Supporting children’s spatial reasoning

Many aspects of spatial reasoning are embedded in children’s everyday lives as well as in early childhood practice. Recognising children’s spatial competencies and interests allows us to build on their strengths, supplementing and enhancing spatial reasoning opportunities within a broad range of early experiences. Whilst activities can offer rich opportunities for spatial reasoning, it is how children and adults engage with these that fosters development. From birth, children are building up knowledge through embodied experience of shape and space. For example, children may be interested in boxes, or in posting items into drawers; they may be exploring ideas of inside or what fits. The adult role is crucial in following the interests of children, recognising and sometimes drawing children’s attention to spatial elements within their play and everyday activities. This is a complex and nuanced role where adults might spontaneously begin or join in with children’s spatial exploration or use spatial words and gestures in context to encourage children to engage in spatial reasoning.

Children’s bodily awareness and physical experiences underpin the development of their spatial reasoning. The large-scale movements that are crucial for physical development, and commonly encouraged during outdoor play, have been found to be important for very young children to learn to interpret views from different perspectives and to visualise these (Oudgenoeg-Paz et al., 2015). Some children may have a strong drive to repeat their actions over and over again, such as moving or throwing things. Athey (1990:37) describes these as schemas: ‘a pattern of repeatable behaviour into which experiences are assimilated and that are gradually co-ordinated’. These occur at different times for different children: for example, some children may show a preference for lining things up or a fascination for putting objects inside other things. As children grow, they draw upon a range of tools to assist them with their spatial thinking and make it more efficient (including words, gestures, images and symbols). Language and gesture are particularly helpful in forming concepts about shape and space. Some commonly over-looked aspects in early mathematics curricula are perspective-taking, symmetry, scaling, and navigation and these are discussed in more detail below.
Physical development

Babies and young children use movement and senses to explore their worlds and communicate their thinking. Spatial awareness underpins spatial reasoning as an embodied process; feeling ‘my body in the world’ so that I can act upon it. Spatial reasoning cannot develop without strong body awareness and strong awareness of the environment. This awareness grows through the integration of sensory systems, providing the body with a combination of internal and external information in order to visualise or mentally represent the environment. It takes a long time to develop and automate these processes and the mental representations children produce need to be updated constantly as their bodies grow and change. This is why young children need such a lot of time to be physically active, gaining feedback from the world around them and experiencing the world’s response to what they do.

Spatial reasoning is underpinned by the intricate linkage between the internal and external information provided by three sensory systems:

- **The vestibular system** – a motor sensor system that registers movement of your body in the world. It is critical for understanding how your body moves in space and how it understands space including balance and awareness of being upright.
- **Proprioception** – body awareness. It provides an embodied understanding of the location of parts of the body and the body in space.
- **The visual system** - supporting static and dynamic understandings of shape and space, e.g. sensing distances between objects. Hearing is also critical for getting feedback from the environment. Children with visual or hearing impairments will rely more on other senses.

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It is crucial that adults recognise the importance of the development of these senses in babies and young children and demonstrate this by providing plenty of space, time and opportunity for children to be physically active throughout the day. ‘Embodied learning’ means that children physically encounter and experience phenomena such as ‘round’, ‘bumpy’, ‘upside-down’ or ‘inside’ and build up their understanding of what these terms are through their senses before, and where appropriate, at the same time as adults provide the vocabulary to support a concept.

**Gesture and language**

The development of children’s spatial awareness and reasoning is enhanced by the use of language and gesture. More precise language helps children to focus on shape properties and spatial positions and to conceptualise these. Research shows that this process is dependent on the quality of children’s experiences, the adult’s role in providing appropriate language and also on the use of gesture by both children and adults. This starts with adults paying attention and responding to babies’ gestures and eye gaze, e.g. for instance when a baby waves a hand to show that they want to climb in a box and the adult acknowledges the child’s gesture, *'You want to go in the box?’* Toddlers with more experience of large-scale movement and toys can understand more sophisticated terms, such as *between* which relates a position to two other objects, or *in front of* and *behind*, which are relative to the viewer (Oudgenoeg-Paz et al., 2015).

Gestures provide initial ways of communicating spatial ideas: these are often requests (or commands!), showing what babies would like to happen (e.g. pointing to where they want to go or putting their arms up if they want to be carried). Adults can supply spatial words for these, like *in* and *up.* Gestures are important ways of supporting language, for instance pointing to an object’s location, moving a hand around when saying *curved,* or turning bodily to explain *left or right.* Many studies have found that gestures help both adults and children to describe and understand features or movements of shapes (e.g. Bower et al., 2020). Adults can encourage children to use gestures, such as putting hands close together for *small* and far apart for *big:* including physical activity in this way enhances children’s learning (Levine et al., 2018).

There are three main types of gestures relevant here:

- gesturing an action required or visualised (e.g. rotating a shape to fit in a puzzle).
• tracing the outline of shapes (as used by Young et al., 2014), highlighting properties and linking these to spatial words and concepts.
• supporting language, helping to communicate otherwise difficult spatial concepts and so providing a bridge to learning new concepts or words (Singer & Goldin-Meadow, 2005).

Spatial language, supplemented and supported by gesture, can be introduced in everyday and play contexts: for instance getting dressed may involve spatial ideas of back to front and inside-out. What is developmentally appropriate for individual children will vary according to their experiences. Most children understand in, on and under at three years old, but only come to understand between and behind when they are four, unless they have had a lot of large-scale movement experience (as mentioned above). Some children will be seven years old before they can use relative terms like left and right, but many four year olds will understand these when accompanied by gestures. Learning spatial vocabulary helps children to conceptualise the distinctions between different positions and properties (Farran & Atkinson, 2016). This suggests that when young children experience difficulties, for instance in copying a model with pieces at right angles to each other, we might supply a term like across, and also a gesture like crossed hands, to help them to conceptualise this relationship. It seems that language helps children to hold more things in mind, so that, for instance, they can remember the shape properties while focusing on moving them to fit them together (Pruden et al, 2011).
Spatial language can:
- help children to use and recall spatial information, such as relationships between objects e.g. next to, in front of (Feist & Gentner, 2007);
- improve children's conceptual understanding by refining spatial categories, e.g. the difference between on and in (Farran & Atkinson, 2016);
- help to draw children's attention to the relevant spatial attributes when problem solving, e.g. relative positions of blocks when copying constructions (Bower et al., 2020);
- highlight the spatial relations that underlie mathematical concepts (e.g. numbers on a number line; Mix & Cheng, 2012).
Exploring and communicating about a range of shapes involves a wide variety of language beyond standard geometrical terms, in order to identify them and tell them apart, especially if we are describing everyday objects and routes. For example, we use informal language such as describing a bendy, wiggly, twisty or zigzag path, making a loop or a circuit and we use analogies like a dogleg junction (in New Zealand signs advise traffic lanes to merge like a zip). When distinguishing leaves and their growth patterns, we may use analogies such as hand-shaped, spear- or heart-shaped, or terms like smooth-edged, serrated, toothy, opposite and alternate. When doing jigsaw puzzles, we might refer to the corner piece or straight edges to differentiate pieces, or use our own terms like sticky-out bits and holes to describe the piece we are searching for or explain why a piece cannot be the right one for the space.

Researchers have found that introducing children to more irregular shapes encourages them to make finer distinctions between shape properties (Verdine et al 2019). This suggests that we should be describing and categorising shape and spatial properties in a broad way, encouraging children’s own voice and creative language or analogies, as well as introducing mathematical terms when these make useful distinctions.

Individual and group differences

Individuals will vary in their spatial abilities according to their characteristics, development and experiences, in ways which are not yet very clear, and which vary for different aspects of spatial reasoning. With regard to gender, although there are differences between men and women regarding mental rotation, there are virtually no differences between pre-school boys and girls; a difference emerges significantly in adolescence but we do not know whether this is due to developmental or environmental causes. For adults there are smaller or no gender differences for some aspects of spatial reasoning, with no differences with some visualisation tasks, such as paper folding and less for navigation than might be expected from popular stereotypes: this suggests there is no such thing as a general spatial ability which some have and others lack. However there is evidence of differences in the experiences of boys and girls, with regard to physical activities, parental language and degree of challenge (Newcombe, 2020). Regarding children’s social backgrounds, children from poorer backgrounds tend to enter schools with lower spatial abilities and may lack experience with spatial resources, and toys.
Middle class parents may use more spatial language, but differences in children’s experience of outside spaces will depend on individual situations. However, children from low SES backgrounds tend to make greater progress in response to teaching (Clements and Sarama, 2020; Verdine, 2017). Children with special needs, such as with visual impairments, show similarities and differences to visually-able children, but spatial concepts and mental representations can be built through movement and touch: for instance directing robots helps children to visualise spatially (Sarama and Clements, 2009.)

In general, it is important to develop spatial reasoning with children from birth to seven, because spatial training is optimally effective for young children (Uttal et al., 2013). Spatial teaching is also particularly effective for children of parents with a lower educational background (Schmitt et al., 2018) and for addressing gender differences (Sarama & Clements, 2009). Teaching spatial reasoning in the early years is also particularly effective for children from low SES families (Heckman, 2006), therefore providing an opportunity to reduce the attainment gap between children from the more and less advantaged communities.

**Environments for spatial reasoning**

This section considers the:

- **physical environment** indoors and outside in terms of layout and resources
- **emotional environment** that plays a significant role in supporting the development of dispositions necessary for successful mathematical learning
- **language environment** where sensitive and timely adult interactions support the development of spatial concepts and spatial reasoning.
Environments are created and maintained by adults. Those who recognise the importance of spatial reasoning are more likely to plan for and encourage it and those who notice children’s spatial play are more likely to give children permission, e.g. to squeeze into spaces or enjoy different perspectives. Adults can positively influence the emotional environment by ensuring that children have ample time to engage in spatial play and by valuing and providing for repetition and revisiting of ideas. Creating an atmosphere of safety and security supports positive attitudes to trial and error and to risk taking. Further, adults need to model curiosity and encourage that disposition in children by showing genuine interest in what children are exploring and finding out.

Some resources to include in provision will be very obvious such as puzzles, block play and shape resources that might be offered in a maths area. What might be less obvious are the opportunities that are, or could be available through setting routines such as lining up or group times and in other areas of provision, e.g. in the book, pretend play, art, workshop or small world provision. Where resources and experiences have the potential to support spatial thinking but it is not a given, it is more often the role of the adult to sensitively interact in children’s play, providing the words alongside the experience or drawing attention to an aspect of spatial thinking. Given that girls and children from low socio-economic-status backgrounds are more at risk of missing out on the opportunities it would be expedient to take notice of these cohorts of children.

Through repeated exposure to the physical environment, resources and experiences children develop an embodied understanding of spatial phenomena, e.g. they gain understanding of shape properties such as the roundness of a ball or the curved property of a piece of guttering by
handling these materials. To appreciate the potential for spatial awareness and spatial reasoning within the layout of the physical environment, a starting point might be to consider it from a child’s perspective, e.g. considering possible routes through the classroom or outdoor space, views from one area of provision to others, vantage points and enclosed spaces that children choose to explore. The outdoor environment is especially suited to physical play and play with open ended materials that can be transported and therefore offers rich opportunities for children to build mental maps of their surroundings. To encourage this, adults may decide to store materials e.g. for den building or transporting water away from the areas where children play with them. Beyond the setting gates there may be further opportunities to support spatial thinking in terms of routes and journeys. Where these routes are frequently travelled and adults allow children the time to explore features of interest to them on the way, adults may notice children developing rituals throughout the familiar journey, e.g. walking along a specific path edging or jumping on a manhole cover. An essential aspect of an enabling environment for spatial awareness and spatial reasoning is that adults recognise the importance of repetition and exploration such as this.
Families support early spatial reasoning development in a range of ways, often without realising this is what they are doing. When family members engage in early physical play and other experiences with children, this supports early spatial exploration and sense-making. Taking children around their locality, rough and tumble play and providing time and space to explore their bodies and the space around them makes a vital contribution to children’s early spatial learning.

Families spend time on the floor with babies, join in with their physical play and move babies around so they experience movement and seeing the world from different viewpoints. This continues to develop with hiding games and encouraging children to explore larger spaces through taking children to gardens and parks where they can run, jump and climb as they become more mobile and independent. As children mature, families often also engage in more structured spatial play with children, such as using jigsaws, puzzles and blocks.

Parents and caregivers use spatial talk frequently with young children as they go about their everyday lives and when playing with them (although the amount varies considerably between families). This talk includes a range of spatial terms such as up and down (direction); big and small (size); edges and corners (features and properties); upside down (orientation); turn and turn over (transformation) (Ho et al., 2018). Where parents are provided with support for what spatial activities they could do with their child and what they might talk about, this supports children’s spatial talk (Polinsky et al., 2017). This might be as simple as recommending or loaning small world figures and vehicles to be included in shared construction play as this provides contexts to use spatial words as the people or cards are moved in and out, up and down or positioned next to or on structures within the play (Ferrara et al. 2011). Children whose families use more spatial words with them use more spatial words themselves (Polinsky et al. 2017, Pruden et al. 2011). These words help the child to form a conceptual understanding of the spatial idea which they use in their spatial thinking. For example, the word inside is associated with interior spaces, being surrounded or encased and as the opposite of outside. This word gives a label to this concept to support clarity in spatial
thinking with the word *inside* coming to mind when deciding where to place an item or when wondering where an item might be, for example. In addition to spatial play and everyday experiences, using spatial language when sharing a picture book is a good way for parents to support children’s spatial reasoning (Szechter & Lieben 2004).

Of course it is not just those in a parental role that support children’s early spatial thinking development. Other children in the family often engage in physical play, model using spatial words and play spatial games and puzzles with children. Shared construction and ball games, for example, are rich opportunities for spatial learning where communication of ideas are necessary within the shared experience and activities can flow, revisited and becoming extended over time. Similarly, members of the extended family enjoy action songs, play games and go on journeys with children. They support children’s spatial learning through pointing out and talking about landmarks (places along the way), perspective (how places appear from where they are or will be) position (where something is) and direction (which way they are going).

Practitioners in settings support children’s spatial reasoning through their interactions and provision but also through their communication with children’s families. This needs to be planned into the regular time to discuss individual children’s mathematical learning and not on an ad hoc or opportunity led basis as some children and their families might get missed, particularly if they are shy or less confident with mathematics. Practitioners support spatial learning in partnership with families by:

- valuing children’s home spatial learning,
- sharing examples of their child’s spatial learning in setting
- providing ideas for extending spatial learning at home

Valuing home learning includes listening to children and their families talk about the physical play and journeys they have experienced together. This may include learning some spatial words in the child’s home language and using gesture alongside these and the English words. Practitioners might encourage families to share photographs with them of their child climbing and exploring, for example, or a model they have made at home using construction toys.

Examples of children’s spatial learning can be shared with families through encouraging children to engage with tasks that can be shared with their families. This might include providing simple drawn maps and photographs of the setting for new children and their families to take home. One nursery, for example, encouraged children to create maps of the nursery to show their families where their favourite places and things were which the children enthusiastically shared with their families. Supporting children to take their own photographs in the setting and whilst on walks with practitioners is another good way of children sharing their spatial learning with families.
Practitioners can also support home learning of spatial reasoning through providing pictures books (such as those on the ‘ECMG spatial reasoning book list’) to be borrowed and shared at home. These could have key spatial words glued inside the cover or on a bookmark to help emphasise these to families alongside enjoying the story. Practitioners also might ask families to take photographs of their journey to the setting which can be made into a map or sequenced by the child (and perhaps taken home to share with families afterwards), encouraging children to sequence the landmarks that are important to them along their journey.
Books

Children’s books provide meaningful contexts to explore spatial reasoning. Adults and children can enjoy books together, using spatial language and exploring spatial problems (such as looking under the bed or behind the door in a lift-the-flap book). Some books are particularly helpful for drawing their reader’s attention to specific types of spatial reasoning, such as perspective-taking or navigating. Our ‘Spatial reasoning book list’ makes some suggestions. Acting out stories or ideas from children’s books, using props or pictures, can help children to move their bodies to explore the spatial aspects physically for themselves. Making their own maps or plans of the places or story sequence from a book can be an enjoyable activity for children, where they can represent what they found in the book or can think creatively to invent their own places or events using their imagination, perhaps extending the story and creating alternative narratives.

Spatial reasoning across the curriculum

Spatial reasoning supports and is developed through learning in curriculum areas other than mathematics. Our ‘spatial reasoning across the curriculum’ document suggests ways in which spatial reasoning can be applied and developed in contexts and activities which do not have a mathematical focus. These are presented as the generic ways in which they support learning (near the centre) and then subject-specific ways are arranged in a wider ring, referenced to school subject areas on the inside (National Curriculum in England) and early years areas of learning in the outer ring (EYFS in England). Recognising, incorporating and extending spatial thinking across the curriculum can benefit both children’s mathematical understanding and their understanding in other areas too. Spatial reasoning connects to a range of areas of learning so developing it with young children from birth to 7 years is a way of building foundations for learning in subject areas beyond mathematics for later schooling and indeed careers and everyday life.