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ORIGINL ARTICLE

The role of movement in young children's spatial experiences: a review of early childhood mathematics education research

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Abstract

Young children's spatial reasoning is critical to mathematics learning from an early age. Recent reviews have drawn attention to the importance of mathematical experiences in the early years; however, an explicit focus on research in spatial reasoning can contribute to a more coherent account of the field. This paper reports a scoping review of qualitative studies ($n = 37$) during the years 2009–2021. The studies analysed in this review provide insight into children's embodied spatial concepts and non-verbal expressions such as gesture and the relationship between spatial reasoning and mathematics learning in early childhood (birth to 8 years). Four main themes were found: (i) children's manipulation and transformation of objects, (ii) children's bodily engagement with and within spaces, (iii) children's representation and interpretation of spatial experiences, and (iv) contexts for spatial learning. While the review illuminates a deeper awareness and a more holistic and embodied view of children's spatial competencies, there remains few studies focussed on children under three years of age. Future directions for ongoing research are identified.

Keywords Early childhood · Mathematics education · Spatial reasoning · Movement · Embodied perspectives

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Introduction

Traditionally, research in early years mathematics education has focused on the content areas of number and measurement, with less attention paid to geometry, spatial relationships, and reasoning (Clements & Sarama, 2011; MacDonald et al., 2012). However, more recent studies have emerged on spatial reasoning in the early childhood domain (see Davis et al., 2015; Elia et al., 2016; Gejard & Melander, 2018; Hawes et al., 2017; Mix et al., 2021; Pollitt et al., 2020; Thom et al., 2021). These studies reflect the diversity of research interests; for example, the impact of focussing on spatial skills on mathematical learning (Hawes et al., 2017; Mix et al., 2021), and spatialising geometry instruction through the use of gestures alongside other semiotic resources (Elia et al., 2016). Other studies have investigated children's exploration of spaces and objects, with spatial-geometric discourse and embodied interaction supporting the noticing of children's understanding of spatial concepts and spatial relations (Gejard & Melander, 2018; Pollitt et al., 2020). Although there is interest in examining the role of spatial competencies in early mathematical learning (see Bower et al., 2020; Mix et al., 2021; Verdine et al., 2017; Young et al., 2018), the relationship between children's spatialised experiences and their early mathematical development is largely unrecognised in informing approaches in early childhood mathematics education (Davis et al., 2015; Putrawangsa & Patahuddin, 2022). A spatialised approach to young children's mathematics education needs to recognise that children are essentially "spatialised beings" as they physically explore spatial dimensions of their world in their everyday experiences from birth; for example, "they learn to crawl, then walk, they are learning to balance in space – and, correspondingly, to 'balance space'" (Whiteley et al., 2015, p. 8). A greater focus on young children's spatial experiences and learning can better reflect their lived experience of being in the world (Clements & Sarama, 2011; Davis et al., 2015; Lowrie & Logan, 2018).

Studies focussed on embodied learning have found that children express mathematical ideas non-verbally. For example, children's use of gesture reveals their embodied awareness of spatial-geometric concepts (Bautista et al., 2012; Ehrlich et al., 2006; Elia et al., 2014, 2016; Kim et al., 2011; Pollitt et al., 2020; Thom & McGarvey, 2015). Our understanding of the role of movement in children's spatial development can be furthered by observing children's whole-body experience of space, movement in space, manipulation of spatial objects, and their reflection on those experiences.

Reviews of early childhood mathematics education research have identified themes in the development of mathematics concepts (see Linder & Simpson, 2018; MacDonald & Murphy, 2019). However, these reviews have not focussed specifically on spatial reasoning and the role of movement in spatial experiences. The aim of this paper is to conduct a scoping review (SR) to identify early childhood education research that describes the role of movement in children's spatial-mathematical experiences in order to address the following research questions:

1. What is the scope and depth of qualitative studies on the role of movement in young children's spatial-mathematical experiences?

2. What do the findings from the SR contribute to the understanding of the role of movement in the field of early childhood mathematics education research?

Background

This section informs the scoping review by describing spatial processes and multiple perspectives on the role of movement in early childhood mathematics education. Recognising that early childhood encompasses different ages in different contexts internationally, for the purpose of this paper we are using the United Nations Educational, Scientific and Cultural Organisation's (UNESCO) (2022) definition of early childhood as birth to eight years and use the terms "children" and "young children" interchangeably to acknowledge the scope of this age range. In this SR, we define early childhood mathematics education as the practice where educators provide learning environments and opportunities for children (birth to 8 years) to engage in a wide variety of mathematical learning experiences (Elia et al., 2018). Furthermore, we refer to the term "school context" to indicate research involving school-age children, and "early childhood education and care" (ECEC) as an encompassing term for research involving children across all prior-to-school contexts.

Spatial processes in early childhood mathematics education

Spatial processes engage spatial reasoning and spatial thinking. Spatial reasoning involves processes where the child recognises and mentally manipulates spatial properties and relations between objects (Mulligan, 2015). Research has identified spatial visualisation, mental rotation, and spatial orientation as essential processes involved in interpreting and representing mathematically relevant information (Lowrie & Logan, 2018). A focus on spatial processes can positively impact children's mathematical learning; for example, mental rotation supports a relational way of thinking about numbers which is a critical aspect of early algebraic reasoning (Rich & Brendefur, 2018). There is also a range of dynamic processes that signal young children's physical and mental engagement with spatial reasoning. These processes include: "locating, orienting, decomposing/composing, shifting dimensions, balancing, diagramming, symmetrising, navigating, transforming, comparing, scaling, sensing, visualising" (Whiteley et al., 2015, p. 5), along with "rotating", "sliding", "reflecting" and "intersecting" (Thom, 2018, p. 23). Spatial approaches in early childhood include being aware of these dynamic processes as indicators of ways that children engage with spaces, "reason *about* objects" and "reason *with* representations" (Battista, 2007, p. 844) in order to spatialise their experiences (Newcombe, 2017).

Spatial thinking involves the ability to orient oneself or objects in space, either physically or mentally, and is an inherent aspect of everyday life (National Research Council [NRC], 2006). More specifically, spatial thinking involves the interaction of three interrelated components, these being: "concepts of space, tools of representation, and processes of reasoning" (NRC, 2006, p. 3), whereby spatial reasoning is recognised as an inherent aspect of spatial thought. Concepts of space involve children's exploration and movement to navigate their environment which is inherently three-dimensional (Whiteley et al., 2015). The second component, tools of representation, involves encoding and decoding spatial relationships (Lowrie & Jorgensen, 2017). This includes representing relations between landmarks in the environment and different perspective points using a variety of representational modes including movement (NRC, 2006). The third component, processes of reasoning, involves interpreting spatial information to make decisions (Lowrie & Jorgensen, 2017), communicating spatial relationships (NRC, 2006), and accessing visuospatial working memory (Hawes et al., 2015b; Owens, 2015). The interaction between the three interrelated components of spatial thought enables children to "develop a habit of mind to think spatially" and make spatially informed decisions in the context of their everyday experiences (NRC, 2006, p. 4).

The role of movement: multiple perspectives in early childhood mathematics education

The study of children's movement is connected with embodied perspectives, as scholars recognise that the role of the body is paramount in the formation of knowledge gained through movement and sensory exploration (Alibali & Nathan, 2011; Merleau-Ponty, 2002; Smith & Gasser, 2005). For example, an embodied perspective may interpret that a child reaching towards an object reflects a non-verbal awareness of dimensions of space that is visible in the child's orientation towards the object and judgements about the distance between the child and object (Franzén, 2015). An embodied perspective views cognition as able to be shaped by and expressed through physical actions (Ionescu & Vasc, 2014) alongside verbal expressions and image making (Elia et al., 2016; Way & Ginns, 2022). Examples of this physical expression include the use of gesture (Austin & Sweller, 2017; deFreitas & Sinclair, 2012; Elia & Evangelou, 2014; Logan et al., 2014; McNeill, 1992); bodily orientation, both dynamically through spaces and movement towards objects (Bautista et al., 2012; Kim et al., 2011); dynamic movement and transformation of objects (Kim et al., 2011; Roth, 2014; Roth & Thom, 2009; Thom, 2018); and the expression of sounds, utterances and use of rhythmic movements (Bautista & Roth, 2012a, b). Embodied expressions can also be revealed through drawing (or viewing) and reflecting upon the image created (deFreitas & Sinclair, 2012; Elia et al., 2016; Thom & McGarvey, 2015).

Similarly, schematic pedagogy involves the intentional practice of attending to children's movement, observed by noticing children's schemas that reveal "structures of thinking" (Atherton & Nutbrown, 2016, p. 63). Schemas are defined as "patterns of repeatable actions that lead to early categories and then to logical classifications" enabling the emergence of generalised ideas (Athey, 2007, p. 49). These observable patterns of action include "dynamic vertical", "dynamic back and forth", "circular rotation", "going over, under or on top of", "going round a boundary", "enveloping or containing", "going through a boundary", and "thought (internalised data)" (Athey, 2007, pp. 115–116). Schemas can therefore provide insight into what can be observed in young children's spatial engagement with objects and spaces (Athey, 2007).

Young children, (babies and toddlers), are essentially "physical thinkers" and form notions of "regularity" and "prediction" about aspects of their environment through "touch and other sensory exploration" including movement (Atherton & Nutbrown, 2016, p. 65). Notions of "structures of thinking", "regularity", and "prediction" are defining features of children's growing Awareness of Mathematical Pattern and Structure (AMPS) (Mulligan & Mitchelmore, 2009). AMPS is based on "two interdependent components; one cognitive (knowledge of structure) and one meta-cognitive (a tendency to seek and analyse patterns)" (Mulligan & Mitchelmore, 2009, p. 38). Both these aspects are considered to underlie how young children perceive and interact with their environment and are powerful connectors to a schematic perspective. Young children's schematic learning can be perceived through bodily movement, as "schemas [patterned actions] develop as a result of both the embodied and mediated experience in the world" (Brierley & Nutbrown, 2017, p. 14). Pedagogical attention to schemas enables young children's thinking to be discernible through observing their movement and interpreting their repeated patterned actions.

Research that engages embodied and schematic perspectives informs what can be learned by observing children's non-verbal expressions of spatial processes and reasoning in their movement. Consequently, the role of movement examined through both an embodied and schematic perspective presents an opportunity for a broader picture of young children's spatial engagement and spatialisation of experiences to be made available.

A synthesis of recent reviews of early childhood mathematics education research and a brief section outlining research beyond this scoping review are now presented.

Recent reviews of early childhood mathematics education research

Recent literature reviews in early childhood mathematics education research have synthesised a broad range of studies on young children's mathematical development (for example, Björklund et al., 2020; Downton et al., 2020; Linder & Simpson, 2018; MacDonald & Murphy, 2019). Linder and Simpson's (2018) systematic review focused on the mathematics teaching practices of current and prospective early childhood teachers. The review highlighted themes such as educators' pedagogical content knowledge and dispositions to engage mathematically, and the resultant impact of interventions on transforming aspects of their mathematical practice. Additionally, Linder and Simpson (2018) noted that quantitative methods were predominant across the studies and recommended the development of more "quasi experimental" and/or "mixed methods methodology" (p. 6) in early childhood mathematics education research.

MacDonald and Murphy (2019) conducted a systematic review of studies in mathematics education for children under four years of age, including educators' knowledge of and attitudes towards young children's mathematical competence, along with the current use of interventions and mathematics instrument development. MacDonald and Murphy's (2019) findings also identified "a trend of utilising task-based interviews and/or standardised assessments" (p. 12) and they advocated for a more balanced research focus to include a broader range of qualitative measures for inquiring into young children's mathematical competence.

Björklund et al.'s (2020) review reported on contemporary perspectives across international research groups in early childhood mathematics education. Of particular interest to this current review were findings from the 13th International Congress on Mathematical Education (ICME) where the theme "embodied action and context" was identified across a range of related studies in early childhood mathematics education (Björklund et al., 2020, p. 4). This theme highlighted ways young children reveal their embodied spatial awareness by examining the role of the body alongside other semiotic resources that inform children's spatial-geometric thinking.

Downton et al.'s (2020) review of early childhood mathematics education research in Australasia emphasised the use of inclusive terminology across early childhood mathematics education research to recognise both informal settings (early learning and care, family/home) and formal educational contexts (school and preschool). Mathematics education research situated within informal contexts emphasised the importance of supporting parents to strengthen young children's engagement in mathematical experiences at home (Downton et al., 2020). The review found that research in the early years of school focused on early number knowledge, statistical reasoning and measurement understandings and acknowledged growing research interest in spatial reasoning. Aspects of play-based approaches to learning were noted across the studies reviewed by Downton et al. (2020); for example, mathematising play-based experiences for formative assessment (see Cohrssen et al., 2016), and play that enabled children's noticing of everyday mathematics (see Marcus et al., 2016).

Common findings across these reviews highlight the limited research in mathematics education with children under four years of age. Furthermore, Downton et al. (2020) note a continuing emphasis on research conducted in formal educational contexts. Contemporary early childhood mathematics education argues that mathematics learning begins at birth, therefore research and methodologies that are attuned to socio-cultural nuances appropriate for infants and toddlers are needed (Björklund et al., 2020). Downton et al. (2020) identified that emerging areas of research need to include children from birth to two years of age, spatial reasoning, and the use of "innovative research methodologies [such as trolley cams, camera glasses, drawings, digital pens] … to make visible the ways in which young children experience mathematics" (pp. 232, 235).

In relation to young children's learning of mathematical concepts, Linder and Simpson (2018) recommended a research focus beyond "number and operations" (p. 289) with children under five years of age, in order to connect more authentically with mathematical ideas that may be more relevant to their age group. MacDonald and Murphy (2019) pointed out that studies using observational data often revealed children's competence in, and engagement with, mathematical concepts such as geometry—specifically spatial ideas emerging from everyday play (see Lee, 2012).

Although motor skills and spatial-assembly skills were noted as predictive factors of mathematical competence (MacDonald & Murphy, 2019) discussion regarding the role of children's movement was only provided in the review by Björklund et al. (2020). This limitation highlights a need for further research into young children's spatial and embodied mathematical competencies.

Research beyond the scoping review

There is broad and growing interest in child development, cognitive science and psychology research domains regarding spatial reasoning and thinking, and young children's mathematical development. For example, some studies have investigated the effect of strengthening children's mental rotation skills (Bruce & Hawes, 2015; Fernández-Méndez et al., 2020). Children's broader spatial transformation skills (including mental rotation) have been observed through puzzle play, object play and paper folding experiences (Hawes et al., 2015a; Levine et al., 2012), and in spatial assembly tasks such as block construction and deconstruction (Verdine et al., 2014).

The relationship between spatial reasoning and mathematics development has been investigated through a number of research domains. The findings from these investigations indicate the positive effect of mental rotation training on children's calculation skills (Cheng & Mix, 2014), number line estimation (Young et al., 2018), and mental transformation on children's arithmetic skills (Frick, 2019; Verdine et al., 2017). Spatial-skills training, involving the use of spatial language and gesture, supported children's attention towards spatially pertinent concepts (Bower et al., 2020). The impact of young children's movement on their resultant spatial ability has also been of research interest (Mohring & Frick, 2013; Oudgenoeg-Paz et al., 2015; Schwarzer et al., 2013), along with how gesturing reveals young children's spatial reasoning (Miller et al., 2020) and their specific engagement with mental transformation skills (Levine et al., 2018).

However, Mix and Battista (2018) note there are pertinent differences between research methodologies in mathematics education, and developmental and cognitive psychology with regards to the type of data and findings they can yield—with the latter reliant on testing that is removed from children's educational context and lived experiences. For the current review, developmental and cognitive psychology literature were not included as the intent of the scoping review was to examine how qualitative research in the mathematics education domain considered the role of movement in children's spatial-mathematical experiences. Therefore, in this review the construct of spatial reasoning was positioned within early childhood education and early childhood mathematics education research, with a particular focus on how children engage in movement spatially and mathematically.

Scoping review method

In this section we outline the SR methodology, the review process and the inclusion and exclusion criteria. Scoping reviews are similar in structure to systematic literature reviews (SLR) as both are evidence based and employ a systematic process (Munn et al., 2018). Similar methods are utilised, however there are subtle differences across these approaches pertaining to the purpose for the review of literature, timeframe and analysis of descriptive information (Munn et al., 2018). The purpose of our review was to provide an overview of current early childhood mathematics education research to illuminate emerging themes and to identify aspects of research that could be further understood through a comprehensive review process.

In this review we drew on Arksey and O'Malley's (2005) approach for a scoping review, involving the following stages: (1) identify the research question, (2) locate relevant studies, (3) define inclusion and exclusion criteria, (4) identify the study selection, (5) compile the data, and (6) collate, summarise and report results. Appendix Fig. 1 illustrates the SR article search and screening process which involves two phases and subsequent refinement of the stages. The phase 1 database search was conducted in 2019, with an additional search conducted in April 2021 (phase 2) which identified recent publications for inclusion. Each phase is now explained in more detail.

Scoping review phase 1

The research questions used to guide the review were:

1. What is the scope and depth of qualitative studies on the role of movement in young children's spatial-mathematical experiences? and,
2. What do the findings from the SR contribute to our understanding of the role of movement in the field of mathematics education research?

The initial phase of the SR was conducted using searches in electronic databases for the period 2009 to 2019. Search terms were applied to the following databases: ERIC (Ebsco), Education Source, Academic Search Complete, and A + Education. Key terms and phrases were searched using the word "AND" to identify studies across related aspects of the research focus, for example (child* OR young children OR preschool* OR kinder* OR early* OR early childhood) AND (math* OR numeracy* OR geom* OR spatial* OR spatial thinking OR spatial reasoning OR spatial awareness OR spatial orientation OR mental rotation) AND (embod* OR moving OR move*). Relevant empirical peer-reviewed journal papers in English, and in early childhood education (including early childhood mathematics education) from 2009–2019 were identified.

The studies identified across databases were collated, with most duplicates removed, resulting in a total of 628 papers for initial screening. As part of the SR, we applied inclusion and exclusion criteria to address the research questions, refine the search and to eliminate irrelevant studies (Arksey & O'Malley, 2005) (refer to Table 1). The four authors collaborated in the SR process, including defining inclusion and exclusion criteria, and the overall synthesis of papers.

Titles were screened for papers that addressed the inclusion criteria identified in Table 1. This included studies that were conducted in an early childhood education context, for example in a family study, child-care centre, preschool, or in the early years of school. Abstracts were then further reviewed, particularly if the research focus was unclear in the title, and further duplicates were removed. The phase 1 search process resulted in 27 papers for review.

Table 1 Inclusion and exclusion criteria for papers

Inclusion criteria	Exclusion criteria
Scoping review phase 1	
Papers published in peer reviewed journals	Non-peer reviewed papers
2009–2019	Papers published prior to 2009
Early childhood education (birth to 8 years*)	Children 9 years or older
Qualitative, quantitative and mixed methods empirical research	
Early childhood mathematics education research	Child development Developmental studies Cognitive psychology Psychology research Experimental designs
Research on spatial experiences in early childhood education and mathematics	
Team recommended studies (additional papers)	
Scoping review phase 2 (additional criteria)	
2009–April 2021	
Qualitative methods	Quantitative methods Mixed methods
Descriptions of children's movement	

*There are three studies where participants are aged 8–9 years, and one family study involving children from 12 months to 10 years

Scoping review phase 2

A phase 2 search was conducted in April 2021 as some relevant papers that met the criteria had been published since the initial search phase and warranted inclusion in the SR. The search process was modelled on phase 1, and a further 65 papers were considered for inclusion. The SR focus was refined to ensure that qualitative research papers were identified with findings that described the role of movement in young children's spatial experiences. As part of the moderation process, team-based recommendations of recent, relevant papers resulted in the inclusion of eight papers meeting criteria for both phases of the SR (refer protocol process described in Woolcott et al., 2020b). The final inclusion resulted in 37 papers for review (refer to Appendix Fig. 1).

Analysis of data

Data were structured and synthesised for common themes (Arksey & O'Malley, 2005). The lead author developed a thematic analysis template to categorise and record descriptive criteria within each paper. These descriptors included the age range of participants and contextualised features. Papers were categorised according to frequency of publication year, location of research, age of participants, research context, methodology, findings and recommendations, along with school contexts and early childhood education and care (ECEC) contexts prior to school (including preschool). A double review process was conducted; one pair of the authors reviewed papers from the school contexts and the other pair reviewed papers from ECEC contexts. The review process included individual authors identifying themes within allocated papers in relation to the role of movement in young children's spatial-mathematical experiences. During the next stage the author team worked in pairs and discussed themes they had developed. Any discrepancies between the reviewing pairs in phase 1 of the identification process were discussed and resolved as part of the moderation process. The team collectively reviewed and generated emergent themes. The lead author conducted the reviews in phase 2 resulting in further refinement of the themes and descriptive analysis in consultation with the other authors. As a result of this moderation process, approximately 40% of papers were double reviewed.

Results

A descriptive analysis of the scope and depth of the studies reviewed in this SR is presented first, followed by a discussion about the four themes identified across the papers.

Descriptive analysis

This SR focussed on identifying peer reviewed early childhood mathematics education research papers using qualitative methods. Both search phases of the SR resulted in an expansion of the timeline to accommodate recent publications (2020–April 2021). The most frequent years for publications were 2015 ($n=7$), 2018 ($n=6$), and 2020 ($n=6$), indicating a growth in research interest in documenting and analysing young children's observed movement in spatial-mathematical experiences. Research studies were conducted internationally, with a majority located in Canada ($n=11$), Australia ($n=7$), and the USA ($n=7$). Internationally, the scope of studies aligns with growing global interest in the development of children's spatial reasoning (see Davis et al., 2015; Lowrie & Jorgensen, 2017; Lowrie & Logan, 2018; Mix et al., 2021; Mulligan et al., 2018, 2020; Verdine et al., 2017; Woolcott et al., 2020a, b; Young et al., 2018).

Terminology defining ECEC and school contexts varies internationally, with the age for children commencing the first year of formal school ranging from 4 to 6 years of age (Gowers, 2020; Omidire et al., 2018). The research contexts identified in the papers reviewed guided the categorisation of the papers into ECEC (including preschool) and school. There were 24 papers referring to research with an ECEC context (including family studies), and 16 papers were based within a school context. Two papers referred to research conducted across ECEC and school sites or involved family studies involving children from 12 months to 10 years. With regards to the specific ages of the children involved, 15% of all the studies included children aged 8 months to 3 years ($n=6$); 45% were studies with preschool children aged 3 to 6 years ($n=18$); and 40% involved school children aged 4 to 8 years ($n=16$). (Note, $n=40$ due to dual coding across research contexts.) Descriptive information of the scoping review is provided in Table 2 and the research context and ages of children are collated in Table 3.

Table 2 Descriptive information of the scoping review

Year of publication	Author/s	Country of research	Research context and children's ages	Participant numbers	Children's movement observed in a spatial-mathematical context
2009	Roth and Thom	Canada	School (7–8 years)	$n=23$	Glances, gesture, transformation of objects
2010	Highfield	Australia	Preschool (3–4 years) School (ages not identified)	$n=11$ $n=22$	Gesture and whole-body orientation, movement of objects
2011	Kim et al	Canada	School (7–8 years)	$n=23$	Gesture (co-emerging with speech), transformation of objects, bodily orientation
2012a	Bautista and Roth	Canada	School (8–9 years)	$n=3$	Gesture (emerging alongside sound), hand/arm movements with objects
2012b	Bautista and Roth	Canada	School (8–9 years)	$n=3$	Beat gestures, movement of hands/fingers/arms, transformation of objects
2012	Bautista et al	Canada	School (8–9 years)	$n=3$	Gesture (alongside speech/utterances), movement of hands/arms/fingers, transformation of objects
2012	Lee	New Zealand	ECEC (13 months–3 years)	$n=32$	Whole-body movement, navigating spaces, transformation of objects
2014	Elia and Evangelou	Cyprus	Kindergarten (4–5 years)	$n=24$	Gesture (alongside speech), categorisation of gestures, locating/moving objects
2014	Elia et al	Cyprus	Kindergarten (5 years)	$n=1$	Gesture (categorisation), transformation of objects
2014	Roth	Canada	School (6–7 years)	$n=3$	Gesture, movement of hands/arms/fingers, transformation of objects
2015	Bartolini Bussi and Baccaglini-Frank	Italy	School (6–7 years)	$n=18$	Gesture alongside verbal explanations/graphic representation, whole-body movement

Table 2 (continued)

Year of publication	Author/s	Country of research	Research context and children's ages	Participant numbers	Children's movement observed in a spatial-mathematical context
2015	Deans and Cohrssen	Australia	Preschool (4 years)	$n = 24$	Gesture, whole-body dynamic movement, transformation of objects
2015	Franzén	Sweden	Preschool (1–3 years)	$n = 13$	Whole-body movement, navigating spaces, orienting around objects
2015	Kaur	Canada	School (7–8 years)	$n = 24$	Gesture, dynamic movement of hands/arms (body-based actions)
2015	Ng and Sinclair	Canada	School (ages not identified)	$n = 44$	Gesture, alongside words, diagrams/visual mediators
2015	Thom and McGarvey	Canada	School (ages not identified)	$n = 2$	Gesture, verbalisations, whole-body movement, kinetic mark making, transactions with objects
2015	Vandermaas-Peeler and McClain	USA	Preschool (33–59 months)	$n = 11$	Whole-body movement, navigating spaces, orienting around objects
2016	Atherton and Nutbrown	UK	ECEC (8 months–3 years)	$n = 7$	Repeated actions (schematic behaviours) including movement of hands/arms/whole body
2016	Chigeza and Sorin	Australia and Canada	Kindergarten (4–5 years)	$n = 41$	Physical interaction in environment (position/orientation) represented by children
2017	Cohrssen et al	Australia	Kindergarten (4–5 years)	$n = 19$	Gesture, whole-body movement, multimodal representation mapping location/journey
2017	Palmér	Sweden	Preschool (3–4.5 years)	$n = 8$	Children's representation/coding for moving programmable robot
2017	Solis et al	USA	Preschool (3–5 years)	$n = 20$	Transforming, manipulating objects

Table 2 (continued)

Year of publication	Author/s	Country of research	Research context and children's ages	Participant numbers	Children's movement observed in a spatial-mathematical context
2018	Gejard and Melander	Sweden	Preschool (5 years)	$n=2$	Gesture, gaze (and talk), body position, body movements, object manipulation
2018	Green	USA	Preschool (3–6 years)	$n=31$	Whole-body movement, navigating spaces, transforming objects
2018	MacDonald et al	Australia	Family study (12 months–10 years)	$n=12$	Gestures, gazes, whole-body changes in orientation towards objects, locating/navigating environment
2018	Omidire et al	South Africa	School (6 years)	$n=20$	Structured whole-body movement experiences
2018	Sabena	Italy	Kindergarten (5 years)	Not identified	Gestures (static/dynamic), with/without verbalisations, whole-body movement/posture
2018	Sumsion et al	Australia	ECEC (18–19 months)	$n=2$	Whole-body movement, navigation, manipulation of objects
2019	Chronika	Greece	Preschool (ages not identified)	Not identified	Bodying with materials, bodies in movement
2019	Hedge and Cohrssen	Australia	Preschool (4–5 years)	$n=6$	Gesture and actions alongside objects
2020	Gillanders and Casal De La Fuente	Spain	Preschool (3–6 years)	$n=6$	Whole-body movement, dynamic melodic motion
2020	Gowers	UK	School (4 years)	$n=2$	Whole-body movement, multimodal representation of location/movement
2020	Kaur	Canada	School (5–6 years)	$n=22$	Pointing and turning gestures, movement of hands/arms/whole body, representing dynamic turns

Table 2 (continued)

Year of publication	Author/s	Country of research	Research context and children's ages	Participant numbers	Children's movement observed in a spatial-mathematical context
2020	Moore et al	USA	School (ages not identified)	$n = 3$	Gestures and body movements simulating movement of programmable robot
2020	Temple et al	USA	Pre-Kindergarten (4–5 years)	$n = 36$	Whole-body movement, dynamic cross lateral motion
2020	Uhlenberg and Geiken	USA	ECEC (12–36 months)	$n = 65$	Repeated actions with objects, including whole-body movement
2021	Kim and Tscholl	USA	Preschool and home setting (3–6 years)	$n = 33$	Gesture and whole-body movement, changes in orientation/positioning

Table 3 Research context and age of children

Research context	Age of children	*Number of papers	% of total papers
ECEC (including family studies)	8 months–3 years	6	15%
ECEC (preschool)	3–6 years	18	45%
School (early years)	4–8 years	16	40%

*$n = 40$ due to coding across categories

Although the number of studies involving infants and toddlers is higher than in previously reported reviews, it was found that these papers encompassed less than a sixth of total research studies in this SR. For example, Linder and Simpson (2018) identified that 5% of the papers reviewed studied children under the age of two years. Similarly, MacDonald and Murphy (2019) identified 9% of studies involving children under three years, with only 4% pertaining to children younger than two years. Downton et al. (2020) identified research opportunities in their paper noting the "emerging field of birth to two mathematics education" (p. 234) and these opportunities appear to still exist.

Methodological approaches

Across the qualitative studies reviewed in this SR, methodological approaches included: (i) a range of observational research methods within naturalistic environments, (ii) use of multiple sources of data to capture participant meaning, (iii) inductive and deductive analytical processes to refine themes emerging from the data (Creswell & Creswell, 2018). For example, studies within naturalistic settings were found in contexts where children were freely engaging with the environment such as toddlers (aged 13 months–3 years) in outdoor spaces (Lee, 2012) and preschool children (aged 3–5 years) in indoor spaces (Solis et al., 2017). Across the qualitative studies we found reference to varying types of observational data, including digital capture and field notes of preschool and school children's observed movement as they engaged with spatial experiences (Bautista & Roth, 2012a, b; Elia et al., 2014). Some studies provided detailed transcriptions of educator and children's conversations or narration of children's observed movement and interactions within spaces. This included infants' navigation of spaces (Sumsion et al., 2018), preschool children's movement in dance episodes (Deans & Cohrssen, 2015), and gardening experiences (Vandermaas-Peeler & McClain, 2015). Other studies provided observational analysis of preschool and school children's engagement with programmable toys in structured tasks (Highfield, 2010; Palmér, 2017) and 12 months to 6-year-old children's unstructured play experiences (Franzén, 2015; Green, 2018).

Some studies intentionally captured multiple types of data. For example, Gilanders and Casal De La Fuente's (2020) study of preschool children's observed movement during block play included video recordings, participant observation, photographs, interviews and field notes. A study set in a family context involving children aged 12 months to 10 years by MacDonald and colleagues (2018) accessed digital video recordings of the movement of the shopping trolley (fitted with a Go-Pro) and children's observations through wearing "recorder glasses with an inbuilt camera to capture point-of-view recordings" (p. 6). In this study, digital data was aligned with audio recordings that enabled the broader conversation among family participants to be captured and compared in order to illuminate participant meaning making. Multiple methods of data collection allowed researchers to observe children's unstructured play and learning from varying perspectives. For example, documenting field notes and video recordings to capture preschool children's spatial-mathematical behaviours and actions with objects in block play experiences (Solis et al., 2017). Some studies applied an ethnographic approach to incorporate data gathered beyond the ECEC setting, for example in the family home with an infant-toddler (aged 8–13 months) (Atherton & Nutbrown, 2016).

Analysis of children's observed movement across studies included inductive and deductive processes. For example, Lee's (2012) observational analysis of toddlers in outdoor contexts gave rise to seven categories of children's engagement mathematically, reflecting an inductive process. Frameworks such as Bishop's (1988) "universal mathematical activities" guided deductive analysis of 12-month to 10-year-old children's mathematical noticing within supermarket experiences (see MacDonald et al., 2018). The interplay between inductive and deductive analytical processes were described in Vandermass-Peeler and McClain's (2015) study of preschool children's gardening experiences where initial coding was revised in later coding sessions. Deans and Cohrssen (2015) describe the reciprocity between inductive and deductive analytical processes as an opportunity for researchers to reflect upon and adjust earlier analytical decisions as insight about new examples of preschool children's embodied spatial thinking emerged within later analyses. Cross-analysis of data sources across iterations of research episodes was effective in capturing emerging patterns and categories of preschool children's movement and gesture while interacting with robots (Kim & Tscholl, 2021).

Scoping review findings

In relation to the second research question, findings from the thematic analysis resulted in four themes that provide insight into the role of movement in children's spatial-mathematical experiences. These being: (i) children's manipulation and transformation of objects, (ii) children's bodily engagement with/within spaces, (iii) children's representation and interpretation of spatial experiences, and (iv) contexts for spatial learning. Discussion pertaining to these themes follows.

Theme 1: children's manipulation and transformation of objects

A majority of papers ($n = 30$) provided insights about children's manipulation of objects. This included investigating affordances of objects preschool children used in their free play when engaging with spatially related ideas, such as "spatial configuration, position, direction/orientation, proportion or alignment" (Solis et al., 2017, pp. 129–130). Broader studies illustrated how play contexts provide opportunities for children (aged 12 months–6 years) to physically manipulate objects through observable actions such as moving, pulling and pushing (Green, 2018; Lee, 2012; Solis et al., 2017). Children's dynamic processes observed through their actions, highlighted the active transformation of self and objects as a feature of symbolic play (Green, 2018). Franzén (2015) noted an infant-toddler's physical interaction with objects encountered in play, describing a child's whole-body actions that were used to gain an embodied perspective of the child's sense of objects in relation to self.

Everyday play contexts such as block-building (Gejard & Melander, 2018) provided opportunities to observe preschool children's verbal and embodied engagement, with spatial categories including location, orientation, exploration of properties of objects, dimensions of space and symmetries as children oriented themselves and arranged objects. Gejard and Melander's study (2018) highlighted preschool children's physical actions such as "gestures, gaze, body positioning, body movements, and object manipulation" (p. 489) during block play that indicated children's attention to specific spatial categories. Similarly, Hedge and Cohrssen's study (2019) examined preschool children's nonverbal, embodied expression of spatially salient ideas as they oriented objects by noticing children's use of gesture and body actions, and considering how these were synchronised within broader conversation around spatial learning.

Infant and toddlers' engagement with spatial categories was observed through everyday play and physical actions with objects (Atherton & Nutbrown, 2016; Uhlenberg & Geiken, 2020). For example, Atherton and Nutbrown (2016) described an 8-month-old child's "containing and enveloping" (p. 66) schematic actions over time. In this context the child was observed placing objects in and out of a variety of containers "emptying out, refilling and covering"—these actions are related to the later development of spatial, geometrical and measurement concepts (Atherton & Nutbrown, 2016, p. 67). Uhlenberg and Geiken (2020) found that toddlers' familiarity with materials was an enabling feature in their ongoing exploration of mathematical relationships between objects. Children's physical actions were observed and categorised into behaviours that can be described mathematically, such as filling and emptying containers, gathering and moving objects from one spot to another, and arranging objects naturally into similar type groupings, along with revealing ideas about one-to-one correspondence through matching and sharing objects with others (Uhlenberg & Geiken, 2020).

The use of programmable robots such as Bee Bots provided opportunities to observe children's intuitive awareness about the motion of objects. For example, preschool and school children's positional and directional language, orientation and transformation of objects (through coding specific movements of the Bee Bots) revealed their awareness of spatial ideas such as rotations, turns and slides along pathways (Bartolini Bussi & Baccaglini-Frank, 2015; Highfield, 2010; Sabena, 2018). Highfield's (2010) analysis noted preschool and school children's awareness of a range of mathematical ideas including spatial concepts (for example, capacity, angle of rotation, directionality, position on a plane and transformational geometry).

Children's sense of mathematical structure was observed through their attention to grid formation, and spatial visualisation was noted through their use of gesturing and movement to "indicate and imagine … where the steps would be" (Highfield, 2010, p. 26). Bartolini Bussi and Baccaglini-Frank (2015) identified and categorised school children's specific use of gesture, that is how "tracing gesture" and "turning gesture" (p. 396) provided insight into children's recognition of dynamic aspects of this experience as they traced pathways, pointed to landmarks and indicated turns along the way. Furthermore, Sabena (2018) described how 5-year-old children's dynamic use of gesturing simulated a Bee Bots motion along a pathway, indicating children's spatial visualisation as they imagine the pathway. A study conducted by Kim and Tscholl (2021) highlighted children's embodied ways of experiencing mathematics through their playful, spontaneous encounters with moveable robots. Emergent categories of embodied phenomena in the study provided insights into pre-schoolers': (i) early mathematical knowledge and reasoning, (ii) utilisation of spaces, and (iii) collaboration with each other (Kim & Tscholl, 2021).

Theme 2: children's bodily engagement with/within spaces

A number of studies provided insight into children's physical exploration and movement with and within spaces ($n=20$). This involved inside spaces (Chronika, 2019; Deans & Cohrssen, 2015; Franzén, 2015; Gowers, 2020; Green, 2018; Sumsion et al., 2018) and outside spaces (Gowers, 2020; Green, 2018; Lee, 2012), and included transcribed observations of preschool children's engagement with spatially related concepts in gardening contexts (Vandermaas-Peeler & McClain, 2015). Green (2018) identified features of inside and outside spaces that afford preschool children's agency to choose and construct play spaces that provided children with greater spatial autonomy. Exemplar features included natural elements that could be used to define dimensions and boundaries of invented play spaces, the freedom to climb trees to gain different spatial perspectives, and those features that enabled observed movement in, on, under or behind landmarks in the environment (Green, 2018).

Across independent studies "concepts about space" was the most common category of children's mathematical engagement (Lee, 2012; MacDonald et al., 2018; Vandermaas-Peeler & McClain, 2015). Lee's study (2012) presented numerous examples of the spatial understandings that children (aged 13 months–3 years) revealed through "the use of the body and movement of the body within space" (p. 35). This included descriptions of children's whole-body actions as they traversed equipment when climbing, balancing and moving across different planes of motion; for example, children moving across, up, down, backwards and forwards, resolving proximity problems through moving objects closer to themselves, and moving themselves towards objects (Lee, 2012). Vandermaas-Peeler and McClain's (2015) preschool study also presented examples of children's observed movement revealing whole-body engagement with spatially related ideas; for example, children "navigated the location of the beans, the trellis and their bodies as they reached up, around and through in order to pick the beans" (p. 16). Similarly, Franzén (2015) described how a one-year-old child's body was used as a tool to experience notions of space between self, surrounding environment, and objects of interest. An example of mathematical expression through movement was found in the description of a child's movement around a cardboard car: "Sara tries to understand size and shape with the help of her body … [measuring] the car with her whole body and experiences it's size while walking round it" (Franzén, 2015, pp. 50–51). Whole-body movement in these examples illustrate children's embodied experience of mathematical ideas.

Some studies investigated the role of dance in engaging preschool children spatially (Deans & Cohrssen, 2015; Temple et al., 2020). For example, Deans and Cohrssen (2015) positioned dance as a semiotic tool for children to express embodied spatial thinking. Their study of pre-schoolers' movement in dance episodes captured engagement with spatial orientation and spatial visualisation evidenced through seven categories of movement. Categories were developed from noticing how children positioned themselves and their props, engaged with "direction" as they moved spatially and used the props to rotate themselves "around an axis" (Deans & Cohrssen, 2015, p. 66). The children also created "two-and three-dimensional body shapes" that were "high and low", along with body shapes that dynamically revealed formation of "lines and angles" (Deans & Cohrssen, 2015, p. 66). Additionally, findings from a dance study involving preschool children conducted by Temple et al. (2020) indicated a growth in children's spatial awareness including their recognition of properties of shapes and use of positional vocabulary. Across these studies children's dynamic movement provided insights into their observable changes in orientation as they moved within spaces and navigated around objects in their environment.

Theme 3: children's representation and interpretation of spatial experiences

In this section we identify papers ($n = 14$) that analysed children's interpretation (decoding) and pictorial/symbolic representation (encoding) of spatial information. These papers highlighted the role of children's movement in representing and re-representing spatial experiences. For example, preschool and school children's use of materials and objects to represent and interpret features of landscapes were indicated in mapping experiences alongside their observable movements including gesture and whole-body orientation (Highfield, 2010; Palmér, 2017). In these studies, programmable robots provided opportunities for children to decode symbols in maps and invent their own symbols to encode movement pathways, with children's observable movement documented alongside their explanation. Children's mapping of their journey to preschool or school and using 3D blocks to recreate 2D representations, enabled researchers to observe how "children's use of gesture provided evidence of their spatial reasoning" (Cohrssen et al., 2017, p. 101). In this study, reasoning across modes of representation, such as 2D images and 3D models enabled children's identification of shapes and use of spatial-directional language to be verbally and non-verbally expressed.

Opportunity to draw and explain features of familiar places provided insights into spatial features children (aged 4–5 years) notice, including aspects of spatial orientation evidenced through their relative position in space in comparison to objects and others around them (Chigeza & Sorin, 2016; Gowers, 2020; Vandermaas-Peeler & McClain, 2015). The use of prompts to physically revisit and explore aspects of mapped places enabled children to reflect upon and modify how movement has been represented (Cohrssen et al., 2017; Gowers, 2020). Essentially, children's drawings (image making) alongside their broader semiotic resources (such as their verbalisations, gesture and changes in bodily orientation) informed a deeper perspective into preschool and school children's spatialisation of experiences (Bartolini Bussi & Baccaglini-Frank, 2015; Cohrssen et al., 2017; Moore et al., 2020; Thom & McGarvey, 2015). A school-based study by Thom and McGarvey (2015) identified how the physical act of drawing enabled geometric awareness about spatial distinctions between 2D shapes and 3D objects, indicating that reflecting upon the image created (artefact) strengthened this relationship further. The role of the educator was affirmed in mediating the interplay of semiotic resources through noticing and intentionally responding to school children's verbalisations, glances, gestures, and changes in bodily orientation that revealed "semiotic traces" of concepts being explored (Bartolini Bussi & Baccaglini-Frank, 2015, p. 393). Moore et al. (2020) indicated that embodied movements such as gesture, alongside school children's concrete representations enhanced "translation" between different representational modes. For example, children were observed using their hands and objects to mark and track movement (or intended movement) of programmable robots, revealing otherwise unseen aspects of their spatial thinking.

Theme 4: contexts for spatial learning

Contexts for spatial learning was the fourth theme identified across the reviewed papers. This theme provided an opportunity to reflect on and examine contextual features of the research and how contexts enable children to engage spatially. These contexts provided spaces that afforded infant, toddler and preschool children's freedom to choose and negotiate play choices (Atherton & Nutbrown, 2016; Franzén, 2015; Green, 2018; Lee, 2012; Sumsion et al., 2018), along with materials that encourage children's spatial autonomy and sustained engagement (Gejard & Melander, 2018; Hedge & Cohrssen, 2019; Solis et al., 2017; Uhlenberg & Geiken, 2020). Family experiences, such as shopping, revealed 12-month to 10-year-old children's active noticing of concepts about location and relative positioning of items in the environment and was captured through observing children's gaze, gesture, bodily orientation and talk with family members (MacDonald et al., 2018).

Interdisciplinary contexts, such as those involving gardening, dance and music, enabled observation of preschool children's whole-body movement and embodied expression of spatial ideas (Deans & Cohrssen, 2015; Gillanders & Casal De La Fuente, 2020; Temple et al., 2020; Vandermaas-Peeler & McClain, 2015). Similarly, preschool and school children's engagement with programmable robots (Bartolini Bussi & Baccaglini-Frank, 2015; Kim & Tscholl, 2021; Moore et al., 2020) and school children's use of software in dynamic geometry environments (DGE) (Kaur, 2015, 2020; Ng & Sinclair, 2015) afforded observation of gesturing, co-gesturing and changes in bodily orientation indicating shifts in children's spatial-geometric thinking.

Numerous papers paid particular attention to how observing and responding to preschool and school children's contextualised gesturing and broader movement enabled specific discourse between adults and children, with respect to spatial learning (Bartolini Bussi & Baccaglini-Frank, 2015; Gejard & Melander, 2018; Hedge & Cohrssen, 2019; Kaur, 2015, 2020; Moore et al., 2020; Ng & Sinclair, 2015; Sabena, 2018). For instance, Bartolini Bussi and Baccaglini-Frank (2015) describe the semiotic potential of artefacts such as Bee Bots in generating spatial-mathematical discourse, with children's individual and collective understandings noticed through their embodied engagement.

Discussion

In this scoping review, recent research literature in early childhood mathematics education was examined to identify the scope and depth of qualitative studies on the role of movement in young children's spatial-mathematical experiences. Findings from this SR indicate that qualitative methods are effective in capturing children's movement and revealing their engagement with observable dynamic processes—including how children used their whole body to orient and navigate around spaces, and located, arranged and symmetrised objects in play experiences. Observational methods used across the qualitative studies enabled aspects of children's movement to be documented and analysed in spatially salient experiences. Types of observational approaches included narratives interpreting young children's physical interaction with objects and spaces, detailed video transcriptions that enabled in-depth analysis of children's whole-body movement, changes in orientation, and use of gesture emerging alongside their verbal explanations and conversations around learning. Observational methods also captured children's interaction within contexts, with intentional discourse (including the use of gesture) evident across a range of studies. Examples include how interpreting and responding to children's embodied actions supported preschool and school children's non-verbal reasoning about their spatial experiences (refer Bartolini Bussi & Baccaglini-Frank, 2015; Hedge & Cohrssen, 2019). Interestingly, observing school children's movement was found to be valuable in "translating" their processes of reasoning from one mode to another (see Moore et al., 2020). Thom (2018) noted that children's engagement with dynamic processes (observable through their movement) can be a powerful enabler for children's spatial reasoning, as embodied actions lay the foundation for language to emerge. These findings highlight that comparative analysis of multimodal data provides insight into the emergence of simultaneous interaction of representational modes, with embodied expressions being valuable means of revealing possible shifts in preschool and school children's spatial understandings.

The four themes identified across the research papers deepen our knowledge and understanding about how children's movement represents and reflects their spatial engagement and spatialisation of experiences. The research focus on children's movement provides perspectives on productive ways of inquiring into children's spatial-mathematical experiences made possible through researchers' noticing how children physically engage with spaces, with objects, and how they represent spatial ideas within everyday contexts. This view of researcher 'noticing' supports Battista's (2007) contention that paying attention to how children are "reasoning *about* objects and *with* representations" (p. 844) is important. Battista's view of reasoning can be expanded to include how children are reasoning *with* space, *with* objects and *through* representations when situated *within* contexts that engage their spatial thinking.

Findings from this SR suggest that: (i) Children's physical exploration with spaces was revealed through the observation of changes in children's whole-body movement within contexts such as gardening, dance, outdoor play, engaging with programmable robots, and block play. Spatial concepts of position, location and navigation were observed as children explored different planes of motion from varying perspectives in both inside and outdoor experiences. (ii) Children's dynamic actions with objects revealed spatial concepts of position, orientation and transformation. A number of these studies were situated within contexts such as engaging with programmable robots, block play and mapping experiences. (iii) Studies that described children's reasoning through representations found that children's movement indicated varying aspects of children's spatial thinking within contexts. For example, mapping experiences enabled opportunities for children to decode and encode spatial information and translate between varying representational modes including use of gesture (Cohrssen et al., 2017; Highfield, 2010; Palmér, 2017).

Some studies reflected an embodied perspective of the role of movement during drawing and dynamic geometry experiences with children in the early years of school (Kaur, 2015, 2020; Ng & Sinclair, 2015; Thom & McGarvey, 2015). Recommendations from these studies indicate that there are further opportunities to re-examine children's embodied expressions of dynamic spatial relationships and spatial reasoning across a broad range of interdisciplinary contexts and activities. The affordances of using outdoor areas to engage infant, toddler and preschool children spatially were discussed in three studies. The recent focus on children's spatial learning outdoors indicates an interest in interdisciplinary approaches investigating children's spatial awareness in outdoor contexts (Campbell & Speldewinde, 2022; Little et al., 2017; Moore et al., 2021; Speldewinde, 2022).

A key finding from this SR was the under-representation of studies focussed on children under three years of age. This finding is consistent with other reviews of early childhood mathematics education research. In this SR, studies that focussed on infants and toddlers highlighted their physical engagement with spatial-mathematical concepts. Of note was how children moved to investigate boundaries and features of play spaces. This was made possible through close observation as to how they made decisions to shift dimensions when navigating around and through equipment in play spaces (Franzén, 2015; Lee, 2012). Infant and toddlers' spatial engagement was also observed when they actively explored spatial-geometric features of objects they encountered in their play contexts through patterned actions such as emptying/filling and covering/uncovering (Atherton & Nutbrown, 2016; Uhlenberg & Geiken, 2020). Thom (2018) maintains that young children's active engagement with dynamic actions from an early age, viewed through an embodied perspective, can illuminate their spatial thinking. Thom's point supports the argument for the inclusion of infants and toddlers as participants in research about their physical engagement with spatial-mathematical ideas.

Concluding thoughts

This scoping review was informed by previous reviews of early childhood mathematics education research, some of which noted that mathematical ideas relevant to young children's lived, informal experiences, such as spatial-mathematical concepts and processes, have been under-represented. Findings from this SR indicate that qualitative research studies can capture a broad picture of children's spatial-mathematical engagement through various data collection methods, including those that involve documenting children's observed movement. The majority of studies reviewed as part of this scoping review documented children's physical manipulation and transformation of objects. A high number of studies provided an embodied perspective and were able to direct attention to how children's movement reveals their non-verbal awareness of location, position, orientation and transformation of objects in inside spaces. An important implication for these findings is that early mathematical thinking can be observed, identified and described explicitly through non-verbal means. A further implication from this review is that outdoor play needs far greater attention in early years' learning contexts and would benefit from an interdisciplinary approach. As research with infants and toddlers is an area noticeably underrepresented in the early childhood mathematics education research literature, this is a priority for future studies. In conclusion, our SR has re-focussed attention on young children's embodied awareness of spatial and broader mathematical concepts through examining qualitative research studies. In doing so, we have provided fresh insights into appreciating how young children develop mathematical ideas from a spatial perspective.

Appendix

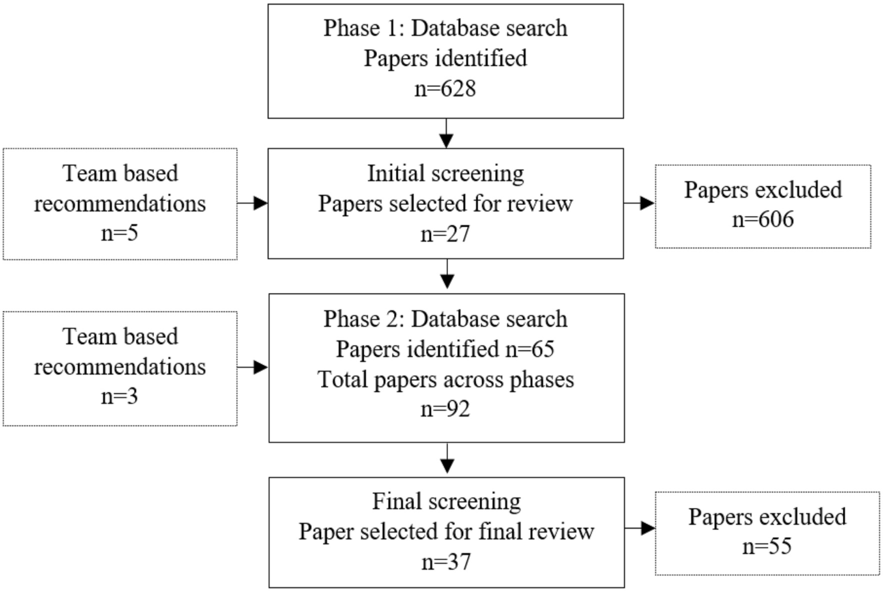

Fig. 1 Scoping review article search and screening process

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Data availability Data sources for this scoping review were secondary sources (published research papers) that were publicly available for review and no empirical data were collected.

Declarations

Consent for publication This research is part of the first author's PhD research.

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