

## Spatial thinking in primary education in Ireland

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Spatial thinking has been shown to span a multitude of disciplinary areas and is recognised as a core competence related to mathematical achievement and participation in Science, Technology, Engineering and Mathematics (STEM) careers. At this time of intense curriculum change at primary level in Ireland, this paper examines the extent to which spatial thinking is made explicit in the Mathematics and draft Science, Technology and Engineering and Social and Environmental Education (SEE) curriculum documents by analysing curriculum learning outcomes against a typology of spatial skills proposed by Newcombe and Shipley (2015). While many spatial skills are explicit in mathematics curriculum outcomes, they remain implicit in the STEM and SEE curriculum specifications.

*Keywords:* Spatial thinking, curriculum, STEM, integration, achievement

### Introduction

The influential US-based National Research Council (NRC) report describes spatial thinking as a combination of concepts of space, tools of representation, and processes of reasoning (NRC, 2005, p. ix). The report argues that without considered attention spatial thinking will remain extensively relied on across the curriculum but not explicitly or systematically taught in any subject area (p. 6). In Ireland, there is evidence of consistent underachievement in Shape and Space. The area has been called out as a priority for development in the recent Literacy, Numeracy and Digital Literacy Strategy (Government of Ireland [GoI], 2023). Internationally, it has been suggested that spatial reasoning should be considered when “designing curricula, training teachers, setting goals and developing assessments” (Newcombe, 2017, p. 37). This is a time of significant curriculum change in Ireland. The primary curriculum framework (PCF) emphasizes interdisciplinary learning experiences and for the first time includes the curriculum area of STEM (Department of Education [DoE], 2023a). This area will consist of two distinct specifications: the mathematics curriculum specification (DoE, 2023b) and a specification for Science, Technology and Engineering (STE). Spatial ideas pertaining to geography are included in the draft Social and Environmental Education (SEE) specification. This paper presents a short overview of relevant literature, then presents an analysis of the extent to which spatial skills are explicit in the published mathematics and draft STE and SEE curriculum specifications.

### Spatial reasoning and achievement

The role of spatial ability as a predictor of success in mathematics and in STEM fields has long been recognised. A UNESCO (2017) research synthesis highlights the foundational role of early spatial abilities for the development of quantitative reasoning, a cognitive domain integral to both scientific and mathematical thinking. While research provides some evidence of gender differences in spatial achievement in favour of boys, it is hypothesised that these arise from the social environment which provides more opportunities for spatial skill development to boys (UNESCO, 2017). Research also demonstrates links between socioeconomic status (SES) and a broad range of cognitive skills in childhood. Spatial skills are among those on which children from lower SES backgrounds perform worse than children from middle or high SES backgrounds (Johnson et al., 2022). In Ireland, the disparity of achievement scores between schools designated as disadvantaged and non-designated schools

is continually noted (e.g., GoI, 2023). Analysis of spatial achievement profiles may be illuminating in terms of developing new ways to tackle this consistent under achievement.

Some researchers advance critiques of a bias toward verbal reasoning and/or mathematics skills in existing educational systems which do not adequately identify and meet the needs of spatially talented students. The US-based analysis of Lakin and Wai (2020) indicates that large numbers of spatially talented students are overlooked in screening procedures and assessments which place a greater value on verbal and mathematical abilities. Additionally, analysis of longitudinal measures showed that spatially talented students had greater academic challenges, including reading difficulties, poor study habits, and behavioural troubles. These students were less likely to complete college degrees compared to other talented students. Such findings may also have relevance in Ireland, where inclusive pedagogy is advocated and the need to enhance outcomes for higher achievers has been noted.

### **Teaching Spatial Thinking**

Research affirms the importance of environmental influences and the malleability of spatial reasoning (Uttal et al., 2013). Spatial thinking may be taught directly or infused in the curriculum. Direct instruction of spatial skills may involve, for example, engaging in play activities that are spatial in nature such as block-building or paper folding (Newcombe, 2017). The second strategy is more indirect and involves ‘spatializing the curriculum’ through the strategic use of tools for spatial thinking during general teaching (Newcombe, 2017, p. 12). Tools may include “spatial language, maps, diagrams, graphs, analogical comparison, physical activity that instantiates scientific or mathematical principles, gesture and sketching” (Newcombe, 2017, p. 37). This approach aims to avoid spatial thinking being seen as an ‘add-on’ to a packed curriculum and instead positions it as a ‘missing link’ that cuts across disciplines (NRC, 2005, p. 7). In the Irish context, Langan (2022) designed an integrated cross-curricular unit of work using the spatial enhancement skills of *visualization instruction*, *sketching*, *gesture*, *spatial comparison* and *spatial language* to target learning outcomes of the Irish Primary Curriculum and spatial thinking skills.

### **Spatial Skills and the Irish primary curriculum**

Uttal et al. (2013) propose that a distinction can be made between spatial thinking related to intrinsic and extrinsic relationships. Intrinsic relationships are understood to mean the “specification of the parts, and the relation between the parts, that defines a particular object” and extrinsic relationships are understood to involve the relationships “among objects in a group, relative to one another or to an overall framework” (Uttal et al., 2013, p. 353). In addition, the research indicates that it is possible to distinguish between reasoning as it pertains to static and dynamic contexts (Uttal et al., 2013). Newcombe and Shipley (2015) expand on the nature of spatial thinking within these distinctions noting, for example, that spatial thinking involves processing both continuous and discrete information, and that scale plays an important role in deciding what will be defined as intrinsic or extrinsic (p. 3). These authors synthesise existing research to identify a list of spatial skills that can be identified in young children (p. 12 - 13). By looking for evidence of the spatial skills identified by Newcombe and Shipley (2015) within relevant areas of the Irish primary curriculum, we sought to identify the extent to which spatial skills are made explicit in curriculum specifications. We examined the learning outcomes of the primary mathematics specification (DoE, 2023b) and the draft specification for Science, Technology and Engineering (STE) (NCCA, 2024a) and Social and Environmental Education (SEE) (NCCA, 2024b). We acknowledge that other conceptualisations of spatial thinking are possible but chose Newton and Shipley’s framework as it specifically considers the spatial thinking of young children.

Table 1 shows Newton and Shipley’s (2015) spatial skills, which encompass dynamic and static contexts, in the far-left column. The intrinsic spatial skills are: *disembedding* (isolating and attending to one aspect of a complex display); *categorisation* (learning categories based on spatial relations); *visualising 3D from 2D*; *penetrative thinking* (visualizing spatial relations inside an object); *mental transformations*; and *sequential thinking* (visualizing the product of a series of transformations). The extrinsic spatial skills are: *locating self and other objects* (e.g., on maps); *alignment* (reasoning about spatial and temporal correspondence); *perspective taking*; *relations among objects in space*; and *updating movement through space* (visualizing movement of an object relative to other objects). Table 1 also shows our analysis of the extent to which these skills are explicit in curriculum learning outcomes. Given the way in which spatial thinking underpins many learning activities, it is possible that classroom activities directed toward various learning outcomes would contain activities that might address the spatial skills. However, ‘explicit’ is only listed if at least one learning outcome addresses the spatial skill directly. The analysis was completed in collaboration between authors, with differences of opinion agreed through discussion.

Not unexpectedly, for the mathematics specification, many of the spatial skills are explicit in the learning outcomes within the Shape and Space strand. While it is positive that many spatial skills are made explicit in the mathematics curriculum, we note that much of this content is a departure from the 1999 mathematics curriculum and teachers will need significant support in reorienting their teaching to address these skills. Skills pertaining to intrinsic spatial relations occur largely in the ‘Shape’ and ‘Transformation’ strand units. We note that the term ‘visualisation’ occurs at the level of the learning outcomes just once, “visualise and model location using symbolic coordinates” (Stage 2, ‘Spatial Awareness and Location’). While opportunities are evident for *penetrative thinking* in some of the progression continua content, e.g., shape dissection at milestone h in ‘Shape’, this remains implicit at the level of the learning outcomes. Many extrinsic spatial skills are evident in learning outcomes associated with the ‘Spatial Awareness and Location’ strand unit. *Perspective taking* involves visualizing the appearance of a scene from a different vantage point (Newcombe & Shipley, 2015, p. 10). Currently this is not present in the learning outcomes of the ‘Spatial Awareness and Location’ strand unit which emphasizes mapping and navigation rather than perspective.

**Table 1**

*Presence and explicitness of spatial skills in the primary mathematics and draft STE and SEE curriculum specifications.*

	Mathematics	STE	SEE
<i>Intrinsic Spatial Relations</i>			
1. Disembedding	Explicit	Explicit	Explicit
2. Categorization	Explicit		Explicit
3. Visualizing 3D from 2D	<i>Implicit</i>	<i>Implicit</i>	<i>Implicit</i>
4. Penetrative thinking	<i>Implicit</i>	<i>Implicit</i>	
5. Mental transformations	Explicit	<i>Implicit</i>	
6. Sequential thinking	Explicit	<i>Implicit</i>	
<i>Extrinsic Spatial Relations</i>			

1. Locating self and objects	Explicit	<i>Implicit</i>
2. Alignment	Explicit	<i>Implicit</i>
3. Perspective taking		
4. Relations among objects in space	Explicit	<i>Implicit</i>
5. Updating movement through space	Explicit	<i>Implicit</i>

For STE, *disembedding* is positioned as a key skill with reference to developing ‘STEM eyes’ and observing everyday objects through a STEM lens a learning outcome in the ‘Nature of STEM’ strand unit. Other skills associated with intrinsic spatial relationships are either not present or implicit only. For example, while categorisation (of plants, animals and materials) is included as a learning outcome, the extent to which this may involve *categorisation based on spatial relations* is unclear. In addition, *visualizing 3D from 2D*, *penetrative thinking* and *mental transformations* are core design skills that students should encounter as part of the engineering design process. The stage 4 ‘Engineering’ learning outcome includes reference to the use of sketching and digital tools to plan designs. These representations may facilitate spatial thinking, but the framing of earlier learning outcomes largely focuses on aspects of the design process which may not involve spatial thinking such as assessing user needs, or reflection on the process. We note little evidence of, but huge possibilities for, extrinsic spatial skills in relation to other STE learning outcomes. *Alignment* involves reasoning about spatial and temporal correspondence such as the use of space as a proxy for time, and the use of space as a proxy for other elements on graphs (Newcombe & Shipley, 2015). This is of relevance to science inquiries such as those mentioned in the ‘Materials’ or ‘Forces and Electricity’ strand units. In the same way, *updating movement through space*, seems likely to underpin thinking in such science inquiries though it is not explicitly mentioned. In addition, the potential of digital technologies to support exploration of static and dynamic representations of space and perspective taking is not mentioned.

The draft SEE curriculum specification contains integrated learning outcomes for stages 1 and 2 and history, geography and integrated outcomes at stages 3 and 4. It is possible to identify outcomes which contain references to spatial skills, but much of this remains at the implicit level as outcomes are written in a very broad manner. For example, the following outcome from stage 4 of the strand unit ‘People, places and space’ could be interpreted in ways that may emphasize only historical or social understandings and not draw in any meaningful way on spatial reasoning: “Investigate people's journeys, the events, and motivations for movement, as well as the impact and influence of movement on people and places” (NCCA, 2024b, p. 18).

### **Implications and recommendations**

Spatial reasoning is more prominent in the new mathematics curriculum than the previous version and teachers will need considerable support in understanding and enacting this. The limitations to the explicit attention to spatial thinking in the draft STE and SEE curriculum raises a number of other challenges. There is a danger that teachers will see spatial reasoning as connected primarily, and possibly only, with mathematics. The extent to which it underpins student learning and achievement in other domains may not be grasped by teachers. In initial and continuing professional development, teachers should be made aware of core spatial skills which reach across curriculum areas, such as those identified by Newcombe and Shipley (2015), shown on table 1. In addition, curriculum support materials would be well

advised to address the gaps identified in table 1 above. They should include explicit attention to (i) visualizing 3D from 2D; (ii) penetrative thinking and (iii) perspective taking.

Nationally and internationally, the research which has shown the importance of spatial thinking for equitable outcomes is being used as a foundation for planning pedagogical interventions. The existing research provides strong guidelines for how this might be achieved in ways which do not add to an already packed curriculum. Attention to spatial tools, such as those used in Langan's (2022) work, should be a core part of teachers' preparation and professional development for STEM education. This is important to increase students' spatial reasoning, but also to ensure that teaching reaches those students who may already be better spatial learners. The principles of the PCF include using evidence-based pedagogical approaches which create equity of opportunity and participation (Government of Ireland, 2023). In addition, the PCF principles advocate for meaningful assessment to inform teaching and learning. This is of importance to those with spatial thinking skills and needs which are not being recognised or met within the current environment. While national and international tests suggest issues with achievement in Shape and Space for learners in Ireland (Government of Ireland, 2024), better data on spatial reasoning, at all levels, is warranted. This pertains to assessing and monitoring the development of children's reasoning, and to the spatial thinking capacity of teachers.

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