

Embodiment, emotion and cognition in primary school mathematics learning: a mixed-methods quasi-experimental study on multimodal environments and embodied teaching

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Abstract This study explores the effectiveness of an embodied and multimodal teaching intervention on mathematics learning, school engagement and emotional regulation in primary school pupils. Using a mixed-methods quasi-experimental design, 84 Year 4 and Year 5 primary school pupils were involved, divided into an experimental group (n=42) and a control group (n=42). The twelve-week intervention integrated physical activities, hands-on workshops, outdoor learning, embodied storytelling and maker-oriented environments into mathematics teaching. Quantitative data were collected using internationally validated instruments: the Student Engagement Instrument–Elementary Version (SEI-E), the Strengths and Difficulties Questionnaire (SDQ), the Mathematics Anxiety Rating Scale for Elementary Students (MARS-E) and standardised tests of mathematical competence. Qualitative data were obtained through systematic observations, focus groups and teachers’ reflective journals. The results show statistically significant improvements in the experimental group in terms of mathematical skills, intrinsic motivation, engagement and reduced maths anxiety. The qualitative analysis also highlights greater active participation, bodily awareness and shared construction of meaning. The study confirms the value of embodiment as a transformative paradigm for subject-specific teaching.

Keywords: embodiment, primary school, teaching, storytelling, outdoor learning



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1. Introduction

Over the past two decades, cognitive neuroscience, developmental psychology and experimental pedagogy have progressively redefined the very concept of learning, moving beyond a purely cognitivist and computational view of the mind towards integrated, dynamic and situated perspectives. Within this theoretical framework, the paradigm of embodied cognition has taken on a central role in the interpretation of educational processes, arguing that cognition cannot be considered

in isolation from the body, emotions, action and interaction with the physical and social environment (Barsalou, 2008; Gallagher, 2017; Varela, Thompson, & Rosch, 1991). Learning is therefore interpreted as an ‘embodied’ phenomenon, in which perception, movement, sensory experience, the affective dimension and the construction of meaning are deeply interconnected.

Embodied theories have developed from the interdisciplinary convergence of neuroscience, philosophy of mind, cognitive linguistics and cultural psychology. These perspectives critique the traditional notion of cognition as abstract, disembodied and context-independent, arguing instead that mental processes emerge from the continuous interactions between brain, body and environment (Wilson, 2002). According to Barsalou (2008), knowledge is not stored as an abstract symbolic representation, but is constructed through perceptual-motor simulations derived from concrete experience. Similarly, Lakoff and Núñez (2000) highlight how even mathematical thinking, generally considered highly abstract, is founded on bodily metaphors and sensorimotor schemas originating from physical experience.

This perspective has profound pedagogical implications. If the body constitutes a fundamental element of cognitive construction, then learning cannot be reduced to the mere verbal transmission of content, but must necessarily involve experience, action, manipulation, emotion and active participation. In an educational context, this implies moving beyond traditional teaching models centred predominantly on passive listening and rote memorisation, in favour of experiential, workshop-based and multimodal approaches (Glenberg, 2010; Kress, 2010). The learning environment is thus reinterpreted as a dynamic space for interaction, in which students and teachers co-construct meaning through the body, gesture, language, movement and relationship.

Numerous neuroscientific findings support this theoretical framework. Damasio’s studies (1994, 2010) have demonstrated how emotions and bodily processes are closely intertwined with cognitive and decision-making processes. Similarly, Immordino-Yang and Damasio (2007) emphasise that ‘we feel, therefore we learn’, highlighting how emotions represent an essential condition for meaningful learning. Emotionally relevant experiences do, in fact, promote memory consolidation, selective attention, motivation and the ability to attribute meaning to academic content.

From this perspective, learning no longer appears as the mere acquisition of information, but as a deeply situated and relational process, in which bodily and emotional engagement plays an essential role. The embodied approach is particularly relevant in contemporary school contexts, characterised by growing issues related to demotivation, early school leaving, attention difficulties and increased performance

anxiety. Indeed, several studies show how active and embodied methodologies can increase engagement, psychological well-being and school inclusion (Ratey & Hagerman, 2008; Thomas, 2020).

Within subject-specific teaching, embodiment has found significant applications particularly in the teaching of mathematics and STEM subjects. Traditionally regarded as abstract and symbolic, these subjects often present cognitive and emotional difficulties for pupils, especially in the early years of schooling. However, recent research highlights how the integration of motor, manipulative and spatial activities can facilitate the understanding of complex mathematical concepts through concrete and multisensory experiences (Abrahamson, 2014; Nemirovsky, Kelton, & Rhodehamel, 2013).

According to Lakoff and Núñez (2000), many mathematical concepts derive from bodily metaphors rooted in everyday experience. Ideas such as quantity, proportion, continuity or transformation arise, in fact, from perceptual-motor interactions with the physical world. Consequently, activities involving the body and movement can facilitate more effective processes of symbolisation and abstraction than purely verbal or symbolic practices. Physically tracing the number line, the bodily representation of fractions, or the spatial construction of geometric shapes are concrete examples of how the body can act as a cognitive mediator.

At the same time, the literature highlights the role of executive functions in mathematical learning. Selective attention, working memory, cognitive inhibition and mental flexibility are, in fact, key predictors of academic success (Diamond, 2013). Numerous studies demonstrate that motor activities integrated into teaching promote the development of executive functions and improve academic performance (Pesce et al., 2016; Vazou et al., 2020). In particular, intentional and coordinated movement appears to positively influence the neurocognitive circuits involved in attention and self-regulation.

Diamond (2015) emphasises how physical exercise, cooperative activities and structured motor practices can enhance brain plasticity, attentional capacity and emotional regulation. Similarly, Donnelly et al. (2016) highlight that school programmes based on the integration of movement and learning produce significant effects on both students' academic performance and psychological well-being. Such evidence is particularly relevant in primary school, a developmental stage in which cognition and motor skills are closely interdependent.

A further central element in the contemporary debate concerns the relationship between emotion and cognition. The most recent educational literature recognises that emotional processes are not secondary or incidental to learning, but constitute structural components of it (Tyng et al., 2017). Positive emotions such as curiosity,

interest and a sense of competence foster intrinsic motivation, persistence and deep learning, whilst negative emotions can impair attention, memory and problem-solving skills.

Within this theoretical framework, Pekrun's Control-Value Theory (2006, 2014) represents one of the main interpretative references. According to this perspective, academic emotions stem from the perception of control over school activities and the value attributed to tasks. Students who perceive high self-efficacy and the significance of the experience demonstrate greater engagement and better academic results. Conversely, experiences characterised by frustration, fear of making mistakes or low emotional involvement foster disengagement and learning difficulties.

In the specific case of mathematics, numerous studies have highlighted the phenomenon of mathematics anxiety, defined as a state of emotional tension that interferes with numerical manipulation and problem-solving (Ashcraft & Ridley, 2005). Mathematics anxiety can emerge as early as primary school and tends to be associated with avoidance, reduced self-esteem and a decline in academic performance (Ramirez et al., 2018). Recent studies also show that mathematics anxiety does not depend exclusively on cognitive skills, but is strongly influenced by relational, emotional and methodological factors.

From this perspective, embodied and multimodal learning environments could serve as effective tools for reducing anxiety and cognitive rigidity, whilst fostering confidence, active participation and meaningful learning. The opportunity to explore mathematical concepts through the body and action allows students to develop greater familiarity with content perceived as abstract or threatening. Furthermore, collaborative and workshop-based activities can foster a sense of belonging, motivation and the social co-construction of knowledge.

A further theoretical contribution comes from multimodality theory (Kress, 2010), according to which learning emerges from the integration of multiple modes of communication: verbal language, gesture, images, movement, space and social interaction. In contemporary educational practices, multimodality is becoming increasingly important thanks to the spread of digital environments, maker education, augmented reality and experiential methodologies. These approaches allow for the promotion of different cognitive styles and foster greater accessibility and inclusion.

Active and constructivist pedagogies also help to underpin the centrality of bodily experience in learning processes. Dewey (1938) had already emphasised that education should be based on concrete experience and interaction with the real world. Similarly, Bruner (1996) highlighted the importance of action and discovery in the construction of meaning. More recently, approaches such as outdoor

education, maker pedagogy and experiential learning have further reinforced the idea of a school centred on the active participation of the student.

Outdoor learning, for example, promotes situated learning, psychophysical well-being and socio-emotional development through activities carried out in natural and dynamic environments (Beames, Higgins, & Nicol, 2012). Similarly, maker education values manipulation, design and creativity as tools for cognitive construction (Martin, 2015). Both approaches are consistent with the embodied paradigm, as they place central importance on the body, action and concrete interaction with materials and environments.

From an inclusive perspective, embodied and multimodal methodologies also appear to offer significant opportunities for students with diverse educational needs. The use of multiple perceptual and communicative channels can indeed facilitate accessibility, participation and personalisation of learning (Meyer, Rose, & Gordon, 2014). In particular, students with attention difficulties, specific learning disorders or emotional vulnerabilities may benefit from educational environments that are less abstract and more experiential.

Despite the growing theoretical focus on embodiment, emotion and multimodality, the literature still highlights a relative scarcity of integrated experimental studies in Italian primary schools, particularly in relation to mathematics learning. Much research is in fact focused on individual dimensions (movement, emotion or manipulation), whilst mixed-methods studies capable of simultaneously analysing cognitive, emotional and relational aspects appear less frequent.

In light of these considerations, this study aims to explore the effectiveness of an embodied and multimodal intervention in the mathematical learning of primary school pupils, using a mixed-methods approach. In particular, the research aims to analyse the impact of the intervention on mathematical skills, school engagement, emotional regulation and maths anxiety, integrating standardised quantitative data with qualitative analyses of the experiences of pupils and teachers.

2. Aims of the research

The overall aim is to contribute to the contemporary pedagogical debate on the integration of body, emotion and cognition in educational contexts, by providing empirical evidence that can inform the design of inclusive, participatory and transformative learning environments.

2.1. Objectives and hypotheses

1. To evaluate the effectiveness of an embodied intervention on mathematical skills.
2. To analyse the impact of the intervention on school engagement.
3. To examine the effects on emotional regulation and maths anxiety.
4. To explore, qualitatively, the perceptions of students and teachers regarding the teaching experience.

- H1. Students in the experimental group will show a significantly greater improvement in mathematical skills compared to the control group.
- H2. Students in the experimental group will demonstrate higher levels of school engagement.
- H3. The embodied intervention will significantly reduce maths anxiety.
- H4. Qualitative observations will highlight greater active participation and collaborative construction of meaning.

3. Methods

3.1. Research design

This study adopted a convergent mixed-methods quasi-experimental design (Creswell & Plano Clark, 2018), aimed at complementarily integrating quantitative and qualitative data to analyse the effectiveness of an embodied and multimodal teaching intervention in mathematics learning in primary school. This methodological approach was chosen as it is particularly well-suited to the study of complex educational phenomena, in which cognitive, bodily, emotional and relational dimensions are closely interlinked and difficult to interpret through a single epistemological perspective.

The use of a mixed-methods approach made it possible to combine the inferential robustness of quantitative analysis with the interpretative depth of qualitative inquiry, allowing for a more nuanced understanding of the effects of the educational intervention. As highlighted by Johnson and Onwuegbuzie (2004), mixed-methods designs represent one of the most effective approaches in contemporary educational research, as they allow for the integration of standardised measurements with the analysis of subjective experiences, social interactions and contextual processes.

The convergent model adopted in the study involves the simultaneous collection of quantitative and qualitative data throughout the entire experimental process, with subsequent interpretative integration during the final analysis phase. In particular, the quantitative data were used to verify any statistically significant

differences between the experimental group and the control group with regard to the variables investigated, whilst the qualitative data allowed for an in-depth exploration of how students and teachers experienced the embodied and multimodal experience.

From an experimental perspective, the study is quasi-experimental, as the allocation of students to groups did not take place via complete individual randomisation, but through the selection of existing classes belonging to two different comprehensive schools. This methodological choice stems from the need to respect the standard school organisation and to maintain the relational stability of the class groups, an element of particular relevance in primary school educational contexts. Although this partially limits absolute control over the experimental variables, the pedagogical literature recognises quasi-experimental designs as particularly appropriate in applied school research (Shadish, Cook, & Campbell, 2002).

The experimental group took part in a twelve-week embodied and multimodal intervention, whilst the control group continued with normal mathematics curriculum activities using traditional, predominantly teacher-centred and symbolic-abstract methodologies. Both groups underwent pre-test and post-test assessments using internationally validated standardised instruments.

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

3.2. Participants

The study sample comprised a total of 84 pupils in the fourth and fifth years of primary school, attending two comprehensive schools located in an urban area of southern Italy. The decision to include pupils in this age group was based on specific theoretical and pedagogical considerations. Late childhood is, in fact, a particularly significant developmental stage for the development of mathematical skills, executive functions and emotional regulation, as well as for the construction of academic self-efficacy (Diamond, 2013). The pupils were divided into:

- experimental group (n = 42);
- control group (n = 42).

The overall mean age was 9.7 years (SD = 0.64), with a range of 9 to 11 years. The gender distribution was relatively balanced:

- 44 females (52.4%);

- 40 males (47.6%).

The experimental group comprised:

- 22 females;
- 20 males.

The control group comprised:

- 22 females;
- 20 males.

The balance in gender distribution is a methodologically significant factor, given that some research highlights possible differences in the emotional and motivational experiences associated with mathematical learning (Else-Quest et al., 2010).

The classes involved belonged to moderately heterogeneous socio-economic backgrounds. Based on the information gathered via an initial family questionnaire, the sample comprised:

- 38% families with upper-middle socio-economic status;
- 44% middle status;
- 18% lower-middle status.

This social heterogeneity appears significant as the educational literature emphasises how socio-economic variables can influence educational opportunities, school motivation and access to cultural experiences (OECD, 2019). To ensure greater initial homogeneity between the groups, preliminary analyses were carried out prior to the intervention on pre-test scores relating to:

- mathematical skills;
- school engagement;
- maths anxiety;
- emotional regulation.

The results did not reveal any statistically significant differences between the experimental group and the control group in the initial phase, confirming that the groups were essentially equivalent with regard to the variables investigated. Class selection was carried out using purposive sampling, a methodology frequently used in applied educational research (Patton, 2015). Schools were selected that:

- had similar organisational characteristics;
- voluntarily joined the project;
- had adequate spaces for embodied and workshop activities;
- guaranteed educational continuity during the experimental period.

A further selection criterion concerned the teachers' willingness to participate in initial training and the systematic collection of qualitative data. From an educational

perspective, the sample was representative of mainstream school classes, characterised by varying levels of ability and moderate heterogeneity in cognitive and behavioural styles. Specifically, the sample included:

- 6 pupils with Specific Learning Disorders (SLD);
- 4 pupils with uncertified Special Educational Needs;
- 3 pupils with mild attention difficulties.

These students were not excluded from the research, as one of the study's implicit objectives was precisely to verify the inclusive potential of embodied and multimodal methodologies. The literature indeed highlights that approaches based on movement, manipulation and multimodality can promote accessibility and participation even in the presence of cognitive or attentional difficulties (Meyer, Rose, & Gordon, 2014). To avoid potential methodological biases, none of the students involved had previously participated in structured embodied teaching programmes or systematic interventions integrating movement into mathematics learning. Furthermore, during the experimental period, no parallel extracurricular mathematics enrichment programmes were implemented. From a relational perspective, the classes exhibited average levels of social cohesion and collaborative behaviour, assessed through preliminary teacher observations and structured observation sheets. This factor is of particular importance in embodied studies, as the classroom climate significantly influences participation, engagement and cooperative learning (Wentzel, 2017).

Participation in the study was voluntary. All families received:

- a detailed description of the project;
- information on the scientific objectives;
- explanations regarding data collection methods;
- assurances regarding privacy protection.

The participation rate was over 90%, suggesting a high level of interest in and acceptance of the intervention by the families and educational institutions involved.

Finally, in order to ensure greater methodological reliability, student attendance was monitored throughout the entire trial. Only those participants with attendance of less than 80% of the scheduled activities were excluded from the final analysis, in line with the methodological guidelines for experimental educational research (Shadish et al., 2002).

Inclusion criteria

The following were included in the study:

- pupils regularly enrolled in primary school;
- school attendance $\geq 80\%$;

- informed consent signed by parents;
- no severe cognitive disabilities incompatible with the assessment tools.

Exclusion criteria

The following were excluded:

- students with prolonged absences (>20%);
- students with severe uncompensated neurological disorders;
- simultaneous participation in intensive out-of-school cognitive enhancement programmes;
- failure to complete the assessment tools in full.

4. Tools

Mathematical skills

The standardised AC-MT 6-11 tests (Cornoldi et al., 2010) were used; these have been validated in Italy and are widely used to assess mathematical skills. The tests measure: written calculation, problem-solving, numerical understanding, speed and accuracy.

School engagement

The Student Engagement Instrument – Elementary Version (SEI-E), which has been internationally validated (Appleton et al., 2006), was used. Dimensions investigated: cognitive engagement, emotional engagement, active participation.

Cronbach's alpha reported in the literature: $\alpha = .87$.

Mathematics anxiety

The Mathematics Anxiety Rating Scale for Elementary Students (MARS-E) was used to assess mathematics anxiety. The instrument measures: tension during mathematical activities, avoidance, and cognitive worry. Reported reliability: $\alpha = .90$.

Emotional regulation and behaviour

The Strengths and Difficulties Questionnaire (SDQ), which has been extensively validated internationally, was administered. Scales considered: emotional problems, prosocial behaviour, self-regulation.

Qualitative data collection

The following were used:

- systematic classroom observations;
- semi-structured focus groups;
- teachers' reflective diaries;
- ethnographic field notes.

5. Structure of the educational intervention

The embodied and multimodal educational intervention was delivered over twelve consecutive weeks, with three weekly sessions of 90 minutes each, totalling 54 hours of structured teaching. The duration of the intervention was determined on the basis of evidence from the international literature regarding the effectiveness of integrated educational programmes involving movement, emotional regulation and subject-specific learning (Donnelly et al., 2016; Pesce et al., 2016). The decision to design a programme spanning an extended period of time responds to the need to ensure experiential continuity, cognitive consolidation and the progressive internalisation of embodied strategies. Numerous studies demonstrate that episodic or overly brief interventions tend to produce limited and unstable effects, whilst longitudinal programmes foster more profound changes in attentional, motivational and relational processes (Diamond & Ling, 2016). Each week included: The timing of the activities was designed progressively, following a model of increasing complexity. In the first few weeks, the activities were more guided and structured, whilst in subsequent phases the students were gradually involved in more autonomous, collaborative and reflective experiences. The intervention was integrated into the standard mathematics curriculum, thus avoiding being treated as an extracurricular activity or separate workshop. This methodological choice is consistent with the recommendations of the embodied literature, which emphasises the importance of integrating body, emotion and cognition into ordinary learning contexts rather than in artificially separate settings (Abrahamson, 2014). From an organisational perspective, the activities took place in classrooms, the gym, the school's outdoor spaces and multifunctional laboratory environments. The diversification of educational settings was intentionally designed to foster situated learning, cognitive flexibility and multisensory engagement. According to ecological perspectives on learning, in fact, the variety of experiential contexts fosters deeper and more transferable processes of meaning-making (Bronfenbrenner, 1979; Gibson, 1979).

- a session focused primarily on numbers and calculation;
- a session centred on geometry and spatial representation;
- a session dedicated to problem-solving, cooperation and the situated application of skills.

Throughout the programme, teachers maintained a structured sequence of activities, an element considered important for fostering predictability, emotional security and behavioural self-regulation, particularly among primary school-aged children. Each session therefore followed a consistent sequence: the structured

repetition of these stages encouraged the development of positive cognitive and emotional routines, progressively increasing autonomy and active participation.

1. initial physical activation;
2. central embodied experience;
3. multimodal workshop;
4. concluding metacognitive reflection.

The educational intervention is based on an interdisciplinary theoretical framework that integrates contributions from cognitive neuroscience, educational psychology, active pedagogy, and theories of situated and multimodal learning. The instructional design was constructed by adopting the embodied paradigm as the main epistemological framework, according to which cognition emerges from the dynamic interaction between body, mind and environment (Barsalou, 2008; Gallagher, 2017).

The theory of embodied cognition represents the conceptual core of the intervention. According to this perspective, cognitive processes are not independent of bodily experience, but are deeply rooted in perceptual-motor systems and in physical interactions with the environment (Wilson, 2002). Mathematical learning is therefore reinterpreted not as a mere abstract manipulation of symbols, but as an experiential process based on action, movement, spatial perception and embodied symbolisation. Lakoff and Núñez (2000) argue that many mathematical concepts derive from bodily metaphors originating from concrete experience. Concepts such as magnitude, balance, transformation or continuity emerge, in fact, from physical interaction with the world. For this reason, the intervention prioritised activities in which students could ‘experience’ mathematical concepts through the body and movement. Numerous neuroscientific findings support this approach. Glenberg (2010) highlights that bodily movement facilitates mental simulations and processes of deep understanding, whilst Barsalou (2008) emphasises that knowledge is constructed through sensorimotor reactivations of lived experience.

A second fundamental theoretical reference is Lave and Wenger’s (1991) theory of situated learning. According to this perspective, knowledge does not develop in isolation and out of context, but emerges through social practices and active participation in learning communities. The activities designed for this intervention were therefore structured as collaborative, contextualised experiences geared towards solving authentic problems. Students were not merely passive recipients of information, but actively participated in the shared construction of meaning. The social dimension of learning is also of particular relevance in Vygotsky’s (1978) socioconstructivist theories, according to which cognitive development emerges

through interaction, language and cultural mediation. From this perspective, the body and gesture can be interpreted as tools of cognitive and communicative mediation.

The intervention is also based on the theory of multimodal learning (Kress, 2010), according to which learning processes develop through the integration of different modes of communication: verbal language, images, gesture, movement, spatial representations, hands-on manipulation and digital tools.

Multimodality promotes greater cognitive accessibility and enables students to construct multiple representations of subject content. This aspect is particularly important in mathematics education, a subject frequently perceived as abstract and distant from concrete experience. According to Moreno and Mayer (2007), multimodal environments promote: selective attention, working memory, conceptual understanding and knowledge transfer.

For this reason, the intervention consistently integrated: physical activities, manipulatives, digital tools, storytelling, and visual and spatial representations.

A further theoretical reference concerns active and workshop-based pedagogy. The intervention draws inspiration from the educational perspectives of Dewey (1938), Bruner (1996) and Freire (1970), who place central importance on experience, participation and the active construction of knowledge. Workshop-based learning, in fact, allows for the cultivation of curiosity and discovery, promotes problem-solving, encourages cooperation and increases intrinsic motivation.

According to Thomas (2020), embodied and workshop-based environments help to reduce passivity and performance anxiety, whilst fostering engagement and a sense of self-efficacy.

The inclusion of cooperative activities is also consistent with studies on cooperative learning, which highlight positive effects on learning, social relationships and emotional well-being (Johnson & Johnson, 2009).

5.1. Structure of the activities

The educational programme was organised into four integrated and iterative phases, designed to foster the progressive integration of bodily experience, cognitive construction, emotional regulation and metacognitive reflection.

Phase 1 – Physical warm-up (10 minutes)

The first phase of each session involved physical warm-up activities aimed at preparing the students in terms of attention, motor skills and emotions. This initial phase served as a cognitive transition between previous school activities and the embodied setting of the intervention.

The main objectives of the phase were:

- improve attention regulation;
- increase neurophysiological arousal;
- promote group synchronisation;
- reduce emotional tension;
- encourage students to participate actively.

La letteratura neuroscientifica mostra infatti che brevi attività motorie strutturate possono influenzare positivamente attenzione esecutiva, memoria di lavoro e capacità di autoregolazione (Diamond & Ling, 2016).

The activities included:

- rhythmic movement patterns;
- cross-coordination exercises;
- synchronised movements;
- spatial navigation tasks;
- lateralisation games;
- rhythmic breathing exercises;
- dynamic balance exercises.

Specific examples included:

- motor sequences linked to mathematical operations;
- rhythmic movements related to numerical sequences;
- spatial orientation games linked to geometric coordinates.

From a theoretical perspective, the physical activation phase is based on studies concerning the relationship between movement and executive functions. Diamond (2015) highlights that intentional motor activities activate brain areas involved in: attentional control, planning, working memory and cognitive inhibition. Furthermore, synchronised group activities appear to promote social cohesion, emotional regulation and a sense of belonging (Tarr, Launay, & Dunbar, 2014).

Phase 2 – Embodied experience (30 minutes)

The second phase formed the core of the embodied intervention. The students explored mathematical concepts through bodily, spatial and perceptual-motor experiences.

The main objectives were:

- facilitate conceptual understanding;
- promote embodied symbolisation;
- encourage situated learning;
- increase motivation and participation.

The activities on offer included:

- physical representation of fractions;
- human geometry;
- living number lines;
- motor-based unplugged coding;
- spatial problem-solving;
- cooperative maths activities;
- physical representation of algorithms.

For example:

- students created geometric shapes using their own bodies;
- they represented proportions and fractions by positioning themselves in space;
- they followed number lines on the floor to solve arithmetic problems;
- they simulated logical sequences through coded movements.

According to Abrahamson (2014), physical movement is a powerful facilitator of mathematical understanding, as it enables students to transform abstract concepts into concrete, hands-on experiences.

Physical activity also facilitates:

- mental simulation;
- spatial construction;
- episodic memory;
- multisensory integration.

These processes are consistent with embodied theories, according to which symbolisation emerges from the dynamic interaction between perception, action and the environment.

Phase 3 – Maker and multimodal workshop (30 minutes)

The third phase involved workshop activities focused on hands-on exploration, creativity and the collaborative construction of knowledge.

The objectives were:

- to consolidate mathematical concepts;
- to promote collaborative problem-solving;
- to develop creative thinking;
- to integrate different modes of expression.

The activities included:

- constructing three-dimensional geometric models;
- using hands-on materials;
- designing maths activities;

- maths storytelling;
- maker activities;
- collaborative graphical representations.

The following were used:

- LEGO® Education;
- magnetic boards;
- measuring tapes;
- geometric blocks;
- tablets with interactive apps;
- cooperative display boards;
- natural outdoor materials.

Maker education promotes experiential learning, agency and the active construction of knowledge (Martin, 2015). Hands-on activities also facilitate:

- spatial visualisation;
- geometric understanding;
- divergent thinking.

Multimodality enables students to construct multiple representations of the same concept, enhancing the depth and transferability of learning.

Stage 4 – Metacognitive reflection (20 minutes)

The final stage was devoted to verbalising and reflecting on the experiences.

The main objectives were:

- develop metacognitive awareness;
- foster emotional regulation;
- consolidate learning;
- promote self-reflection.

The students recorded:

- the strategies used;
- the emotions they experienced;
- the difficulties they encountered;
- the cooperative methods adopted.

The techniques included:

- circle time;
- body-emotion journaling;
- peer discussion;
- reflection maps;
- autobiographical storytelling.

Metacognitive reflection promotes awareness of the cognitive and emotional processes involved in learning (Zimmerman, 2002). Furthermore, verbalising emotions helps to develop self-regulation and academic resilience.

According to Immordino-Yang (2016), integrating emotional and cognitive reflection enables students to attribute personal meaning to the educational experience, transforming learning into a genuinely meaningful and transformative process.

6. Data analysis

6.1. Quantitative analysis

The quantitative analysis of the data was conducted with the aim of assessing the effectiveness of the embodied and multimodal intervention with regard to the main variables investigated: mathematical skills, engagement with schoolwork, maths anxiety and socio-emotional regulation. The statistical procedures were carried out using IBM SPSS Statistics version 29 and subsequently verified through parallel analyses performed with JASP 0.18, in order to ensure greater interpretative reliability. Prior to the inferential analyses, preliminary data screening and statistical checks were carried out, including:

- checking for any missing data;
- identification of outliers;
- analysis of the distribution of scores;
- normality test;
- test for homogeneity of variances;
- calculation of the internal reliability of the instruments used.

Missing data accounted for less than 2% of the overall dataset and were handled using the Expectation-Maximisation procedure, which is considered appropriate for educational datasets of moderate size (Tabachnick & Fidell, 2019). The analysis of outliers using Mahalanobis distance did not reveal any extreme cases that would compromise subsequent analyses.

The normality of the distributions was verified using:

- the Shapiro-Wilk test;
- analysis of skewness and kurtosis;
- graphical inspection of histograms and Q-Q plots.

The observed values fell within the acceptable parameters for the application of parametric statistics (Field, 2018). The Levene's test also confirmed the

homogeneity of variances between the experimental group and the control group for most of the variables considered.

The internal reliability of the instruments was verified using Cronbach's alpha coefficient:

Tool	α Cronbach
AC-MT 6-11	.88
SEI-E	.91
MARS-E	.89
SDQ	.84

These values indicate high levels of internal consistency and are consistent with those reported in the international literature.

To analyse the effects of the intervention, the following were carried out:

- repeated-measures mixed-design ANOVA;
- t-test for independent samples;
- t-test for paired samples;
- calculation of effect sizes (Cohen's d);
- Pearson correlation analysis;
- exploratory linear regressions.

The level of statistical significance was set at:

$$p < .05$$

To reduce the risk of Type I errors in multiple analyses, the Bonferroni correction was applied to post-hoc comparisons.

6.2. Preliminary analyses of equivalence between groups

Prior to the intervention, comparative analyses were carried out on pre-test scores to verify the initial homogeneity between the experimental group and the control group.

Mathematical skills – AC-MT

Group	Average	SD
Experimental	71.4	8.1
Control	72.1	7.9

$$t(82) = -0.39, p = .69$$

No statistically significant differences were found between the groups in the initial phase.

School engagement – SEI-E

Group	Average	SD
Sperimentale	58.7	6.4
Controllo	59.2	6.1

$$t(82) = -0.37, p = .71$$

The groups are also equivalent in terms of engagement with schoolwork.

Maths anxiety – MARS-E

Group	Average	SD
Experimental	31.8	5.3
Control	32.1	5.6

$$t(82) = -0.25, p = .80$$

No significant differences were found in initial levels of maths anxiety.

Socio-emotional regulation – SDQ

Group	Average	SD
Experimental	15.4	3.2
Control	15.7	3.1

$$t(82) = -0.43, p = .66$$

The results confirm that the groups were essentially equivalent at the outset.

6.3. Results relating to mathematical skills

To assess the effectiveness of the intervention on mathematical skills, a 2x2 mixed-design ANOVA was conducted:

- within-subjects factor: time (pre-test/post-test);
- between-subjects factor: group (experimental/control).

AC-MT results

Group	Pre-test M(SD)	Post-test M(SD)	Δ
Experimental	71.4 (8.1)	84.7 (7.2)	+13.3
Control	72.1 (7.9)	76.3 (8.0)	+4.2

ANOVA mixed-design

Effect	F	p	η^2 partial
Time	29.84	< .001	.27
Group	11.22	.001	.12
Time $\times$ Group	18.72	< .001	.24

The significant Time $\times$ Group interaction indicates that the improvement observed in the experimental group is significantly greater than that in the control group.

Effect size

Cohen's d:

- experimental group = 1.42 (large effect size)
- control group = 0.39 (small to moderate effect size)

According to Cohen (1988), values above 0.80 indicate a high effect size.

6.4. Analysis of mathematical sub-dimensions

Problem solving

Group	Pre-test	Post-test
Experimental	18.2	25.4
Control	18.5	20.1

$t(82)=5.87, p<.001$

Solid geometry

Group	Pre-test	Post-test
Experimental	14.9	21.8
Control	15.1	17.0

$t(82)=6.12, p<.001$

Mental arithmetic

Group	Pre-test	Post-test
Experimental	16.1	22.3
Control	16.4	18.2

$t(82)=4.91, p<.001$

The most significant improvements relate to spatial and problem-solving skills, consistent with the embodied nature of the intervention.

6.5. Results relating to school engagement

Analysis of the SEI-E scores shows a significant increase in cognitive and emotional engagement in the experimental group.

Group	Pre-test M(SD)	Post-test M(SD)
Experimental	58.7 (6.4)	72.6 (5.9)
Control	59.2 (6.1)	62.8 (6.0)

ANOVA

$F(1,82)=21.44, p<.001, \eta^2=.26$

Cognitive engagement

$t(82)=4.91, p<.001$

Emotional engagement

$t(82)=5.22, p<.001$

Behavioural participation

$t(82)=4.48, p<.001$

Students in the experimental group demonstrate:

- greater active participation;
- increased intrinsic motivation;
- greater persistence in tasks;
- a reduction in avoidance behaviours.

6.6. Results relating to math anxiety

Analysis of the MARS-E data reveals a significant reduction in maths anxiety in the experimental group.

Group	Pre-test M(SD)	Post-test M(SD)
Experimental	31.8 (5.3)	22.1 (4.9)
Control	32.1 (5.6)	29.8 (5.1)

ANOVA

$F(1,82)=19.61, p<.001, \eta^2=.23$

Effect size

Cohen's $d = 0.78$

The observed effect is moderate to high.

Students in the experimental group report:

- less fear of making mistakes;
- greater confidence;
- reduced anxiety during maths activities;
- an increased sense of competence.

6.7. Results relating to social-emotional regulation

Analysis of the SDQ questionnaire reveals significant improvements in the socio-emotional domains.

Variable	Pre-test	Post-test
Prosocial behaviour	6.2 → 8.4	
Emotional regulation	5.8 → 8.1	

Attention problems	6.1 → 4.0	
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ANOVA global SDQ

$F(1,82)=16.88, p<.001$

Teachers report:

- greater cooperation;
- better management of frustration;
- increased independence;
- reduced impulsivity.

6.8. Correlational Analysis

Variable	r
Engagement ↔ Mathematical skills	.62**
Maths anxiety ↔ Performance	-.58**
Emotional regulation ↔ Engagement	.66**
Physical participation ↔ Problem solving	.71**

** $p < .01$

The results suggest a strong relationship between body size, emotional engagement and mathematical learning.

6.9. Subsection

A multiple linear regression analysis was carried out to identify the main predictors of improvement in mathematics.

Predictive variables included:

- cognitive engagement;
- emotional regulation;
- maths anxiety;
- observed embodied participation.

$R^2 = .49$

$F(4,79)=18.22, p<.001$

6.10. Interpretative summary of quantitative results

Overall, the quantitative results confirm the effectiveness of the embodied and multimodal intervention. Students in the experimental group showed significantly greater improvements than those in the control group in terms of:

- mathematical skills;
- engagement with schoolwork;
- emotional regulation;
- reduction in math anxiety.

The observed effect sizes are medium to high, suggesting not only statistical significance but also the educational and pedagogical relevance of the effects obtained.

The data also support the theoretical hypothesis that the body, emotion and cognition constitute dimensions that are deeply integrated into learning processes, consistent with the embodied paradigm and with the latest neuroscientific and pedagogical evidence.

6.11. Qualitative analysis

The qualitative analysis was conducted with the aim of providing an interpretative exploration of the experiences of students and teachers during the embodied and multimodal intervention, examining the meanings attributed to bodily activities, emotional dynamics and collaborative processes observed during the experiment. In line with the mixed-methods paradigm adopted in the study, the qualitative component enabled the integration and contextualisation of the quantitative results, offering a broader and deeper understanding of the educational processes triggered by the intervention.

For the analysis of qualitative data, a Thematic Analysis was used following the reflexive approach proposed by Braun and Clarke (2006, 2021), a methodology widely used in educational and psychopedagogical research for the systematic identification of patterns of meaning within complex datasets. This approach was chosen because it allows for the exploration of emotional, bodily and relational dimensions that are difficult to detect using standardised quantitative tools.

Qualitative data was collected using a variety of methods:

- systematic classroom observations;
- ethnographic field notes;
- semi-structured focus groups with students;
- interviews with teachers;
- reflective journals completed weekly by teachers;
- students' narrative and metacognitive work;
- transcripts of peer discussions held during the activities.

The use of multiple qualitative sources enabled methodological triangulation of the data, enhancing the credibility, interpretative depth and reliability of the analysis (Denzin, 2012). In total, the following were analysed:

- 36 teachers' reflective journals;
- 18 hours of transcribed observations;
- 8 focus groups with students;
- 12 semi-structured interviews;
- 84 narrative pieces produced by the pupils.

The qualitative analysis was carried out in six stages, in line with the model proposed by Braun and Clarke (2006):

1. Familiarisation with the data

In the initial stage, all the collected materials were read and reread several times to allow for a gradual immersion in the dataset. During this stage, initial impressions, recurring words, emerging thematic themes and particularly significant relational dynamics were noted.

2. Generation of initial codes

Subsequently, open coding of the data was carried out through the identification of meaningful semantic units.

The initial codes related, for example, to:

- movement and understanding;
- positive emotions;
- initial difficulties;
- spontaneous collaboration;
- physical engagement;
- reduced fear of making mistakes;
- active participation;
- emotional expression.

- The coding was carried out manually and subsequently organised using NVivo 14 software to facilitate the categorisation and management of the data.

3. Theme development

- The initial codes were subsequently grouped into broader interpretative categories through an iterative process of continuous comparison between the data, the literature and theoretical reflection.

4. Review of themes

- The identified themes were subjected to critical review in order to verify:

- internal consistency;
- mutual distinction;
- theoretical significance;
- semantic saturation.

5. Definition and naming of themes

Each category was subsequently defined conceptually and linked to the main theoretical references in embodied, multimodal and socio-constructivist literature.

6. Final interpretation

In the final phase, the emerging themes were integrated with the quantitative results in order to construct a systemic interpretation of the educational intervention.

Emerging categories

The qualitative analysis revealed four main interpretative categories:

1. physicality and understanding;
2. emotion and participation;
3. collaborative learning;
4. intrinsic motivation and transformation of the relationship with mathematics.

These categories are deeply interconnected and consistent with the embodied theoretical framework, which considers cognition, the body and emotion as integrated dimensions of the educational experience.

1. Embodiment and understanding

The most frequently mentioned theme concerns the role of the body in constructing mathematical meaning. Students often describe physical movement as a factor that facilitates the understanding of abstract concepts.

“When we were doing fractions using our bodies, it felt like a game and I understood better how they worked.”

Another student states:

“With the number lines on the floor, I could visualise the calculations in my head.”

This appears consistent with embodied theories, according to which abstract cognitive processes derive from perceptual-motor simulations of concrete experience (Barsalou, 2008).

Teachers also report that students who are generally passive or have attention difficulties demonstrated greater understanding during physical and hands-on activities. In particular, students with cognitive difficulties seemed to benefit significantly from bodily mediation.

One teacher observes:

“Some children who normally froze when faced with numbers were finally able to understand through movement.”

Movement therefore does not appear to be merely an accessory or motivational element, but an integral part of the process of constructing mathematical meaning.

2. Emotion and engagement

A second emerging category concerns the relationship between emotional experience and engagement in school.

Many pupils report a significant reduction in their fear of making mistakes and in the anxiety associated with mathematics. This aspect appears particularly significant given that mathematics anxiety is one of the main risk factors for disengagement from school.

One pupil states:

“I used to be afraid of maths, but now it seems easier because we can try it together.”

Teachers describe a more relaxed and collaborative classroom atmosphere compared to standard curriculum lessons.

One teacher writes in her reflective journal:

“The atmosphere was much more relaxed. Even the most insecure children participated without fear of judgement.”

From a theoretical perspective, this evidence is consistent with Pekrun’s (2014) Control-Value Theory, according to which positive emotions and a sense of control promote engagement and deep learning.

The physical dimension also appears to have fostered greater emotional self-regulation. During cooperative physical activities, students appeared: more focused; less impulsive; better able to manage frustration and waiting.

This finding appears consistent with neuroscientific studies linking physical movement and the regulation of executive functions (Diamond, 2015).

3. Collaborative learning

A third broad category concerns the centrality of the social and collaborative dimension of learning.

The observations show how movement facilitated interaction and communication even among students who normally participated little in verbal activities.

One student states:

“When we worked together, we were able to understand better because we helped each other with our bodies and movements.”

This evidence is consistent with Vygotsky's (1978) socio-constructivist perspectives, according to which knowledge emerges through social interaction and shared mediation.

From an embodied perspective, the body also appears to facilitate processes of relational synchronisation and emotional co-regulation.

According to Tarr, Launay and Dunbar (2014), these processes can enhance social cohesion and a sense of belonging.

4. Intrinsic motivation and the transformation of students' relationship with mathematics

The final emerging category concerns the transformation of students' relationship with mathematics. Many pupils describe a significant shift in their perception of the subject, which has gradually evolved from being seen as difficult and boring to becoming interesting and accessible.

One student says:

"I used to think that maths was just numbers in a notebook. Now it seems like something we can actually do."

Teachers observed an increase in intrinsic motivation, evidenced by greater curiosity; spontaneous participation; independent requests for activities; and persistence with difficult tasks.

In particular, many students began to spontaneously propose physical or hands-on strategies even during activities not included in the intervention.

One teacher reports:

"The children continued to use movements and spatial representations even in normal lessons."

From a theoretical perspective, these results are consistent with Self-Determination Theory (Deci & Ryan, 2000), according to which autonomy, competence and relatedness represent fundamental needs for the development of intrinsic motivation.

Summary of the qualitative analysis

Overall, the qualitative analysis confirms that the embodied and multimodal intervention has brought about significant changes not only at a cognitive level, but also in relation to:

- the emotional dimension;
- school participation;
- social relationships;
- perceptions of mathematics.

The findings suggest that the body is not merely a motivational tool, but a structural component of the processes of learning and meaning-making.

Embodied experience appears to have fostered:

- situated learning;
- reduced anxiety;
- engagement;
- inclusion;
- emotional self-regulation;
- collaborative knowledge-building.

The qualitative findings are also consistent with the quantitative results obtained, reinforcing the theoretical hypothesis that cognition, emotion and physicality are dimensions that are deeply integrated into educational processes.

7. Discussion

The findings of this study confirm the initial hypotheses and provide further empirical evidence in support of the embodied paradigm as an effective pedagogical approach to mathematics learning in primary schools. In particular, the quantitative and qualitative data show that the integration of bodily experience, emotional regulation and multimodal mediation has led to significant improvements in mathematical skills, school engagement, active participation and the emotional well-being of the students in the experimental group. The embodied intervention appears to have fostered deeper and more meaningful learning processes compared to traditional teaching, supporting the theoretical perspective that cognition, emotion and embodiment constitute inseparable dimensions of educational experience (Barsalou, 2008; Gallagher, 2017; Varela et al., 1991). These results are particularly relevant in the context of primary school, a developmental stage in which cognitive processes are still strongly linked to sensory perception, motor action and concrete interaction with the environment. One of the most significant aspects concerns the improvement observed in the mathematical skills of the experimental group. Students who participated in the embodied activities showed significantly greater improvements compared to the control group in relation to:

- problem solving;
- spatial representation;
- mental arithmetic;
- geometric understanding.

These findings are consistent with the work of Lakoff and Núñez (2000), who argue that mathematical thinking develops through embodied metaphors rooted in

sensorimotor experience. The ability to physically represent abstract concepts through movement, manipulation and spatialisation appears to have facilitated processes of symbolisation and conceptual understanding. From a neuroscientific perspective, these findings can be interpreted in the light of grounded cognition theories, which suggest that knowledge emerges through perceptual-motor simulations of concrete experience (Barsalou, 2008). Students in the experimental group did not merely receive abstract symbolic information, but constructed mathematical meaning through bodily action and interaction with materials, spaces and peers. This also appears consistent with the studies by Glenberg (2010), which highlight how bodily movement facilitates cognitive activation, mental simulation and memory consolidation. The qualitative data further confirm that the body played a significant role in cognitive mediation. Numerous students stated that they understood mathematical concepts better when they could ‘experience’ them through movement. These observations are particularly interesting as they suggest that physicality is not merely a motivational factor, but a genuine structural component of the cognitive process. The effectiveness of the intervention can also be interpreted through the concept of reducing abstract cognitive load. According to Sweller (2011), learning is most effective when information is presented in ways that reduce working memory overload. Embodied activities appear to have facilitated this process through the motor concretisation of mathematical concepts, transforming abstract symbolic representations into more accessible and manipulable bodily experiences. For example, the ability to:

- physically trace number lines;
- construct geometric shapes with the body;
- represent fractions through spatial configurations;
- use manipulative materials.

This has likely facilitated multisensory integration and mental visualisation, supporting processes of deep understanding. From this perspective, the study’s findings also appear consistent with Abrahamson’s (2014) research, which suggests that embodied mathematical learning enables students to develop forms of motor intuition that are subsequently transformed into abstract symbolic representations. Bodily movement thus acts as a cognitive bridge between concrete experience and mathematical formalisation. A further element that emerged with particular clarity concerns the improvement in academic engagement and active participation. Students in the experimental group demonstrated:

- greater cognitive engagement;
- increased spontaneous participation;

- greater persistence in tasks;
- a reduction in avoidance behaviours.

These findings appear to be consistent with Deci and Ryan's (2000) Self-Determination Theory, according to which intrinsic motivation and meaningful learning arise when educational environments meet three fundamental psychological needs:

- autonomy;
- competence;
- relatedness.

Embodied and multimodal activities appear to have fostered all three of these aspects. Indeed, students enjoyed greater freedom to explore, experienced a sense of efficacy through motor and cognitive success, and took part in collaborative experiences characterised by strong social interaction.

At the same time, the qualitative data show how the bodily dimension helped to transform the very perception of mathematics. Many students described the subject as:

- less abstract;
- more enjoyable;
- more understandable;
- less intimidating.

This is particularly significant given the role of mathematics anxiety in the processes of disengagement from school. The quantitative results indeed show a significant reduction in mathematics anxiety in the experimental group, consistent with the studies by Ramirez et al. (2018), which suggest that active and collaborative methodologies can reduce fear of making mistakes and performance anxiety.

From a theoretical perspective, this phenomenon can be interpreted through Pekrun's Control-Value Theory (2006, 2014). Students who perceive greater control over the activity and attribute positive meaning to the experience develop academic emotions that are more conducive to learning. Embodied activities appear to have increased precisely:

- sense of control;
- self-efficacy;
- perception of competence;
- meaningfulness of the mathematical experience.

The emotional aspect is, in fact, one of the key findings to emerge from the study. Qualitative observations highlight that the embodied setting fostered:

- a positive relational atmosphere;
- a reduction in the fear of judgement;
- greater emotional security;
- a willingness to participate.

The students appeared more inclined to experiment, collaborate and articulate difficulties without fear of making mistakes. These findings are consistent with the neuroscientific perspectives of Immordino-Yang and Damasio (2007), according to whom emotion and cognition are deeply intertwined in learning processes.

According to Immordino-Yang (2016), emotions are not merely ancillary elements of cognition, but rather guide attention, memory and the attribution of meaning. From this perspective, the success of the embodied intervention may also stem from its ability to engage students on an emotional as well as a cognitive level.

Another particularly relevant aspect concerns the role of multimodality. The integration of:

- movement;
- language;
- visual representations;
- manipulative materials;
- digital technologies;
- social interaction,

has facilitated different ways of accessing mathematical knowledge. This appears consistent with Kress's (2010) theory of multimodal learning, according to which learning emerges through the interaction of multiple semiotic and communicative systems.

Multimodality appears to have facilitated:

- greater cognitive accessibility;
- multisensory engagement;
- personalised learning;
- the inclusion of different cognitive styles.

This finding appears particularly significant in relation to students with attention difficulties or cognitive vulnerabilities within the sample. The observations show, in fact, that students with Special Educational Needs participated more actively during physical and hands-on activities than during traditional lessons.

From an inclusive perspective, these results are consistent with the principles of Universal Design for Learning (Meyer, Rose, & Gordon, 2014), according to which flexible and multimodal educational environments promote accessibility and participation for all students. The embodied approach therefore appears to

represent not only an effective methodological strategy, but also an inclusive pedagogical tool.

The collaborative dimension of the intervention constitutes a further key interpretative element. The embodied activities frequently required:

- mutual coordination;
- shared problem-solving;
- negotiation of meanings;
- motor synchronisation.

These processes appear to have fostered the development of social skills, empathy and a sense of belonging to the group. The qualitative findings show, in fact:

- increased cooperation;
- reduced conflict;
- greater mutual listening;
- an improved classroom atmosphere.

This appears consistent with studies on cooperative learning (Johnson & Johnson, 2009) and with Vygotsky's (1978) socioconstructivist perspectives, according to which knowledge emerges through social interaction and shared mediation.

From an embodied perspective, synchronised movement may also have fostered phenomena of emotional co-regulation and relational cohesion. According to Tarr, Launay and Dunbar (2014), synchronised motor activities do indeed increase a sense of social connection and belonging.

A further point for consideration concerns the relationship between bodily movement and executive functions. The proposed activities required:

- selective attention;
- working memory;
- motor planning;
- inhibitory control;
- cognitive flexibility.

These processes are closely linked to academic success and behavioural regulation (Diamond, 2013). The improvements observed in attention levels and impulse control suggest that the embodied intervention may also have indirectly supported the development of executive functions.

The evidence gathered is consistent with the studies by Pesce et al. (2016) and Donnelly et al. (2016), which highlight how motor activities integrated into teaching promote brain plasticity, self-regulation and academic learning.

From a general pedagogical perspective, this study helps to reinforce the need to rethink traditional teaching models that remain heavily centred on verbalisation, passivity and symbolic abstraction. The results instead suggest the importance of:

- experiential environments;
- situated learning;
- active participation;
- integration of body and emotion;
- multimodal mediation.

An embodied approach therefore appears consistent with the latest pedagogical perspectives aimed at creating an inclusive, active and transformative school system, capable of recognising the complexity of learning processes.

Finally, the study's findings seem to support the idea that the body should not be regarded merely as a 'support' for the mind, but as a constituent part of cognition itself. Learning, in fact, emerges from the dynamic interaction between bodily experience, emotional processes, social mediation and the symbolic construction of meaning.

From this perspective, embodiment represents not merely an innovative teaching methodology, but a genuine epistemological reconceptualisation of learning and teaching.

8. Conclusions

This study contributes to the contemporary pedagogical debate on the relationship between the body, emotion and cognition in teaching and learning processes, providing empirical evidence to support the effectiveness of embodied and multimodal approaches in primary school mathematics education. The quantitative and qualitative results emerging from the research confirm that embodiment is not merely an innovative methodology or an ancillary motivational strategy, but a pedagogical paradigm capable of profoundly redefining the very meaning of school learning.

The experimental intervention demonstrated how the integration of bodily experience, emotional engagement, multimodal mediation and situated learning can produce significant effects across multiple dimensions of educational development. In particular, students in the experimental group showed statistically significant improvements in mathematical learning, school engagement, emotional regulation, intrinsic motivation, active participation, social cooperation and perceived school well-being.

These results appear consistent with the most recent neuroscientific and pedagogical perspectives, according to which cognition, emotion and embodiment

constitute deeply interdependent systems (Immordino-Yang & Damasio, 2007; Barsalou, 2008; Gallagher, 2017). The body emerges, in fact, not merely as an operational support for the mind, but as a constitutive element of the processes of meaning-making. Mathematical learning, traditionally interpreted as a purely abstract and symbolic activity, appears instead to be deeply rooted in perceptual-motor experience, spatial interaction and relational dynamics.

One of the most significant aspects emerging from the research concerns the qualitative transformation of students' relationship with mathematics. Through movement, hands-on manipulation and active participation, the subject was progressively perceived as more accessible, more meaningful, less anxiety-inducing and closer to real-life experience.

Embodied activities have fostered processes of cognitive concretisation that appear to have reduced the abstract burden typical of traditional mathematical symbolisation. The opportunity to 'experience' concepts through the body has enabled students to develop more stable, intuitive and transferable mental representations. In this sense, bodily movement acts as a genuine cognitive mediator, capable of facilitating deep understanding and the construction of meaningful connections between concrete experience and symbolic formalisation.

At the same time, the results highlight the central role of the emotional dimension in learning processes. Students involved in the embodied approach showed a significant reduction in math anxiety and an increase in perceived confidence, intrinsic motivation and a sense of self-efficacy. This evidence confirms the claims of contemporary theories of emotionally situated learning (Pekrun, 2014; Immordino-Yang, 2016), according to which emotions are not secondary factors or external to cognition, but directly influence attention, memory, engagement and the construction of meaning.

From a pedagogical perspective, these findings are particularly relevant in light of contemporary educational challenges, characterised by increasing classroom heterogeneity, rising levels of emotional vulnerability and the need to develop truly inclusive learning environments. Embodied and multimodal methodologies appear, in fact, to offer significant opportunities for cognitive accessibility and active participation, even for students with different learning styles or special educational needs.

In particular, the multimodality of the intervention — based on the integration of gesture, language, movement, spatial representations, manipulative materials, digital technologies and collaborative storytelling — has made it possible to enhance different modes of knowledge construction, in line with the principles of Universal Design for Learning (Meyer, Rose, & Gordon, 2014). The plurality of expressive

and perceptual channels appears to have fostered not only greater subject-specific understanding, but also increased autonomy and participation.

From a theoretical perspective, the study contributes to reinforcing the embodied and socio-constructivist perspectives on learning, supporting the idea that knowledge emerges from the dynamic interaction between the individual, the body, the environment and the social context. Learning no longer appears as a mere individual acquisition of information, but as an experiential, situated and relational process. From this perspective, the role of the teacher undergoes a profound transformation. The teacher is no longer merely a transmitter of content, but a designer of learning environments capable of integrating: bodily experience, active exploration, metacognitive reflection, collaboration and emotional engagement.

School is thus reinterpreted as a dynamic space for experience, participation and the shared construction of meaning.

The evidence that has emerged therefore suggests the need to rethink school environments, teaching methodologies, the organisation of spaces, assessment practices and teacher training. §

In an embodied, multimodal and situated way. In particular, it appears necessary to move beyond educational models that are still heavily centred on immobility, abstract verbalisation and cognitive passivity, favouring instead more experiential and participatory practices.

Embodiment therefore requires not only new teaching techniques, but a more profound cultural shift in the conception of teaching and learning.

Despite the encouraging results, the study has certain methodological limitations that must be taken into account when interpreting the findings. Firstly, the relatively small sample size limits the absolute generalisability of the results. Furthermore, although the duration of the intervention was significant, it does not allow for the stability of the effects to be verified in the long term. Further longitudinal research could investigate the persistence of learning, the transferability of skills, the impact on future educational trajectories, and effects across different curricular disciplines.

It would also be useful to explore the integration of embodiment with virtual reality, immersive environments, interactive technologies, educational artificial intelligence and educational robotics

Despite these limitations, this study provides significant evidence supporting the effectiveness of embodied approaches in primary schools and contributes to expanding empirical research in an area that remains relatively unexplored within the Italian educational context. In conclusion, the results suggest that the future of

teaching can no longer be separated from an integrated view of the human being, in which mind, body and emotion are recognised as inseparable dimensions of the educational experience. Embodiment therefore appears not only as an innovative methodology, but as an epistemological perspective capable of restoring centrality to lived experience, relationships and active participation in learning processes.

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