slow-paced dance with iconic support for the part-whole structure $4+4+1$; (Figure 25), culminating in a forceful rotation at the cardinal value of 9 (Figure 26).
Weight	A1E1: Maximised body weight in jumping and landing, followed by lighter weight at the answer ($25-5=20$; Figure 5). A1E2: Light weighted static body posture at the sum in part-whole relations (Figure 10). A1E3: Heavily weighted forward and return jumps in $100-90=10$ (Figures 12 and 13). A2E1: High and forceful stomps while dancing 8 (Figure 17). A2E1: Lightly weighted tiptoeing dance of 12 (Figure 18). A2E2: Heavy weight on the lead foot during a forceful beanbag throw (Figure 20). A2E3: Lightly weighted body posture in the extension of cardinality $2+3=5$; (Figure 31).
Bodily coordination and spatial interaction	A1E1: Long jumps, ground and mid-air rotations, and precise spatial interactions along the number line, landing on articulated points in the extension of parts and wholes of numbers (Figure 4). A1E1: Controlled body-spatial interaction with the number line: a long jump to 25, balanced pause, turn, then a deliberate jump to 20 (Figure 5). A1E2: High jumps, rotations, mid-air sideways movements, and post-rotation balance in coordinated interaction with the number line (Figures 6–9). A2E1: Fluent, rhythmic dance of 12 in continuous spatial interaction (Figure 18). A2E1: Combined rotation and high jump at the cardinal value “nine” (Figure 19). A2E2: Rapid, rhythmic dance without iconic support, counting in English rather than Norwegian (Figure 23). A2E3: Rigid rhythmic stepping (Figure 25) and fluent tiptoeing dance (Figure 29), structured by bodily interaction with iconic matrices.
Shape and improvisation	A1E1: Creative, dynamic and static body shapes in jumping part-whole relations (Figure 4). A1E2: Improvised, elegant, and expressive static and dynamic body postures in the extension of the whole in number relations (Figure 10). E2E3: Forceful, dynamic body shape during rotation at the cardinal value of 9 (Figure 26). E2E3: Graceful, static body posture at the cardinal value of 5 (Figure 31).
Phrasing and alignment with number sense	A1E1: Forceful jump to 25, balanced turn, and weighted jump to 20 ($25-5=20$; Figure 5). A1E2: Weighted, paced and coordinated movements in two bodily mid-air rotations ($10+10=20$; Figure 8), balancing elegantly in the sum (cf. third image in Figure 10). A1E3: Jump to 20, balancing on one leg, 180° rotation, jump to 10, and elegant rotation at the difference in $20-10=10$ (Figure 11). A1E3: Forceful rotations on “one”, “nine” (mid-air), and “ten” in coordinated, articulated phrasing of the number relation $1+9=10$ (Figure 14). A2E3: Slow-paced walk to “three more than six” ($6+3=9$; Figure 24), deliberate dance of the part-whole structure $4+4+1$ (Figure 25) and dynamic rotation at the cardinal value of 9 (Figure 26). A2E3: Run to “three more than five” ($5+3=8$; Figure 27), sideways movement transitioning between symbolic and iconic modalities (Figure 28), rapid dance of the part-whole relation $4+4=8$; (Figure 29) and forceful rotation at the cardinal value of 8.

Pace: This theme occurred in a wide range of movement tempos, from static postures, slow walks and deliberate steps to quick, dynamic jumps, rotations, fast tiptoeing dances and runs (Table 1). In Activity 1, high-tempo, forceful rotations, both on the ground and mid-air, were evident in the number relation $1+9=10$ (Figure 14), contrasting with the more sustained, measured pace of rotation in $5+5=10$ (Figure 15). In Activity 2, one student extended the concept of addition through a

deliberate walk to the sum of $6+3$ (Figure 24), continued with a slow dance of the part-whole structure $4+4+1$ (Figure 25), and culminated in a dynamic rotation at the cardinal value 9 (Figure 26). Similarly, in Activity 1, achieving $25-5=20$ on the two-metre-long number line required a long initial jump, necessitating a quicker pace (Figure 5), unlike the more measured movements seen on the shorter 0–10 line, which also incorporated moments of stillness (Figure 10). These variations in pace highlight three key aspects. Firstly, the ability to adjust pace enables students to synchronise movements with their mathematical abilities. Secondly, the diversity in tempo reflects the flexibility and interpretative space within number relations. Lastly, the pace affects the prominence and interplay of other expressive themes, shaping the overall embodied extension of number sense.

Weight: Students demonstrated a nuanced control of weight in their movements, adapting the force of their jumps and the delicacy of their landings to align with the demands of the mathematical task (Table 1). In Activity 1, the intensity of their jumps varied significantly, particularly in more challenging tasks such as leaping to 100 and back to 10 (Figures 12 and 13), illustrating their ability to modulate between light and strong weight exertion. The pursuit of aesthetically appealing numerical relationships also appeared to shape their application of weight, as they balanced strength and finesse in their movements (Figures 10, 14 and 15). In Activity 2, the weight exerted during the beanbag toss ranged from strong pressure on the lead foot in forceful throws (Figure 20) to lighter, more controlled efforts. Similarly, the dance sequences revealed a spectrum of weight application: robust, heavy stomps (Figure 17) contrasted with light-footed tiptoeing (Figure 18) and rigid, lightweight movements (Figure 16) as students embodied part-whole relations. Their use of weight further varied in their extension of cardinality, from high jumps (Figure 30) and vigorous rotations (Figure 26) to smoother, more continuous movements on the ground.

Bodily coordination and spatial interaction: This theme occurred in extensions of number sense that required balance, precise execution of movement sequences and repeated actions, as seen in jumping number pairs and the dance of part-whole relations (Table 1). In Activity 1, bodily coordination was evident in students' ability to pause and balance after high-effort jumps, such as leaping to 25, turning mid-air, and subsequently jumping back, demonstrating the intricate motor control required for subtraction (Figure 5). The complexity of this coordination was further highlighted in long and high jumps, sideways movements and mid-air rotations (Figure 4), where rhythmic precision in landing on articulated parts or wholes was key.

In Activity 2, rhythmic structure played a central role in coordinating movements. The number dance showcased a range of movement qualities, from rigid stepping (Figure 16) to fast tiptoeing, fluid cyclical movements (Figure 18), both with and without iconic matrices, illustrating how rhythm intertwines with part-whole relations. The students' ability to conclude their dance sequences with a balanced bodily rotation at the cardinal value (Figure 26) and to harmonise rotation with a high jump (Figure 19) further demonstrated the interplay between rhythm and bodily coordination. Additionally, the fast rhythmic dancing and counting in English (Figure 23) illustrated how variations in pace amplified or moderated the rhythm's complexity and its impact on coordination.

Body shape and improvisation: This theme became visible as students employed a variety of dynamic and static body shapes to creatively extend numerical relationships (Table 1). In Activity 1, aesthetic exploration was central to students' improvised static and dynamic body configurations when embodying number relations (Figures 4 and 10). The most striking observation during the sessions focused on the beautiful jumping of number pairs was the students' joy and engagement in improvisational and aesthetic movement, which often took precedence over pursuing mathematical complexity or movement pace (Figure 10). Additionally, high jumps, lateral moves, and ground or mid-air rotations (e.g., 180° and 360°) across different number lines demonstrated creative and spontaneous bodily expressions of number relations. In Activity 2, improvised elegant dynamic movements (Figure 26) and static body postures in the final step of the number dance (Figure 31),

highlighted how students infused expressive bodily shapes into their embodied extensions of cardinal values.

Phrasing and alignment with number sense: The integration of pace, weight, bodily coordination and spatial interaction, and body shape and improvisation into composite movements was central to how students extended number sense concepts in the two activities. This synthesis allowed for complex, expressive mathematical extensions, illustrating how multiple movement elements can be seamlessly woven into mathematical ideas (Table 1). We present two examples of this integration. In Activity 1, students demonstrated a sophisticated interplay of expressive movement qualities while jumping number pairs. For instance, in $25-5=20$, they combined pace, weight and rhythmic coordination, executing a long, forceful jump to 25 (cardinality), a controlled, balanced landing, followed by a powerful 180-degree rotation back to 20 (subtraction). This sequence required precise bodily control, fluid transitions and strategic movement adjustments to embody the mathematical concept. In Activity 2, the beanbag throws, runs and dances demonstrated a seamless integration of movement qualities in extending ordinality, cardinality and part-whole relations through embodied action. For example, one student walked deliberately to “three more than six”, transitioned into a structured dance of the part-whole relation $4+4+1$ and concluded with a dynamic rotation of the cardinal value 9. The orchestration of pace, weight and improvisational shape in this sequence showcased a nuanced embodied extension of part-whole relations. These expressive transitions not only reflected number sense concepts but also highlighted how diverse movement qualities, from controlled, measured motions to fluid, dynamic shifts, can be harmoniously combined in embodied mathematical experiences. A defining feature of this task design is its unique affordance for students to become artists in their embodied learning experiences. By allowing for personal and creative movement interpretations, the approach fosters a highly engaging, dynamic and individually meaningful way of exploring mathematics through movement.

6. Discussion

In our discussion, we explore how expressive elements align with number sense. We conclude by reflecting on expressiveness as a principle in embodied design research, given its potential to enhance engagement and creativity while fostering meaningful, situated learning experiences in mathematics education.

6.1. Energetic extension of number sense through pace and weight

Caviola et al.'s (2017) review suggested that time pressure can negatively impact students' arithmetic performance, which often leads to stress. However, our findings indicate that the students self-regulated their pace and weight, adapting movement to their mathematical understanding. For instance, in Activity 2, students chose to walk or run to the beanbag and embodied the part-whole structure at a rapid, moderate or leisurely pace, ranging from heavy-weighted stomps to light-footed tiptoeing steps. We observed that a quicker pace was generally associated with greater mathematical fluency, which is consistent with Bjørnebye's (2022) finding that fluency in embodied addition was linked to synchronising complex movement patterns. These embodied contrasts, starting and stopping, balancing and moving, changing direction, force and tempo, especially within rhythm (Roth, 2011), helped to emphasise both variant and invariant features of the learning objectives. Our observations of energetic shifts in pace and weight align with the creative dance activities designed by Leandro et al. (2018), where students adjusted their pace to match mathematical content, using variations in movement tempo and intensity to embody numerical patterns and operations. Supporting multimodal learning in an outdoor setting through adjustments in pace and weight enabled more expressive and dynamic mathematical engagement than typically found in traditional classroom environments.

6.2. Structuring number sense through bodily coordination

In the layered, two-coloured square matrix, students identified the number 8 through rhythmic cycles of steps (Figure 29). This multimodal experience, combining visual, verbal, auditory and kinaesthetic elements, aligns with Roth's (2011) argument that rhythm integrates sensory modalities into a cohesive learning experience. Similarly, Sinclair et al. (2016) suggested that bodily rhythm enhances number sense and counting skills, reinforcing the idea that movement and rhythm can support early mathematical learning. Previous research has also suggested that structured and patterned representations facilitate students' number sense (e.g., Björklund et al., 2021), and our findings indicate that spatial modulation of bodily rhythm in the number dance serves as such a patterned experience (e.g., Fenyvesi et al., 2019). Unlike STEAM research that promotes dance as a pedagogical tool for mathematics learning (e.g., Wood, 2008), our findings align more closely with those of Leandro et al. (2018), demonstrating that dance rhythm functions both as an expressive layer and as a structuring element in students' situated mathematical learning. This perspective is further supported by Whitacre et al. (2009), who argued that expressions are inseparable from the concepts they embody – in this case, students' number sense. Additionally, the outdoor setting provided the space for students to extend their number sense through rhythmic dance, reinforcing the role of contextual movement in mathematical engagement. These findings align with Duijzer et al. (2019), who emphasised that real-world contexts and physical representations are crucial in supporting students' embodied mathematical learning.

6.3. Motor creativity in the extension of number sense

Our analysis highlights how students engaged creatively through improvised body postures and movements, extending mathematical concepts into unique embodied experiences (Table 1). This aligns with Goldin-Meadow et al. (2009), who advocated for integrating motor representations of the body into mathematical learning as part of a holistic educational approach. Similarly, Abrahamson and Sánchez-García (2016) suggested that embodied learning entails devising new movement patterns, reinforcing the connection between physical activity and mathematical understanding.

Whilst previous studies had focused on the direct modelling of mathematical concepts through body shapes (Parsley & Soriano, 2009), our findings suggest that different body parts play unique roles in embodied learning. This aligns with Leandro et al. (2018), who found that creative body postures and gestures encouraged students to engage with arithmetic. Moreover, Reber et al. (2004) argued that the perceived beauty of a scientific experience enhances its credibility, which resonates with the students' expressive engagement in our study. Activity 2 provided a multimodal experience, allowing students to explore ordinality, cardinality and part-whole structures in diverse ways. Ordinality was visually and physically experienced through the trajectory of the beanbag and the movement to the landing site, whilst cardinality was expressed both symbolically and iconically, as well as through part-whole structures in the dance. This supports the embodied perspective that highlights multimodal coordination and transitions as being fundamental to mathematical learning (Nathan & Alibali, 2021). Additionally, our approach to embodied learning design parallels the Maths in Motion programme developed by Fenyvesi et al. (2019), which demonstrated how structural, spatial, rhythmic and symbolic aspects of mathematics are creatively extended through embodied exploration. By situating the learning activities outdoors in dynamic, multimodal contexts, students were able to physically interact with abstract mathematical concepts in a manner that traditional classroom environments often constrain.

6.4. Expressiveness as an embodied mathematical design principle?

Our two activities, grounded in embodied design research principles, required substantial bodily engagement and were closely connected to number sense (see Skulmowski & Rey, 2018). Unlike digital embodied design research, which typically promotes linear movements to represent the

mental number line (e.g., Dackermann et al., 2016; Ruiter et al., 2015), our approach incorporated bodily expressiveness as a central design principle in an outdoor setting. This full-body extension of number sense enabled students to explore numerical relationships through large-scale, expressive actions, thereby enriching their mathematical engagement beyond symbolic reasoning. Addressing critiques regarding the vague empirical foundation of concepts such as immersion and presence in embodied design (Skulmowski & Rey, 2018), our findings demonstrate engagement through creative body postures and movement patterns. Expressive movement not only reinforced existing knowledge but also introduced new mathematical insights (Gadanidis et al., 2016). This was particularly evident in Activity 2, where 6-year-olds interacted with unfamiliar numbers, and in Activity 1, where the transition from addition to subtraction enabled students to perceive arithmetic relationships through movement. We propose that expressive themes expand embodied design principles beyond constrained task-specific physical actions, offering a richer spectrum of engagement. However, we acknowledge that excessive multimodal information can sometimes hinder mathematical performance (Mayer & Moreno, 2003). Moments of self-correction and guided intervention suggest that although expressiveness enhances engagement, some students required support to align multimodal experiences with mathematical accuracy. Nonetheless, unlike traditional classroom environments, our outdoor setting and focus on expressiveness allowed students to explore mathematics through pace, rhythm, bodily coordination and force, thereby fostering an immersive and meaningful learning experience.

7. Summary and concluding remarks

The embodied perspective conceptualises learning and thinking as relational, integrating brain, body and environment while challenging rigid cognitive boundaries (Nathan & Alibali, 2021; Shapiro & Stolz, 2019). Within this view, expressions are not isolated but serve as embodied extensions of mathematical ideas, inherently intertwined with the concepts they convey and uniquely shaped by their contextual use (Newen et al., 2018). To capture these complexities, we combined the L/BMA movement framework with descriptive movement terms to analyse expressiveness in students' bodily extensions of number sense. Our findings suggest that the expressive themes pace, weight, bodily coordination and spatial interaction, body shape and improvisation are deeply interconnected and become meaningfully phrased through students' diverse embodied extensions of number sense. This interplay fosters a creative and artistic approach to mathematics, encouraging personal interpretation and engagement (Paniagua & Istance, 2018; Sinclair, 2004).

Educators can recognise expressiveness in embodied mathematics by understanding the dynamic interaction between students and their environment, and by encouraging the exploration of numerical relationships through aesthetic, rhythmic, playful and innovative movements (Bjørnebye et al., 2023; Bjørnebye & van Bommel, 2025). This highlights that mathematics extends beyond abstract calculation, functioning as a medium for creativity and self-expression, and fostering holistic and meaningful engagement with the subject. Such an approach moves beyond traditional teaching methods, embracing "the student as artist" (Whitacre et al., 2009), where mathematical understanding emerges through expressive bodily environmental interactions.

We acknowledge the complexity of analysing movement-based mathematics due to its subjective and improvisational nature (Moore & Yamamoto, 2012). Examples from our research, such as the sophisticated postures, rotations and dynamic movement sequences observed in our study exemplify expressive acts that resist easy categorisation. However, we argue that our qualitative, descriptive approach, rather than quantitative measurement, offers valuable insights for embodied mathematics task design (see Paniagua & Istance, 2018). Additionally, our focus on critical events may limit generalisability, as including less expressive examples might have provided a more comprehensive view. Nevertheless, highlighting qualitative aspects of expressiveness in key moments demonstrates its potential as a meaningful element in embodied mathematical learning. Ultimately,

our study contributes to embodied design and STEAM research by enriching our understanding of expressiveness within mathematics education. Future research should aim to develop robust frameworks for modelling expressiveness in mathematical learning.

Declarations

Author contributions. First Author: Literature review, conceptualisation. methodology, data analysis, original manuscript preparation, review-editing and writing. Second author: Conceptualisation. methodology, data analysis. review-editing and writing.

Conflicts of interest. The authors declare no conflict of interests.

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Data availability statement. The data supporting the findings of this study consist of video recordings and transcripts involving young children and are subject to strict ethical and privacy regulations. To protect participants' confidentiality, the datasets are not publicly available.

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