# An Invisible Skill? The Impact of a Spatial Ability Training Programme on Self-Concept and Maths Attainment

Submitted by Thomas de Sausmarez, to the University of Exeter as a thesis for the degree of DEdPsych in Educational, Child and Community Psychology, June 2022.



I certify that all material in this thesis which is not my own work has been identified and that any material that has previously been submitted and approved for the award of a degree by this or any other University has been acknowledged.

## Abstract

Spatial thinking has traditionally received much less educational focus in the curriculum, with most pedagogical content being related to, reading, mathematics and science (National Research Council, 2006). Spatial ability is correlated with performance in several different cognitive skills including maths (Lowrie et al., 2017) and reading (Giovagnoli et al., 2016). Furthermore, spatial abilities have been shown to respond well to focussed interventions (Uttal, Meadow, et al., 2013). Academic self-concept is an evaluative self-perception that is generated through the interpretation of, and experience of academic activities in a school environment (Marsh & Craven, 2006). A ten-year longitudinal study found that academic self-concept predicted educational attainment over and above prior achievement, even when controlling for other factors including family socio-economic status, family structure and academic achievement (Guay et al., 2004). This research project investigates what impact an intervention aimed at improving spatial skills can have on maths attainment and self-concept.

In Phase 1, participants were administered an adapted version of the Self-Description Questionnaire-1 (SDQI) (Marsh, 1990). The SDQI measures self-concept in three academic areas (reading, mathematics, and general school). Participants were in years 4/5, in line with the appropriate age groups for the original SDQI. Additionally, I added a fourth academic area to the measure – spatial ability. Pupils (*N*=178) were administered a maths self-concept, reading self-concept scale and a spatial self-concept scale. To ensure understanding, participants were shown a novel 3-min video illustrating different spatial skills. Initial data analysis showed that the novel spatial self-concept measure has good internal consistency (Cronbach’s alpha=.845). Test-rest reliability scores were also good. Spatial self-

concept is significantly correlated with both maths self-concept (*r*=.435, *p*<.01) and reading self-concept (*r*=.318, *p*<.01).

Phase 2 of the study investigated the impact of a spatial skills training programme on maths attainment and spatial self-concept. The training programme consisted of 10, 20-minute sessions which focused on different spatial sub-skills. The spatial sub-skills selected were informed by Lowrie et al. (2017). This phase was a quasi-experimental design, with participants (*N*=57) recruited from two local schools. Participants completed pre- and post- intervention measures of maths attainment, and reading, maths and spatial self-concept. A process evaluation was also completed. Data analysis revealed a significant interaction between intervention group and time, in regards to maths attainment (*F* (1, 56) = 16.291, *p*>0.01). This demonstrates that engagement in the training programme resulted in an increase in spatial maths attainment. However, there was no impact upon any self-concept (spatial, maths or reading) observed in the statistical data. 11 Participants who engaged in the research programme were interviewed post-intervention. Interviews were transcribed and analysed using reflexive thematic analysis (Braun & Clarke, 2006). Three key themes emerged from the data: transfer, the dynamic nature of spatial skills, and new self-perceptions.

This project has implications for the greater use of spatial skills training programmes for intervention for children with maths difficulties, which are discussed. Similarly, implications for how the results can inform future maths curriculum development are also evaluated. Finally the strengths and limitations of the research project and design are summarised.

# Acknowledgements

This research would not have been possible without the support of the young people and schools who took part in each part of the studies. I am grateful for all the kindness and accommodations they made for me throughout this research project.

I am grateful to all of the tutors and staff on the DEdPsych team, particularly my supervisors Brahm Norwich and Margie Tunbridge, for their support and encouragement throughout the past three years.

Finally, I wish to thank my family and Katy, for all their love and support throughout this entire process.

# Contents

## Index of Tables

## Index Of Figures

# Chapter 1

## Introduction

There is a positive correlation between educational attainment, social and life outcomes (Vera-Toscano et al., 2017). Research into improving educational attainment has been broad in its reach, but there are areas that are relatively under-researched, such as spatial skill development, assessment and intervention (Yang et al., 2020). In this thesis I will examine the effectiveness of a newly developed spatial skills training programme on spatial maths attainment and self-concept. Both spatial abilities and self-concept, amongst other factors, have been shown to impact upon academic attainment (Lowrie et al., 2017; Ghazvini, 2011). Aptitudes in spatial ability have been shown to be correlated with long-term outcomes and success in future careers, particularly within science, technology, engineering, and maths (STEM) (Uttal, Miller et al., 2013). Waite and McDonald (2019) noted that “STEM professions are recognised by educators and business leaders as being pillars to national economies that vie for wealth and prosperity” (p. 3). Similarly, they note that the global job market is currently experiencing an increase in knowledge-intensive jobs, and a growth in STEM occupations. Due the expanding demand for people to engage in STEM professions, it is important for the education system to focus on supporting young people to develop the skills which they need to flourish in such industries, alongside it’s other key functions. Due to the established link between spatial abilities and STEM careers, further research investigating effective spatial abilities training is a valuable area of study, due to its important mediatory role in supporting students with their academic attainment. Self-concept is also linked to attainment (Marsh, 2011), so the study of spatial self-concept is another associated area of study previously neglected.

In Chapter One of this thesis, I will explore and review the relevant research into both spatial abilities and self-concept. In the literature review, the research around each concept will be discussed and evaluated, beginning with spatial skills and then self-concept. The importance, and different definitions of spatial abilities will be reviewed, before discussing the links with other cognitive abilities. Individual differences in spatial abilities will be explored, as well as the links with mathematical attainment. Likewise, the importance of, and the different definitions and models to explain and measure self-concept will be reviewed, and the role of emotion in learning will be considered. Additionally, I will identify some areas of contention and gaps in the research literature. Following on from this, the concepts of spatial abilities and self-concept will be integrated, because considered together, there emerges a conceptualisation that provides a unique and novel way of approaching assessment and intervention.

The gaps in the research relating to the novel integration of spatial abilities and self-concept informed aspects of the Methods (Chapter Two) and Results (Chapter Three) sections of this thesis. This study consists of two phases. Phase 1 is concerned with the development of a novel 'spatial self-concept' measure and explores the correlations between the spatial self-concept domain and other previously established domains of maths self-concept and reading self-concept. The 'spatial self-concept' measure was based on the Marsh (1986) Self-Description Questionnaire I (SDQ-I). Similarly, the SDQ-I was used to measure maths self-concept and reading self-concept. Despite its age, the SDQ-I has been used for a number of years as a reliable and valid measure of self-concept (Marsh, 2011), and therefore was considered to be an appropriate basis for constructing a novel spatial self-concept measure. Phase 2 of this research project examines the impact of a novel spatial ability training programme, based upon a spatial curriculum outlined by Lowrie et al. (2018). Participants completed measures using the newly developed spatial self-concept measure, a maths self-concept measure, a reading self-concept measure, and a spatial maths attainment measure. Data was collected pre-intervention and post-intervention. Following participant engagement in the intervention, a process evaluation was undertaken, which involved the collection of pupil views on the perceived quality of the intervention, and perceptions of change in their spatial skills. In the Method section (Chapter Two) I will outline the design, participants, materials, and research procedure for both phases of the research project.

I will summarise the findings from the research, and explore the implications of my findings in relation to the current literature into spatial ability and self-concept. Furthermore, I will evaluate the implications of my findings for professional practice and future research. Finally, I will provide a self-appraisal of how the thesis has been completed and reflect on my experience of the research process. I will close the thesis with a justification of its unique and distinctive contribution to the field of research into teaching and learning of spatial abilities and our understanding of spatial self-concept.

## The Literature Review

### Spatial Abilities

Spatial ability is a critical skill for everyday tasks, including learning, training, and working (David, 2012). Spatial ability is the foundation for us to understand and interpret our geometric world (Lowrie et al., 2017). Some of the practical skills that require spatial ability include navigating our surroundings and visualising a diagram whilst solving a maths problem (Booth & Koedinger, 2011). Over the past two decades, researchers in psychology and education have been increasingly investigating the role of spatial ability in science, technology, engineering, and maths (STEM) achievement (Uttal, Miller et al., 2013). Several different studies have linked spatial ability to success in STEM outcomes and lifelong STEM career achievement (e.g., Kell et al., 2013; Nath & Szücs, 2014). Wai et al. (2009) investigated the relationship between spatial ability and STEM careers and found that higher spatial skills in U.S. high school students were correlated with the likelihood that individuals would enter a STEM career 11 year later, even when controlling for possible related variables such as maths and verbal skills. It has been argued that this may be because many STEM careers require skills such as analysing and imagining transformations of spatial relations (Uttal, Meadow et al., 2013), as well as using graphs, maps, or computer models (Hegarty, 2010). Historically, the predominant educational focus has been on pedagogical content related to reading, maths, and science. Spatial thinking has received much less attention (National Research Council, 2006). Whilst there is general agreement that spatial abilities are an overarching set of skills that help to navigate and interpret the world (Lowrie et al., 2017), there is significant variability in the definitions used (Hegarty & Waller, 2004).

### ***The Definition of Spatial Abilities***

Spatial skills have been described as spatial ability, visuo-spatial ability, spatial reasoning, and visuo-spatial thinking (Hegarty & Waller, 2004). There is also a theoretical debate about the sub-types of specific spatial skills that make up spatial ability as a whole (Lowrie et al., 2017). This point is echoed by Newcombe and Shipley (2015) who argue that many other theorists have considered the term spatial ability to be a unitary concept, but in fact, there are hundreds of different spatial tests, and “many factor analytic studies have suggested that there are several types of spatial abilities” (p.2). Different researchers have posited and differentiated between the components of spatial abilities, but these often do not align well with each other (Newcombe & Shipley, 2015). There will now be a review of the different conceptual components of spatial ability and a consideration of the interrelationships between them.

Linn and Petersen (1985) were one of the first authors to separate spatial abilities into components. They define spatial ability as made up of three components: spatial visualisation, mental rotation, and spatial perception. Spatial visualisation is the ability to complete multistep “manipulations of spatially presented information” (p. 1484). Mental rotation is the ability to rotate two or three-dimensional objects in your mind, and then determine their positions following having been rotated around an axis. Finally, spatial perception is the ability to determine spatial relationships with respect to the orientation of one’s own body, despite distracting information. Lowrie et al. (2017) replaced spatial perception with spatial orientation as a component in their study, defined as “the ability to imagine how a stimulus array will appear from another perspective” (Kozhevnikov et al., 1999, p.4), whilst continuing to use Linn and Petersen’s (1985) working definitions of mental rotation and spatial visualisation.

In contrast to these conceptualisations, Newcombe & Shipley (2015) and Uttal, Meadow et al. (2013) argued for a novel way of defining spatial skills. They organised a 2x2 schema for spatial skills which separated them based on two fundamental distinctions between types of spatial representations. These include whether spatial information is intrinsic (e.g., individual differences between shapes and part-based representations) or extrinsic (relationships between objects and frames of reference), and whether they are static or dynamic, with relation to objects. Intrinsic information is the information you would typically use when defining an item, for instance by its shape. On the other hand, extrinsic information refers to the relation an object has to others within a group. An example of this differentiation is as follows: the spatial information that distinguishes a pen from a pencil is intrinsic information, whereas the spatial relations between the pen and the pencil and the relationship between each of them to the wider world is extrinsic. Some evidence to support the intrinsic-extrinsic skill distinction comes from Kozhevnikov and Hegarty (2001) who found a dissociation in the performance of individuals in mental rotation tasks (an intrinsic skill) and perspective taking tasks (an extrinsic skill). Newcombe and Shipley (2015) and Uttal, Meadow et al. (2013) also argue that there is an important distinction between static and dynamic tasks. The previous example demonstrated two objects that were static; however objects can move or be moved. Such manipulation of objects can change their intrinsic specification, for instance when they are rotated, folded, or cut. Equally, moving an object changes its relationship to other objects within a spatial framework. This distinction between skills is supported by research which has found that some object visualisers (skilled at intrinsic-static skills) are discrete from spatial visualisers (skilled at intrinsic-dynamic skills) (Kozhenikov et al., 2005; Kozhenikov et al., 2002). This has relevance to individual differences within spatial skills, as artists are more likely to be object visualisers and scientists are more likely to be spatial visualisers (Uttal, Meadow et al., 2013). Table 1. has been developed from Uttal, Meadow et al. (2013) and Newcombe and Shipley (2015) and maps different conceptualisations to relevant skills, against examples of measures.

**Table 1**

*The Mapping of Different Conceptualisations of Spatial Abilities*

| Newcombe and Shipley (2015) | Linn and Petersen (1984) | Description | Example of measures |
|---|---|---|---|
| Intrinsic-static | Spatial Visualisation | Perceiving objects, paths, or spatial configurations within distracting background stimuli | Embedded Figures Task, Flexibility of Closure, Mazes |
| Intrinsic-dynamic | Spatial Visualisation | Piecing together objects into more complex configurations or visualising and mentally transforming objects (from 2D-3D or vice versa) | Block Design, Paper Folding, Mental Cutting, Paper Folding |
| Intrinsic-dynamic | Mental Rotation | Rotating 2D or 3D objects | Vandenburg Mental Rotation, Cube Comparison, Purdue Spatial Visualisation, Card Rotation |
| Extrinsic-static | Spatial Perception | Understanding spatial principles e.g. horizontal invariance or verticality | Water-level, Water-clock, Plumb-Line, Cross-bar, Rod and Frame Test |
| Extrinsic-dynamic | Spatial Orientation | Visualising an environment from a different position. | Piaget’s Three Mountains Task, Guilford-Zimmerman-spatial Orientation. |

*Note.* adapted from Newcombe & Shipley (2015).

Figure 1 demonstrates that whilst there is disagreement in the components and definition of spatial abilities, many of the different theorists' conceptualisations overlap with one another. For instance, Lowrie et al. (2017) considered both mazes and paper folding to be tests of spatial visualisation, whereas Newcombe and Shipley (2015) separated these skills into intrinsic-static and intrinsic-dynamic respectively. Likewise, Newcombe and Shipley considered both paper folding and card rotation to be examples of intrinsic-dynamic, whereas Lowrie et al. (2017) chose to distinguish these skills as spatial visualisation and mental rotation. I conducted an extensive literature search in 2021 which revealed that the Linn and Petersen's (1985) definitions are by far the most frequently cited. This informed the decision to use Lowrie et al.'s (2017) adapted conceptualisation of spatial skills, originally developed by Linn and Petersen (1985) (mental rotation, spatial visualisation, and spatial orientation) within this research project. All topics covered in the intervention sessions developed for this research were mapped on to Lowrie et al. (2017) and Newcombe and Shipley (2015) respectively. The process of reviewing domains of spatial abilities demonstrated that different subtypes often overlap, despite describing the same phenomena. For instance, the first session in the intervention involved two dimensional (2D) mental rotation, which can be conceptualised amongst both mental rotation (for Lowrie et al., 2017; Linn & Petersen, 1985) and intrinsic-dynamic (Newcombe & Shipley, 2015; Uttal, Meadow et al., 2013) domains simultaneously. Whilst there are disagreements in the exact definition of spatial abilities, and its different components, there is a large body of research demonstrating how different levels of spatial ability correlate with other cognitive abilities.

Table 1 also outlines several different assessment tools which measure different spatial abilities. It is important to note that these assessment tools, rather than measuring spatial skills holistically, measure specific spatial skill subtypes. This includes many assessment tools used by practicing EPs. For instance, the British Ability Scales, Third Edition (BAS-3) (Elliot & Smith, 2011), a standardised assessment kit commonly used by EPs, contains two sub-tests which contribute towards a spatial battery score. These sub-tests are the Recognition of Designs and the Pattern Construction sub-tests. These sub-tests map on to different sub-skills as outlined in Table 1, respectively. The Recognition of Designs subtest measures "short-term visual memory" (p. 53) and it requires "analysis of shape, relative size and orientation, retention of that information in visual-spatial memory and then comparison of the recalled information with an array of options to identify the match" (Elliot & Smith, 2011, p. 53). This subtest, in line with the definitions outlined above fits to the intrinsic-static (Newcombe & Shipley, 2015) and spatial visualisation (Linn & Petersen, 1984) definitions. The other subtest, Pattern Construction, measures "non-verbal reasoning and spatial visualization in reproducing designs with wooden blocks, foam squares and coloured cubes" (Elliot & Smith, 2011, p. 53). Whilst this subtest also links to the spatial visualisation (Linn & Petersen, 1984) subtype, like the Recognition of Designs, it measures intrinsic-dynamic under the Newcombe and Shipley (2015) conceptualisation. This shows that whilst the BAS-3 professes to measure spatial ability as a whole, it has two measures of spatial visualisation under the Linn and Petersen (1984) definitions. In summary, all spatially based tasks can be mapped onto different conceptualisations of spatial ability. Table 1 lists several of these tests and maps to which respective subskill of spatial ability they measure clearly. It is important when using spatial skills assessment tool to acknowledge which subskills they measure, and more importantly, which spatial ability subskills they do not. For a measure to accurately measure spatial skills more holistically, a variety of different spatial tasks which cover each of the different subtypes would be required.

### *The Relationship between Spatial Abilities and Other Cognitive Abilities and Attainment*

Spatial ability is correlated with performance in different areas of the curriculum including maths (Lowrie et al., 2017) and reading (Giovagnoli et al., 2016). The most commonly cited area associated with spatial capabilities is maths achievement. Numerous studies have highlighted the relationships between maths performance and spatial skills (Lowrie et al., 2017). Generally, people who perform better on spatial tasks, also perform better on tests of mathematical attainment or ability (Holmes et al., 2008; Rasmussen & Bisanz, 2005). There is a general consensus that maths is in some ways spatial in its nature (Jones, 2002). Geometric reasoning tasks require the transformation of both 2-D and 3-D shapes and spatial visualisation has been shown to be predictive of success in geometric reasoning tasks (Battista, 1990). Some studies have provided evidence that higher spatial visualisation ability is strongly predictive of performance in maths (Lowrie et al., 2017). Despite mathematical ability being the most commonly associated skill with spatial abilities, there are also associations with other cognitive skills. A moderate relationship between spatial ability and reading comprehension tasks has been observed (Hegarty & Kozhevnikov, 1999), even though mental rotation or the physical manipulation of objects were not required. Other research has investigated the role spatial abilities play in reading. Reading, like maths, is a highly complex process in which several different neurocognitive functions are integrated. Spatial abilities play a key role because of the multi-faceted visual sensory processing involved when reading (Giovagnoli, 2016). Some studies have demonstrated the relationship between spatial and reading skills (Vidyasagar & Pammer, 2010; Stein, 2014). Key visuo-spatial skills are needed when learning to read, even at the most basic level; students must be able to recognise individual letters and perceive their ordering in space (Vernon, 1957). This means that some children with reading difficulties struggle to develop effective visual strategies linked to spatial deficits (Giovagnoli, 2016). Conversely, some children with developmental dyslexia and/or reading difficulties have been shown to have very strong spatial abilities (Cooper et al., 2004). The functions behind reading difficulties and/or developmental dyslexia are very complex, and the debate is controversial. Researchers have found it difficult to draw clear conclusions about the impact of spatial training on reading; however, the associations identified makes it an important consideration in evaluations of spatial interventions.

### *Reading Difficulties and Spatial Abilities*

Dyslexia is a specific learning difficulty which is “characterised by persistent difficulties in learning how to read accurately, fluently, and in reading comprehension” (Giovagnoli et al., 2016, p. 1). The field of dyslexia is one which is highly contested (Kirby, 2020). I am limited by space to preclude a full treatment of all the complexities of the definitions of dyslexia. Nonetheless there are some relevant research studies which are related to reading difficulties and spatial abilities.

Educational psychology research has typically focussed heavily on deficit when exploring the area of reading problems, and specific learning difficulties (SpLD) in literacy (e.g., Dyslexia), rather than focussing on strengths (Burgoyne, 2010).

There has been a growing view amongst some researchers and educators, that those who have a SpLD in literacy may also have compensatory aptitudes in relation to their spatial abilities (von Karolyi et al., 2003). Neurological evidence may provide some support for this compensatory hypothesis, with some neuroscience researchers suggesting that the 'Dyslexic' brain may process visual-spatial information in an atypical way (Riccio & Hynd, 1996). Brains of those with diagnoses of Dyslexia show different activations in brains, compared to what would be expected, during both language and non-language-based tasks (Helenius et al., 1999; Shaywitz, 1999). Nonetheless, different studies have provided conflicting evidence about whether SpLD in literacy are associated with spatial abilities, with different studies reporting "superior, inferior, and average levels of visual-spatial abilities associated with Dyslexia" (von Karolyi et al., 2003, p. 427). It is important to note that there are several challenges associated with research studies investigating both Dyslexia and visual-spatial abilities, which may partly account for the lack of consensus in the research. Firstly, there is little consistency in the definition of, and diagnostic criteria for, Dyslexia. Similarly, a range of different measures can be used (many of which are outlined earlier in this literature review) to assess spatial abilities (von Karolyi et al., 2003). For instance, a 3-D mental rotation task may have been used in one study (measuring mental rotations abilities), whereas in another a visual perception task may have been administrated (measuring spatial visualisation). The combination of these two inconsistences between different research studies makes comparing multiple research studies challenging. Nonetheless, some (Burgoyne, 2010; von Karolyi et al., 2003) have found some encouraging evidence in support of the hypothesis, which I will now outline.

Von Karolyi et al. (2003) compared two groups of middle and high school students in the USA. The two selection criteria of the two groups were one with a diagnosis of Dyslexia, and a control group of students with no prior diagnosis of any learning difficulties. Each group were administered measures for global processing of visual-spatial information. They found that the students with a diagnosis of Dyslexia were able to complete certain spatially based tasks more rapidly, but with no less accuracy, than students without a diagnosis. In contrast, Winner et al. (2001) similarly tested the hypothesis that Dyslexia is associated with superior visual-spatial abilities. They found that individuals with dyslexia failed to show any superiority in visual-spatial tasks compared to control groups. Furthermore, they found that indivduals with Dyslexia demonstrated some deficits regarding spatial-visual tasks. Winner et al. (2001) argued that the reason for this effect may have been due to the sample. The sample was undergraduate students, and they argued that this may have resulted in those with more severe dyslexia not being part of the sample (as they may not have pursued admission into the University). Burgoyne (2010) investigated the hypothesis that those with specific learning difficulties in reading may have linked superior visual-spatial abilities. They conducted a longitudinal study across a ten-year period with five children with identified reading difficulties, and their mothers. Burgoyne (2010) found that the participants were able to overcome their reading difficulties through interventions, alongside encouragemet outside of school for their spatial abilities. All the participants had followed careers which used spatial abilities (e.g. STEM career). Nonetheless, they did find “the link between spatial ability and reading problems was less secure” (p. 3). The main conclusions drawn from this research was that a strengths based approach to learning is important for those with specific learning difficulties.

Whilst there is disagreement within the research literature regarding the link between spatial abilities and reading difficulties, the presence of evidence linking the two provides an interesting area for research. A gap in the research however, is the impact of spatial abilities training upon those with reading difficulties. There are two interesting research questions which emerge from the literature. First, would those with reading difficulties be more responsive to spatial ability training, due to underlying aptitudes in spatial ability? Second, due to underlying aptitudes in spatial tasks in those with reading difficulties, would those with reading difficulties have a greater increase in their positive perception of their academic abilities, due to the recognition of a previously unknown skills?

### *The Flexibility of Spatial Abilities*

It has been seen that there is a relationship between spatial abilities and future performance in other cognitive abilities, and a long-term impact on predicting STEM careers (Kell et al., 2013; Nath & Szücs, 2014). Studies that aim to improve outcomes in these domains by enhancing spatial skills therefore have important societal value. However, the success of such interventions rely on the assumptions that spatial skills are suitably malleable or flexible, and that training aimed at addressing them is feasible and within the financial and time limitations of a research project. There is some disagreement over these assumptions. Sorby (1999) claimed that children receiving one term of an additional spatial training intervention led to an improvement in spatial skills, and those gains exceeded one standard deviation on a cognitive assessment task. On the other hand, some researchers such as Sims and Mayer (2002) claimed that spatial training had small or non-significant effects, and did not transfer to other, non-trained tasks. Sims and Mayer (2002) is an older study, and their findings are counterbalanced by more recent meta-analyses, such as Uttal, Meadow et al. (2013). Uttal, Meadow et al. (2013) conducted a literature review into the malleability of spatial thinking in response to training or intervention. They found an overall medium effect size due of spatial training of .47 (*Hedges g*) relative to controls who received no training, on subsequent performance on spatial tasks. Therefore, they concluded that spatial skills were malleable. Furthermore, they found that three different training methods, namely, playing video games, practicing spatial tests, or specific spatial course training, improved spatial skills. In addition, although there was variability in the training effects, there was not an overall difference between the different training categories (video games vs. spatial tasks vs. spatial course training). From their data they concluded that a variety of spatially focussed training methods can be used to markedly improve spatial skills. In addition to establishing the malleability of spatial skills, Uttal, Meadow et al. (2013) investigated the durability of the changes observed in spatial skills over time and concluded that improvements acquired following training were maintained after multiple months. Some longitudinal studies on the impact of spatial training programmes also found training effects persisted over time, after a four month follow-up period (Feng et al., 2007). In summary, there is good recent evidence that spatial skills are not only malleable, but that well-designed, intensive training can have long-lasting, durable benefits.

Yang et al. (2020) conducted a similar meta-analysis investigating the impact of spatial skills training programmes, but this time in children aged 0-8 years of age. In line with Uttal, Meadow et al. (2013), Yang et al. (2020) found that diverse training strategies (including hands-on exploration, visual prompts, and gestural spatial training) can significantly promote children's spatial skills. Crucially, Yang et al.'s (2020) meta-analysis reported a greater overall effect size ($g$=.96) than Uttal, Meadow et al. (2013) (*g*=.47). As mentioned, Yang et al.'s (2020) participants were children age 0-8 years of age, whereas Uttal, Meadow et al. (2013) had no selection criteria based on age. Taken together, this provides tentative support for the argument that spatial skills are more flexible in younger age groups than older age groups. That notwithstanding, further research is still needed to explore this, as both the Yang et al. (2020) and Uttal, Meadow et al. (2013) meta-analyses only included published papers, and there may be a publication bias (Thornton and Lee, 2000). Likewise, Uttal, Meadow et al. (2013), split studies into three age brackets in their meta-analysis, under 13 years of age, 13-18 years of age, and over 18 years of age. They found no difference in the malleability of spatial skills between these age categories. Although there is no clear evidence supporting greater effectiveness in early intervention programmes for younger children, the body of evidence supports the feasibility and potential value in further exploring intervention effects with 8–10-year-olds.

Research therefore has demonstrated that a range of spatial ability training programmes have been effective in improving spatial skills in children and young people. This indicates that there is value in developing a spatial abilities intervention compatible with the UK curriculum. An important focus of study would be the impact of such a programme on other cognitive abilities, as well as consideration of the mechanisms that support such learning, e.g., self-concept. One of the findings from both Uttal, Meadow et al. (2013) and Yang et al. (2020) was that gender was found to moderate training effects. Therefore, it is also important to consider some of the individual differences in spatial ability performance.

### ***Individual Differences within Spatial Abilities***

Whilst research has demonstrated the effectiveness of spatial ability training programmes, their effectiveness is not consistent across different groups, and there can be an influence on their effectiveness based on individual differences. For instance, both gender and level of anxiety related to maths tasks can influence upon training programme effectiveness. I will now evaluate these effects.

**Gender.** Gender differences have been reported in spatial thinking. For instance, males generally score higher on spatial ability tasks (Maeda & Yoon, 2013). Some successful and effective intervention programmes have demonatrated increased performance gaps in favour of males (Reilly & Neumann, 2013), particularly regarding mental rotation tasks (Voyer et al., 1995). However, other studies have shown similar rates of performance in males and females following intervention programmes (Terlecki et al., 2007). Moe (2009) found that females benefit more from spatial training if they are supported by encouraging feedback. Therefore, there is evidence that gender differences are not only present in spatial thinking abilities, but at times in responses to intervention. Gender effects have also been shown with regard to maths and spatial anxiety. Girls rate higher in maths and spatial anxiety than boys (Lauer et al., 2018). However, girls have reported greater test anxiety (Devine et al., 2012) and general anxiety than boys (Hill et al., 2016), so the effect may not be domain specific.

**Spatial & Maths Anxiety*.*** The consideration of affective factors which may impact upon performance in spatial tasks is important to take into account, for instance, anxiety. Maths anxiety is a broad term used to describe negative emotions about maths (Ashcraft & Moore, 2009). Maths anxiety is strongly negatively associated with maths achievement (Betz, 1978), an effect which is independent of intelligence (Hembree, 1990). Furthermore, maths anxiety is positively correlated with other types of anxiety, such as general anxiety and test anxiety (Ashcraft, 2002). There is evidence of a negative correlation between maths anxiety and spatial abilities (Maloney et al., 2011). However, the relationship and interaction between spatial abilities and maths anxiety is complex and under-researched. Likhanov et al. (2017) share the view that this interaction is complicated, a conclusion based on their research into the relationship between maths anxiety and spatial ability. They found that neither the main effects of gender and maths anxiety, nor the interaction between them, were a significant predictor of spatial ability performance. Likewise, students with high maths anxiety scores report a worse sense of direction, more spatial anxiety, more general anxiety, and perform more poorly on behavioural tests of small- and large-scale spatial skills (Ferguson et al., 2015). The relationship between these constructs is an area of research that would benefit from further investigation.

### ***Spatial Skills: A Summary***

Spatial skills can be seen to be a critical skill for everyday tasks, including learning, training, and working (David, 2012). There are several different definitions and conceptualisations used in the literature to define this aspect of cognitive functioning and its different components (e.g., Uttal, Meadow et al., 2013; Newcombe & Shipley, 2015; Linn & Petersen, 1985; Lowrie et al., 2017). These categorisations overlap and map on to one another. Spatial abilities have been shown to be linked to other areas of learning, including maths (Lowrie et al., 2017) and reading (Giovagnoli et al., 2016). There are individual differences in spatial skills, with factors such as gender (Maeda & Yoon, 2013) and maths anxiety (Maloney et al., 2011) being associated with variations in spatial abilities. However, meta-analyses of research into the flexibility of spatial skills have shown that structured training programmes can improve spatial abilities across different age groups (Uttal, Meadow et al., 2013; Yang et al., 2020). Taken together, these studies provide justification for extending the research into spatial abilities, which have been shown to be flexible and amenable to intervention, with the potential for learning to generalise to other cognitive domains. However, there is limited research that has investigated the way in which spatial abilities programmes impact upon other cognitive domains. Therefore, a primary aim of this research is to investigate the influence of a spatial abilities training programme on spatial and other cognitive skills, as well as considering the role of self-concept (Marsh & Martin, 2011) in any change.

## Self-Concept

### *The Importance of Self-Concept*

Self-concept is considered a crucial factor which is associated with people's behaviours and emotional outcomes, including, academic achievement, happiness, suicide, anxiety and so on (Branden, 1994). Ahmed and Bruinsma (2006) consider self-concept to be a theory of self-evaluation, and that it is made up of a "network of ideas about the self and that self-consistency (being consistent with oneself) and self-enhancement (the tendency to maintain positive belief about oneself) are important features" (p. 554). The OECD (2003) remarked that self-concepts are "closely tied to students' economic success and long-term health and wellbeing" (p.9). Maximising self-concept is considered a key goal of education and is an important way to address social inequalities experienced by disadvantaged groups, for instance those of low socioeconomic status (Marsh & Craven, 2006). Self-concept is one of the oldest theories or constructs in psychology. An extensive literature review completed in 2021 revealed that most of research has been conducted by, or heavily referenced Marsh (e.g., 1984, 2007). As such, Marsh is a very influential researcher into self-concept; his theories are well accepted and oft-cited in many peer-reviewed articles, hence his work guided the approach to investigation of self-concept in the current study.

### ***The History and Definition of Self-Concept***

Before reviewing the current research in self-concept, it is important to acknowledge the theoretical bases on which definitions are posited. Self-concept as a construct is one of the oldest in psychology and has been used widely in a range of different disciplines (Marsh, 1990). It has been considered in psychology for over 100 years and James (1890) devoted a whole chapter to it in his initial textbook on psychology. Despite its age and popularity, Marsh (1990) argues that through most of the 20$^{th}$ century, self-concept studies lacked “sophistication in theory, measurement, or methodology” (p. 78). Many studies investigating self-concept read do not include definitions by researchers. This observation is echoed by Marsh (1990) who states, “Self-concept, like many other psychological constructs, suffers in the ‘everybody knows what it is’, so that researchers do not feel to provide any theoretical definition of what they are measuring” (p.79). Shavelson et al. (1976) acknowledged the lack of a clear, consistent definition of self-concept in the research literature. They broadly defined self-concept as, “…a person’s perception of himself. These perceptions are formed through his experience with his environment…and are influenced especially by environmental reinforcements and significant others” (p.441). Marsh and Martin (2011) built upon the Shavelson et al. (1976) definition and added:

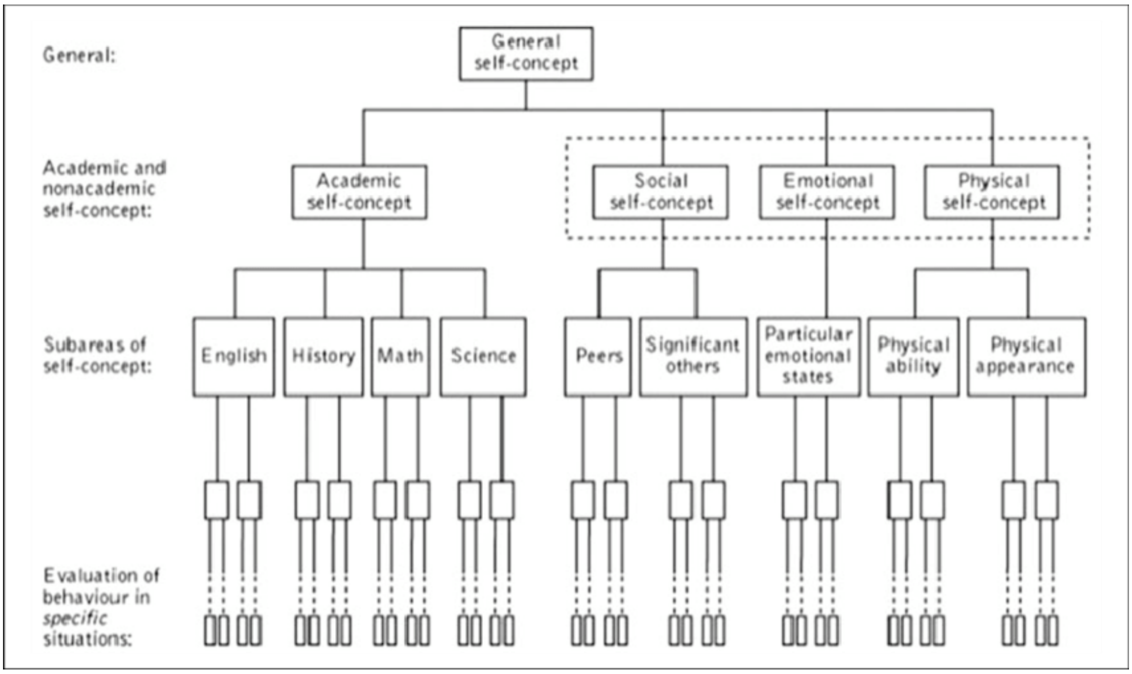
> Self-concept is multifaceted and hierarchically organised with perceptions of personal behaviour in specific situations at the base of the hierarchy, inferences about self in broader domains (e.g., social, physical, and academic) at the middle of the hierarchy, and a global self-concept (also known as self-esteem) at the apex (p.79).

Furthermore, Marsh and Martin (2011) used this definition to differentiate between self-concept and self-esteem, two constructs which are often confused in the literature. It is important to recognise that self-concept does not exist in isolation, and it is influenced by social factors and self-attributions (Shavelson et al., 1976). Although self-concept is a hypothetical construct, it can still be useful in predicting and explaining behaviour (Marsh & Martin, 2011).

As previously noted, self-concept is multifaceted and hierarchical (Marsh & Martin, 2011). Shavelson et al. (1976) divided general self-concept into two overarching constructs: academic self-concept and non-academic self-concept. Academic self-concept is organised into self-concepts in specific content areas, for instance, English and maths. Non-academic self-concept is divided into physical, emotional, and social self-concepts. Shavelson et al. (1976) divided physical self-concept into physical ability and physical appearance. Likewise, social self-concept was organised into peer relations and relations with significant others. Figure 2 visually demonstrates Shavelson et al.'s (1976) self-concept model. Crucially, Shavelson et al. (1976) highlighted the domain specificity of self-concept, whilst still acknowledging it as a holistic, general construct (Marsh & Martin, 2011).

**Figure 1**

*The Shavelson et al. (1976) model of self-concept.*




Whilst the Shavelson et al. (1976) model of self-concept was influential in the reconceptualisation of self-concept as a multidimensional, rather than a unidimensional concept, more recent research has challenged the model's validity. Marsh et al. (2012) noted that under the Shavelson et al. (1976) model, it would be assumed that English self-concept and math self-concept to be closely correlated, so that they would be linked together as part of a higher-order, academic self-concept. However, Marsh et al. (2012) found correlations between English and maths self-concept to be close to zero. In response to this, Marsh et al. (2012) argued that self-concept would be better measured at a level of consistency which is consistent with specific issues, in parallel with more general measures of self-concept (e.g., academic self-concept & non-academic self-concept). Additionally, it is important to consider the Shavelson et al. (1976) model in the context of 2022. Modern technology, the internet and social media has provided interesting questions in regard to where new, previously nonexistent sub-types of self-concept, such as e-identity and gaming self-concept sit within models of self-concept. In conclusion, The Shavelson et al. (1976) model provides a crucial basis for the conceptualisation of different sub-types of self-concept as distinct, however, conclusions based upon the idea that all sub-types can be placed within a hierarchy should be discussed and evaluated carefully.

There are wider topics, philosophies and epistemological considerations in relation to the construct of self-concept, but these go beyond the current scope of this literature review.

### *Alternative Conceptualisations of Self-Concept*

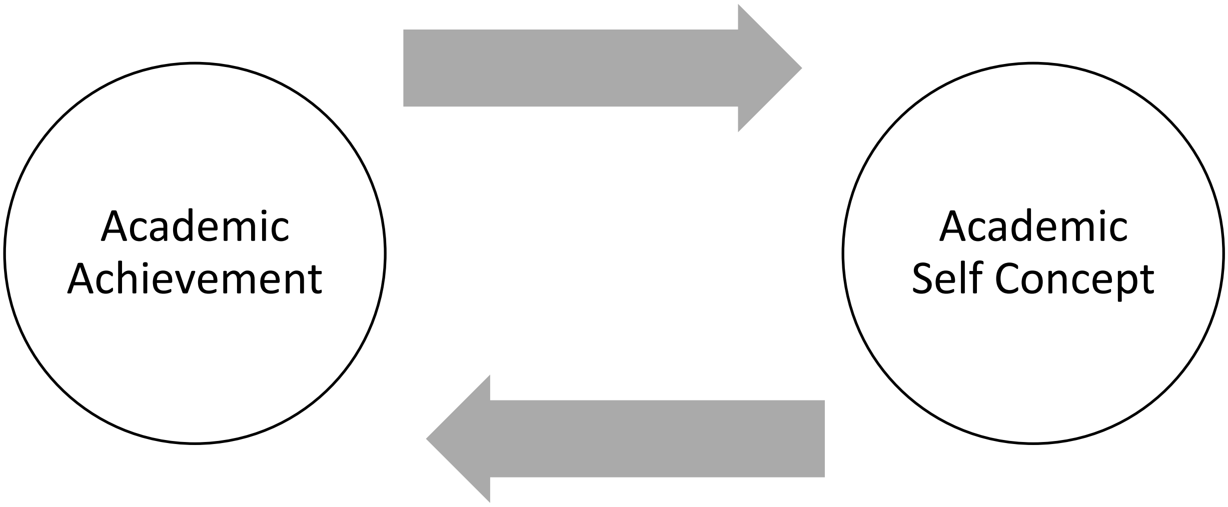
Although there are different and alternative conceptualisations of self-concept within the literature, there are clear strengths to the Marsh and Martin (2011) definition, with several research studies that back up their view (e.g., Waugh, 2001; Marsh et al. 2020). As such, the Shavelson et al. (1976) and Marsh and Martin (2011) conceptualisation will be the assumed model for the purposes of this research, and their definitions adopted.

### *Academic Self-Concept: The Reciprocal Effects Model*

A link between academic self-concept and attainment/academic performance is well established in the literature (Ghazvini, 2011; Marsh & Craven, 2006; Marsh & O'Mara, 2008). Guay et al. (2004) conducted a ten-year longitudinal study to ascertain children's self-concept, in relation to family socio-economic status, family structure (e.g., nuclear family vs. single parent family) and academic achievement in grades 3, 4 and 5 in elementary schools in Canada. They reported that academic self-concept predicted educational attainment levels ten years later, over and above prior achievement. These results were consistent across different cohorts. Furthermore, the relationship between self-concept and educational attainment remained significant, even when controlling for family socio-economic status, family structure and academic achievement. Huang (2011) conducted a meta-analysis to assess the magnitude of the longitudinal relationship between self-concept and academic achievement. They found that across 39 independent samples, the mean longitudinal correlation between prior self-concept and subsequent academic achievement ranged from $r$=.20 to $r$=.27. However, the relationship between self-concept and academic achievement was not unidirectional. They also found that across the 39 independent samples, the mean longitudinal correlation between prior academic achievement and subsequent self-concept ranged from $r$=.19 to $r$=.25. In summary, Huang's (2011) findings "demonstrated the positive effects of self-concept on academic achievement and of academic achievement on self-concept" (p. 524), in other words, a bi-directional relationship. This is further supported by Chamorro-Premuzic & Furnham (2006) who proposed that academic self-concept both facilitates and moderates the impact of attitudes on both learning and academic performance. Marsh and Martin (2011) conceptualised the relationship between self-concept and academic achievement in the Reciprocal Effects Model (REM). The REM posits that "academic self-concept and academic achievement are mutually reinforcing, each leading to gains in one another – and its extension to other achievement domains" (p. 2). There is a large body of research which supports the REM (Huang, 2011; Chamorro-Premuzic & Furnham, 2006; Marsh, 1990; Marsh, 2007; Marsh, 2011; Marsh et al., 1999; Marsh & Craven, 2006). Figure 1 provides a visual representation of the reciprocal effects model of self-concept.

**Figure 2**

*Visual Representation of the Reciprocal Effects Model of Self Concept (Marsh and Martin, 2011)*

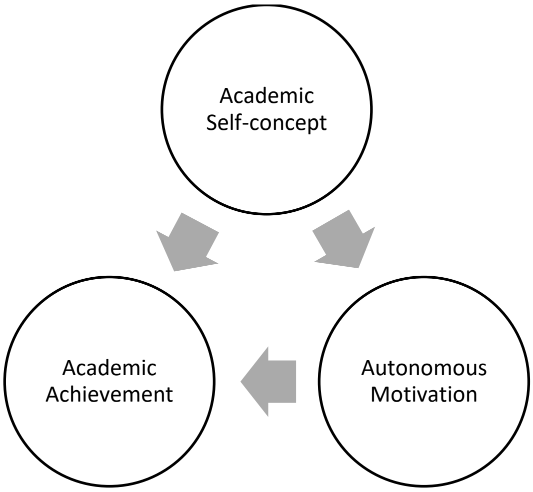



It is noteworthy that whilst the REM implies that academic attainment and academic achievement are mutually reinforcing, the focus of this conceptualisation is framed positively. Although improvements in either factor could result in a positive cycle of improvement, it should also be noted that mutually reinforcing factors may result in a negative cycle. If an individual is consistently struggling to achieve academically, this is likely to impact negatively on their academic self-concept (as per the REM model). As such, this may lead to a negatively reinforcing cycle. It is important to note that there are factors that can impact upon an individual’s ability to achieve academically, for instance if they have a specific learning difficulty.

The REM theory of self-concept is not without its critics. Baumeister et al. (2005) challenged the importance of positive self-concept, and positive self-belief more generally. Focussing solely on self-esteem as an element of self-concept, Baumeister et al. (2005) conducted a literature review of studies linking self-esteem with academic achievement. They reported that efforts to increase people's self-esteem have little importance in improving academic achievement or preventing undesirable behaviours. In a challenge to Baumeister et al.'s (2005) claims, Marsh and Craven (2006) contended that by only including studies investigating self-esteem, that they took an overly narrow, unidimensional perspective. Furthermore, Baumeister only considered studies that had been conducted prior to 1990 and did not use more up-to-date statistical methodology and conceptual developments in self-concept theory (Marsh & Martin, 2011). Crucially, in support of Marsh and Craven's (2006) position, a meta-analysis conducted by Valentine and DuBois (2005) found that academic self-belief had a stronger impact upon subsequent school attainment than that of more global-self beliefs, such as self-esteem. Similarly, Ahmed and Bruinsma (2006) argued that other research which reported significant relationships between self-concept and academic attainment (e.g., Byrne, 1996; Cokley, 2003; Cokley, et al., 2001; Marsh 1990), and that the reciprocal effects model failed to consider an important aspect related to academic achievement - autonomous motivation. In support of this hypothesis, they noted that self-determination theory suggests that self-competence (a closely related term to self-concept) can be important antecedent of autonomous motivation (Deci & Ryan, 1995). In order to consider autonomous motivation as an influencing factor with relation to academic self-concept and academic achievement, Ahmed and Bruinsma (2006) developed an alternative, integrated motivational model of academic achievement (See Figure 2), in contrast to the REM. This model conceptualises academic self-concept as an overarching factor, at the apex, which influences both academic achievement and autonomous motivation. Additionally, however, autonomous motivation also influences academic achievement.

**Figure 3**

*An Integrated Motivational Model of Academic Performance*




*Note: Adapted from Ahmed and Bruinsma (2006).*

Ahmed and Bruinsma (2006) explored the relationships between these factors in order to test their hypothesis, and found that their data fit the model, with all proposed path coefficients achieving adequate statistical significance.

Whilst autonomous motivation may have a role in in influencing both academic self-concept and academic achievement, I would argue that the REM model proposed by Marsh and Martin (2011) can still take autonomous motivation into account. First, whilst academic self-concept may have a role in influencing autonomous motivation, it is not the only factor that does so. Other factors which have been suggested to influence autonomous motivation are basic psychological need satisfaction, learning engagement, and life satisfaction (Guo, 2018). Any model which conceptualises the relationships between psychological factors such as academic self-concept and academic achievement, could theoretically include other psychological factors, in an increasingly complex interrelated web. Therefore, I would argue that the REM model of self-concept proposed by Marsh and Martin (2011) intentionally simplifies the relationship between the two psychological factors, without theoretically discounting other influencing factors. The Ahmed and Bruinsma (2006) model, rather than contrasting with the REM, is in fact complementary to it. Therefore, for the purposes of this literature review and research project, the REM will remain the main model used to conceptualise the relationship between academic self-concept and academic achievement. Nonetheless, in line with Ahmed and Bruinsma's (2006) conceptualisation, other influencing factors including autonomous motivation, basic psychological needs satisfaction, learning engagement and life satisfaction will be considered, due to their potential roles in influencing academic self-concept.

In summary, Marsh's (2011) position is that to observe the effects of self-concept on subsequent academic performance (and vice versa), there is a need for strong domain specific self-concept. On balance, the hypothesis that academic self-concept can be integrated "into a single theoretical framework based on a multidimensional perspective of self-concept and supporting the REM" (Marsh & Martin, 2011, p. 19) is a reasonable position. Therefore, there is a clear justification for exploring the relationship between a domain specific self-concept (spatial self-concept) and associated academic achievement (spatial ability) in the research aims of this study.

### *Cultural Differences in Self-Concept*

Most theories of motivation and cognition are considered to be universally applicable. However, some researchers have begun to challenge this position, instead noting that the relationship between self and culture has important psychological consequences that should be taken into account. Human behaviour, culture and self-definition are “inextricably interwoven” (Ahmed and Bruinsma, 2006, p. 558). Hofstede (2011) posited a model of six dimensions of national cultures: Power Distance, Masculinity/Femininity, Long/Short Term Orientation, Uncertainty Avoidance, Indulgence/Restraint and Individualism/Collectivism. Individualism vs. Collectivism is related to the “integration of individuals into primary groups” (p. 8). Hofstede (2011) summarised that in individualistic societies “we find cultures in which the ties between individuals are loose: everyone is expected to look after him/herself and his/her immediate family” (p. 11), whereas in collectivist cultures “people from birth onwards are integrated into strong, cohesive in-groups, often extended families (with uncles, aunts and grandparents) that continue protecting them in exchange for unquestioning loyalty, and oppose other in-groups” (p. 11). Different cultures vary in their position on the continuum of individualism to collectivism, with Asian cultures often taking a more collectivist approach, whilst European and North American cultures are positioned closer to an individualist approach. It is important to note that collectivism vs. individualism refers to the pattern set by a culture or society, rather than the position or values of an individual. An individual in a society or culture that is considered individualistic may hold independent values that relate closer to a collectivist attitude, and vice vera. Hofstede et al. (2010) developed an Individualism Index and evaluated 76 countries. They found that more developed and Western countries tended to be more individualistic, whereas less developed, and Eastern countries tended to be more collectivist.

Markus and Kitayama (1990) argued that the notions of individualism and collectivism have a profound and important influence on the nature of individual experience, including factors related to cognition, emotion, motivation, and the sense of self. They theorised that more individualistic societies are more likely to adopt independent views of self (e.g., self-concept) whereas collectivist societies are more likely to adopt interdependent views of self. In other words, individualistic societies have a stronger notion that there is an “inherent separateness of distinct persons” (p. 226), and that the inner attributes (e.g., self-concepts) of individuals within these societies are significant in regulating behaviour (e.g., a perception of oneself as a strong mathematician, influences attitudes and approaches to learning in maths lessons). Collectivist societies, on the other hand, are more likely to identify the “fundamental connectedness of human beings to one another” (p.227), and as such the self is most meaningful when it is considered within the context of social relationships with others (Markus and Kitayama, 1990). Crucially, Heine et al.(1999) argued that whilst self-concept is a central concept in individualistic societies and cultures, it is less important in collectivist cultures. This notion can be demonstrated by research that suggests that those from Asian cultures are more likely to look for, and be motivated to decrease inconsistencies between their perceived performance and the performance of the rest of a class, rather than those from Western cultures who are more likely to use affirmation to improve performance when their values with regard to self-concept are under risk (Heine, 2003).

The acknowledgement of cultural differences in the evaluation of self-concept has important implications for the generalisability of research investigating self-concept across cultures, and the models developed to conceptualise them. All of the models which relate to self-concept evaluated in this literature review (e.g., Marsh &

Martin, 2011; Shavelson et al., 1976) have been conceptualised and researched in Western cultures. Thus, they are more likely to take an individualistic conceptualisation of self (e.g.  “The inherent separateness of distinct persons”, Markus & Kitayama, p. 226). I would argue that within collectivist cultures, academic self-concept may be less influential on subsequent academic achievement, as it is conceptualised within the REM (Marsh and Martin, 2011). Instead, when considering collectivist cultures, a more interdependent model which takes into account the impact of social influences may be more important. The current research was undertaken within the United Kingdom, which is considered to be a more individualistic society (Hofstede, 2011). Therefore, the models evaluated within this literature view have applicability to such a population. However, consideration will need to be given to the generalisability of findings related to self-concept, when taking more collective, societies and cultures into account.

***Measuring Self-Concept***

Several instruments have been developed to measure self-concept. Most of the research investigating change in self-concept make use of self-report (Gore & Cross, 2011). Self-report measures come in one of two forms: either reactive or spontaneous (Brinthaupt & Erwin, 1992). Reactive self-report requires participants to locate themselves within one or more dimensions which have been established by the researchers (Gore & Cross, 2011). These usually take the form of quantitative data collection with questionnaires. Some examples of such self-concept measures include the Self-Description Questionnaire (Marsh, 1992), the Pier-Harris Self-Concept Scale 2 (Piers et al., 2002) and the Self-Perception Profile for Children (Harter, 1982). Spontaneous self-report measures involve participants answering open-ended questions on their views about themselves (gathering qualitative data).

These methods assess a more generalised view of self-concept, but responses are likely to be influenced by situational effects (Gore & Cross, 2011). Generally, reactive self-report measures are more commonly used as they make analysis easier (Gore & Cross, 2011) , whereas spontaneous self-report measures tend to have higher construct validity (Brinthaupt & Erwin, 1992). Whilst spontaneous self-report measures are preferable (Gore & Cross, 2011), there is justification for the research aim to develop a reactive self-concept measure for spatial abilities. Although there are limitations, these are counter-balanced by the strong evidence for good construct validity and internal reliability in some of the reactive self-report measures such as the Self-Description Questionnaire (Marsh, 1992).

The Self-Description Questionnaire (SDQ-I) (Marsh, 1990) is based on the previously mentioned Shavelson et al. (1976) hierarchical and multidimensional model of self-concept (Morin et al., 2015). This hierarchical structure is reinforced in the SDQ-I from the inclusion of scales which assess hierarchically superior constructs, namely global self-esteem, and general academic self-concept (Marsh, 1987). Marsh (1990) developed three different self-concept scales (SDQ-I, SDQ-II and SDQ-III). The SDQ-I is the instrument used to measure self-concept in children under the age of 12 years. It was developed to measure self-concept in three academic domains (Reading, Maths and General-School) and four non-academic domains (Physical Ability, Physical Appearance, Peer Relations and Parent Relations) (Marsh, 1990). The SDQ-I is considered by Byrne (1996) to be the most psychometrically validated self-concept measure for 8–12-year-olds. Marsh (1990) reviewed the internal consistency of each of the measures and the correlations between them. Internal consistency reliability estimates for each of the individual self-concept and total scores were good ($.80 \geq \alpha \geq .94$). Furthermore, the correlation coefficients between each of the individual self-concept scales were relatively low (*r*=.17). This provides strong justification not only for the reliability of the SDQ-I as a scale, but also provides evidence for Shavelson et al.'s (1976) multi-dimenstional conceptualisation of self-concept. If self-concept was a unidimensional construct, you would expect a strong correlation between all of the domains, as they would all influence each other.

A similar measure of self-concept is the Self-Perception Profile for Children (SPPC, Harter, 1982). In contrast to the SDQ-I, the SPPC focuses purely on self-esteem rather than wider self-concept. The SPPC measures five specific domains of self-esteem: scholastic competence, social acceptance, physical appearance, and behavioural conduct (Guerin & Tatlow-Golden, 2019). Muris et al. (2003) reviewed the SPPC's reliability and validity. They found that the reliability of the scale was satisfactory, with good internal consistency and test-retest reliability. Furthermore, they claimed that the scale correlated in a theoretically meaningful way with child, teacher and parent reports of both personality and psychopathology. Overall, they concluded that the SPPC was also a psychometrically validated measure for assessing children's self-esteem.

The Piers-Harris 2 Children's Self-Concept Scale (PH2, Piers et al., 2002) is a similar self-esteem scale which has been frequently cited in use with children (Butler & Gasson, 2005). The original PH scale is much older than the SDQ-I and SPPC, and was unidimensional (Piers & Harris, 1964). However, the updated version (PH2) identifies six specific domains of self-esteem: happiness and satisfaction, freedom from anxiety, physical appearance and attributes, popularity, behaviour, and intellectual and school status. Flahive et al. (2011) explored the psychometric reliability and validity in a multimedia version of the PH2 in a sample of 248

Taiwanese children. They concluded that a newly developed multimedia version of the PH2 had acceptable psychometric qualities, with strong internal consistency, convergence, and criterion validity. The children in the Flahive et al. (2011) study also rated their experience of using an online version of the questionnaire to be preferable, over the traditional pen and paper format. Whilst there are several different questionnaire methods which seek to measure self-concept, well cited instruments such as the SDQ-I, the SPPC and the PH2 are not without their critics.

Guerin and Tatlow-Golden (2019) examined the SDQ-I, SPPC and PH2 using a demographically representative cohort of children in Dublin (*N*=651). They then compared findings in the light of salient self-concept factors identified by the participants in a linked follow-up mixed methods study. They found that the SPPC and SDQ-I were “considerably more psychometrically valid than PH2” (p. 1526). Along with Marsh and Holmes (1990), Guerin and Tatlow-Golden (2019) concluded that the PH2 may be an unsatisfactory measure for assessing self-esteem in children. They noted “The PH2 factor analysis failed to replicate any factor from the original scale, the factors extracted lacked conceptual clarity, and a large negative item factor was extracted, suggesting that it is less suitable for younger children.” (p.1526). On the other hand, Guerin and Tatlow-Golden (2019) identified that much stronger factor patterns aligned between the SDQ-I and SPPC, and they concluded that this indicated that there may be some psychometrically distinct aspects of children’s self-concept. The dimensions which they found to be valid dimensions of self-concept were sports ability, school, ability, maths enjoyment and ability, reading enjoyment and ability, peer popularity, behaviour, and parent relationships. In a challenge to Marsh and Martin (2011), they argued that it was not possible to distinguish statistically between global (i.e., self-esteem) and appearance self-concept. Guerin and Tatlow-Golden (2019) argued that their results suggest that appearance self-concept is too closely correlated to global self-concept to consider the two constructs to be distinct from one another. In summary, Guerin and Tatlow-Golden (2019) challenged some of the findings of Marsh (1990; 1992) and Marsh and Martin (2011), particularly with regard to how effective the SDQ-I is at measuring global self-concept. However, they still found strong evidence that aspects of academic self-concept, such as maths enjoyment and ability, may be distinct domains. One of the aims of this research study is to develop a spatial self-concept measure, and Guerin and Tatlow-Golden (2019) provides tentative support that a novel academic self-concept scale regarding spatial ability may provide a useful measure of a distinct conceptual domain, separate from global self-esteem.

***Maths Self-Concept***

The evidence of a bidirectional link between academic self-concept and subsequent academic achievement (Marsh & Martin, 2011) has been discussed. It has been shown that improvements in academic self-concept are associated with improvements in academic achievement (Timmerman et al., 2017). A similar relationship is demonstrated in maths self-concept and maths attainment. More specifically, several different studies have noted a correlation between maths self-concept and maths attainment (Luo et al., 2014; McWilliams et al., 2013; Parker et al., 2013). McWilliams et al. (2013) found that maths self-concept correlates more strongly to maths attainment than it does to academic self-concept. Likewise, Swann et al. (2007) argued that domain-specific self-concept should be used to predict domain-specific achievement. In relation to spatial skills, this would provide support for a hypothesis that there should be a correlation between spatial self-concept and spatial ability.

## Spatial Abilities and Self-Concept in Professional Practice

In this thesis, I will examine the effectiveness of a novel spatial skills intervention programme on improving spatial skills and maths attainment. Spatial skills are important to a variety of everyday tasks (David, 2012). Good spatial abilities have been linked to high performance and attainment in several subject including maths, English and science (Uttal, Miller et al., 2013). Assessment of individual children is a major focus of professional activity for educational psychologists (EPs) (Freeman & Miller, 2001). Different forms of assessment are available to EPs; for instance, dynamic assessment and standardised assessment are used to test hypotheses (Groth-Marnat, 2009) and plan interventions based on interpretation of the information gathered (Hussain & Woods, 2019). These assessments often involve spatially-based tasks. Two widely used standardised assessments in EP practice are the Weschler Intelligence Scale for Children, Fifth Edition (WISC-V) (Weschler, 2014) and the British Ability Scales, Third Edition (BAS-3) (Elliot & Smith, 2011). Both have subtests which produce an overall score for spatial abilities, or a spatial 'cluster'. Likewise, dynamic assessment tools such as the Spatial Relations subtest, the Mental Rotation subtest, the Visual Figure Ground test, and the Dynamic Embedded Figures Test can be used to assess spatial ability in children (Tzuriel & Egozi, 2007). Despite the availability of these tools to assess spatial ability, there is a surprising lack of research exploring the practical implications of the findings for professional EPs. A literature search in the professional practice journal for EPs in the UK, 'Educational Psychology in Practice' in March 2022, found only two publications which directly investigated spatial abilities. Neither piece of research was conducted in the United Kingdom. Thus, the importance of spatial abilities to school attainment (Uttal, Miller et al., 2013) coupled with the good selection of assessment instruments available to EPs, highlight the relevance and importance of enhancing professional knowledge, understanding and practice in this area.

## An Integration of Spatial Skills Attainment and Spatial Self-Concept

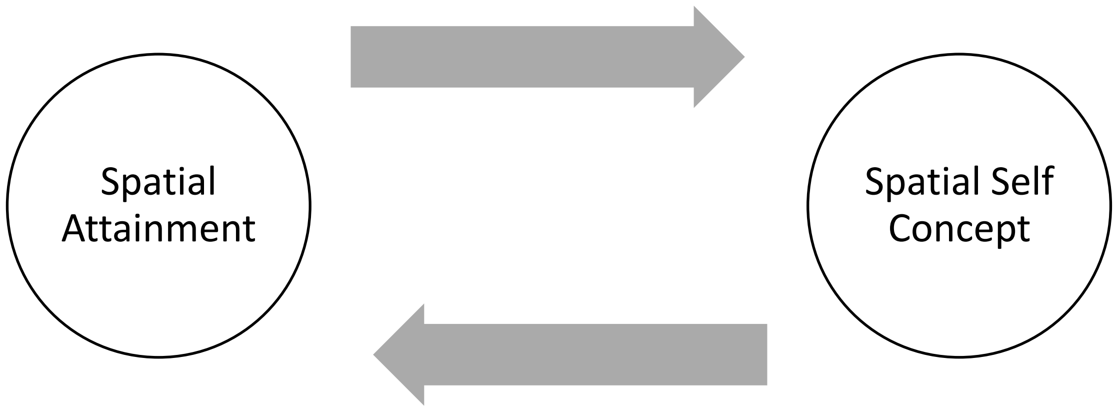
Throughout this literature review, two key points have been argued. Firstly, that spatial skills, whilst linked to other cognitive abilities, represent a distinct set of competencies. Secondly, that “self-concept is multifaceted and hierarchically organised with perceptions of personal behaviour in specific situations” (Marsh & Martin, 2011, p. 79). Taken together, this suggests that there may be a domain-specific self-concept regarding spatial skills, or spatial self-concept. An extensive literature search conducted by these authors revealed no study that has investigated or assessed spatial self-concept. This demonstrates a gap in the research into both spatial skills and spatial self-concept. There is no published instrument to measure spatial self-concept. Once a spatial self-concept instrument has been developed, the question of how spatial self-concept can be influenced through intervention can be investigated. Spatial skills are known to be malleable and respond well to structured, intensive intervention (Uttal, Meadow et al., 2013). Other domain specific academic achievements are associated with increases in corresponding academic self-concept (Marsh & Martin, 2010), for instance in maths (McWilliams et al., 2013), so the questions arises as to whether this is the case for spatial self-concept and achievement. This research question is the focus of the second phase of this study.

### *The Reciprocal Effects Model*

The link between academic self-concept and attainment/academic performance is well established in the literature (Ghazvini, 2011; Marsh & Craven, 2006; Marsh & O’Mara, 2008). If spatial self-concept can be established as domain-specific notion, then a bi-directional cyclical relationship would be expected between spatial skills and spatial self-concept, as it is within other achievement domains, such as maths (Jameson & Fusco, 2014) and reading (Higgins et al., 2015). The Reciprocal Effects Model of Spatial Self Concept therefore proposed. This is visually represented in Figure 4.

**Figure 4**

*Visual Representation of the Reciprocal Effects Model of Spatial Self Concept (REMSASC)*




This model proposes that development in spatial abilities will be associated with improved spatial self-concept. The reciprocal and bi-directional nature of the relationship suggests that the two aspects develop in tandem via mutually reinforcing mechanisms. This relationship supports a hypothesis that improvements in spatial abilities can be achieved through a spatial training intervention programme and that this will lead to an increase in spatial self-concept.

***Interventions to Increase Self-Concept***

Whilst there has yet to be research investigating the impact of a spatial ability training programme upon spatial self-concept, there has been some research that has investigated this relationship with regard to reading self-concept. Higgins et al. (2015) researched the role of the "Literacy Lift-Off" reading intervention on levels of reading self-concept. "Literacy Lift-Off" is derived from the established Reading Recovery programme, an approach that is supported by empirical evidence as an effective early literacy intervention (Briggs & Young, 2003; Quay et al., 2001; Schmitt & Gregory, 2005; Schwartz, 2005). Higgins et al. (2015) used a quasi-experimental design to investigate the impact of "Literacy Lift-Off", delivered on a whole class basis. They reported that this intervention was associated with statistically significant improvements in reading attainment and reading self-concept beliefs, concluding that a specific, manualised approach can be effective in improving both literacy skills and reading-self-concept. The findings of this research provide support for the hypothesis that a spatial skills training programme can have an impact not only on spatial and maths attainment, but also potentially upon related self-concept beliefs, such as maths and spatial self-concept. Similarly, Higgins et al.'s (2015) research demonstrated that a programme delivered to a whole class can have an impact on attainment and self-concept.

**Synthesis of Research Aims**

The research and guidance found in the literature which I have outlined informed the research design of this project. In order to study spatial self-concept as a novel construct, a new measure must be developed. Research and theory published by Shavelson et al. (1976) and Marsh (2011) provide an interesting basis for determining where spatial self-concept would be conceptialised within already their established models of self-concept (e.g. hierarchal model and REM). This would be achieved through studying the relationships between spatial self-concept and other subtypes of self-concept. Equally, whilst research has demonstrated the value of spatial ability training upon spatial attainment, no research to this point has studied the impact of such training upon self-concept. This research will investigate this original area. Finally, a link between specific learning difficulties in reading and spatial abilities has been suggested (von Karolyi et al, 2003). Therefore, investigating the impact of spatial ability training on those with reading difficulties, compared to other is an interesting area of research. As such the following research aims has been developed:

1) To develop a brief measure of spatial ability self-concept with good criterion validity and internal reliability for year 4/5 pupils (aged 9 to 10-years-old) in mainstream primary schools.
2) To explore the relationships between spatial self-concept and other selected academic self-concept measures (reading, maths & general academic ability) in year 4/5 pupils (aged 9 to 10-years-old) in mainstream primary schools in the UK.
3) To investigate whether a 10-session programme, delivered once a week, focussing on spatial skill development leads to improvements in spatial ability, maths attainment, spatial self-concept.
4) To investigate the relationship between self-concept and spatially-based maths attainment.
5) To investigate whether a 10-session programme, delivered once a week, focussing on spatial skill development leads to improvements in spatial ability, maths attainment or spatial self-concept, in those with reading difficulties, compared to others.

# Chapter 2

## Method

### Introduction and Research Questions

I will now outline the structure which this methods section will follow. Firstly, I will set out the research questions and associated hypotheses, as have been generated from the research aims set out in Chapter 1. Next, I will outline my epistemological positioning, which informed the overall research design used for this project. Then the research procedures and data analysis methods used will be outlined, followed by a discussion of ethical considerations.

These aims outlined in Chapter 1 are linked to the following research questions (RQs) and associated hypotheses:

#### ***Phase 1***

*RQ1:* Does the novel self-concept measure show satisfactory reliability and validity, in relation to internal consistency, test-retest reliability and criterion validity?

*Hypothesis 1:* The spatial self-concept scale will show good internal reliability and test-retest reliability.

*RQ2:* What is the nature of the relationships between spatial self-concept and other aspects of academic self-concept, specifically maths self-concept and reading self-concept?

*Hypothesis 2a:* Spatial self-concept will be correlated positively with maths self-concept.

*Hypothesis 2b:* Spatial self-concept will be correlated positively with reading self-concept.

*Hypothesis 2c:* Maths self-concept and reading self-concept will not be correlated with one another.

*Hypothesis 2d:* Spatial self-concept will be more strongly positively correlated with maths self-concept than reading self-concept. This is due to reported correlations between spatial skills and other cognitive abilities, such as maths and reading.

***Phase 2***

*RQ3:* How effective is the novel spatial skills intervention programme at improving spatial skill maths attainment and spatial self-concept, compared to a control group?

*Hypothesis 3a:* Short weekly interventions focussing on spatial skills will lead to improvements in spatial ability performance, maths attainment, maths self-concept.

*Hypothesis 3b:* Short weekly interventions focussing on spatial skills will lead to improvements in spatial self-concept.

*RQ4:* Is there a significant relationship between student spatial and maths self-concept, and performance on the spatial maths attainment measure?

*Hypothesis 4a:* Spatial self-concept will be positively correlated with performance on the spatial skill maths attainment.

*Hypothesis 4b:* Maths self-concept will be positively correlated with performance on the spatial skill maths attainment.

*RQ5:* How effective is the novel spatial skills intervention programme at improving spatial skill maths attainment and spatial self-concept, for participants with low reading self-concept?

*Hypothesis 5:* Participants with low reading self-concept will show greater improvements in spatial self-concept, compared to those who score in the average and high range of reading self-concept.

Quantitative data analytic methods were considered the most appropriate means to address these research questions and hypotheses. Additionally, a process evaluation involving the collection of qualitative data was considered to be a relevant way to explore the participants' experiences and perceptions of the spatial training intervention programme. The following process evaluation questions (PEQs) were explored:

- PEQa) How well was the programme implemented?
- PEQb) What are the barriers and facilitators of delivery?
- PEQc) What are the perceived student outcomes from engagement with the programme?
- PEQd) What are the perceived mechanisms that are taking place in the intervention, that brought about change in any identified outcomes?
- PEQe) To what extent does the intervention appear to facilitate children's engagement?
- PEQf) To what extent can teachers deliver this programme?

**Epistemological Positioning**

Epistemology has been referred to as the theory of knowledge (Hillerbrand, 1988). When approaching any form of empirical research, a researcher takes a position or set of assumptions about their view of the nature of knowledge. These positions or assumptions make up the basis from which their research design is developed. Therefore, it was important for me to establish my personal epistemological position as justification for my research design, alongside making decisions about the most appropriate methods to use to gather information and analyse findings.

One epistemological position which has been influential in psychological research is positivism. Positivism was a term first devised by Auguste Comte in 1822. It assumes that all knowledge and phenomena can be explained through predictions, observations and conclusions that can subsequently become laws (Waliaula, 2022). Therefore, positivism holds the assumption that there is an absolute truth which can be determined, and that social reality can be explained only through science (Waliaula, 2022). In contrast to the assumptions held by positivism, social constructionism takes the philosophical position that there is no such thing as absolute truth, instead arguing that all knowledge is constructed (Burr, 2015). The adoption of a positivist or social constructionist approach will be central to decisions about the most appropriate research methods to use. Bahari (2010) argued that different methods are based on the epistemological position taken and stated that qualitative research is often based on social constructionist perspectives, whereas quantitative research is usually based on a positivist approach.

The current study sits in between positivism and social constructionism in that to address each of the outlined research questions, a mixed methods approach is required. Whilst the research questions posited for first phase of the study requires quantitative data collection and analytic methods, the second phase requires both quantitative data (in the form of pre- and post- intervention measures), as well as qualitative data (in the form of semi-structured interview data gathered as part of a process evaluation). Some argue (e.g., Bahari, 2010) that there is a middle ground to be found within the duality of positivism versus social constructionism. Howe (1998) summarised that ‘pure’ positivists and social constructionists advocate for an incompatibility theses; that neither qualitative nor quantitative research approaches should be mixed. This alternative research strategy that can used in mixed methods research. In contrast to this position, Johnson and Onwuegbuzie (2004) argued that mixed methods (i.e., a combination of qualitative and quantitative methods) can act as a “natural complement to traditional qualitative and quantitative research methods” (p. 14).

There are two epistemological approaches that could be selected for the basis of this research study: critical realism and pragmatism. Some theorists argue that critical realism positions itself in between positivism and social constructionism, addressing the issues which are raised by opponents of both philosophies in tandem (Cruickshank, 2012). Critical realism is a distinct philosophical position which was first posited by Bhaskar (2008). The critical realism position states that unobservable structures create all observable events, and thus it is important to understand the underlying mechanisms that generate the observable world (Leroyal, 2021). In contrast to all the previous epistemologies outlined, pragmatism is less concerned with gaining the truth through ideas, but focusses instead on the experience (Smith, 2021). Norwich (2019) summarised why using mixed methods research has been argued as pragmatic, noting that the pragmatic, “way of framing it detaches the rationale for designing research studies from metaphysical considerations, as in the metaphysical paradigm perspective, and links the rationale merely to practical methods” (p. 248). Whilst both positions would allow for mixed methods approaches, there are some important distinctions between the two. Allmark and Machaczek (2018) summarised the differences between the approaches.

The philosophical differences between pragmatism and realism are profound. Pragmatism views scientific inquiry as the attempt to find theories that work, that make a difference, to a practical or intellectual problem. Those that work best are true; or to put it another way, true theories are those that work best in resolving our problems. By contrast, for realism, scientific theories are true if they correctly describe "the mind-independent natural and social worlds, worlds which consist of mechanisms, entities and forces that lie beneath the world we actually experience." (Allmark & Machaczek, pp. 25-26).

Whilst I understand and appreciate the arguments and philosophies from each of the different epistemological positions, for this research project a mixed methodological approach, from a critical realist stance was considered most appropriate. In support of this position, Cheng and Metcalfe (2018) argue that the two different paradigms and methodologies (qualitative and quantitative) can be reconciled through critical realism. The critical realist ontology requires researchers to focus "on either structures or agents to the exclusion of the other cannot account for the totality of the social experience, and it is the interaction between the two which needs to be the focus of the research" (Scott, 2007, p. 15). Therefore, under the critical realism perspective, using mixed methodologies is an important research methology. It was important that qualitative methods maintained their paradigmatic nature for the purposes of this research project. However, this approach can be intermeshed with quantitative data methods so that there can be a richer understanding of the phenomenon under study (Moran-Ellis et al., 2006). This means that if the intervention proposed did not succeed in finding answers to the questions outlined in my hypotheses (using quantitative data collection methods), then there is further data that explores experiences and processes perceived by participants through engagement in the intervention. This qualitative data will provide data which may in turn inform future interventions and research designs. Nonetheless, a firm epistemological and philosophical grounding is crucial for the effective use of certain qualitative methods (Devers, 1999). I will now outline appropriate methodologies for both the quantitative and qualitative elements of this research project, and the epistemological assumptions made, in order to adequately address the research questions.

For the quantitative data collection and analysis, a hypothetico-deductive approach in an experimental design, which was run in parallel with an exploratory-inductive approach using qualitative data collection and analysis, was considered to be an appropriate methodology. It is argued that this combination and balance of deductive and inductive approaches maximises scientific progress (Jebb et al., 2017). I will now evaluate each of these parallel approaches and how they specifically influenced my research design.

Explanatory theories in psychology are often evaluated using the hypothetico-deductive method (Haig, 2009). There are two steps to the hypothetico-deductive method. First, a theory or hypothesis is drawn from already existing research which is proposed to test (hypothetico). Following this, research methods are selected to specifically test the hypotheses (deductive) (Nola, 2007). This approach was the one adopted for the quantitative phases of the research project. It is important to note that a quantitative approach makes some clear assumptions which will influence the development and conduct of this research project, that are at odds with a social constructionist paradigm. In psychology, all researchers have values and beliefs that they bring in relation to the study area, and it is impossible to remove all bias when approaching research. In order to try and correct for any bias in this research, questionnaire data was collected, and statistical analyses were conducted. All measures used were objective assessment measures, with good reliability and validity.

On the other hand, for the qualitative data collection and analysis, a slightly different approach would be required. A hybrid process of both deductive and inductive approaches (Fereday & Muir-Cochrane, 2006) offered the potential to explore my pre-exisiting views about influencing factors (deductive) whilst conducting "detective work" (inductive) to uncover new theories (Jebb et al., 2017). A process evaluation provides the opportunity to gather semi-structured interview information and analyse it using thematic analysis (Braun and Clarke, 2006). In line with the mixed methodological epistemological position, a process evaluation can gather the exploratory-inductive data. As is the case with this research study, process evaluations are usually carried out in conjunction with outcome evaluation (e.g., pre-, and post- measures), using qualitative research approaches during or after the implementation of an intervention (Cheng & Metcalfe, 2018). This allows researchers to evaluate and explain the outcomes of the intervention (Lewin et al., 2009; Moore et al., 2015). Qualitative methods offer "empirically-based insights into the fidelity of implementation and the causal mechanisms or pathways, interactions and contexts driving different facets of an intervention and how it is experienced by participants" (Cheng & Metcalfe, 2009, p. 1). As such, the process evaluation sought to focus on experiences the participants had whilst engaging in the research study. Whilst the questions asked as part of the semi-structured interview must be developed from a hypothetico-deductive position, the data analysis must be from an exploratory-inductive position, where themes can be derived from the data. The switching between the tight approach to enquiry used in the quantitative data collection and analysis, and the more open approach used in the qualitative data analysis allows for an enquiry cycle which can begin with experiment and end with exploration.

The implications and limitations of the mixed methodological epistemological position will be reviewed in the Discussion section of this paper, and the conclusions summarised.

**Research Design**

Phase 1 of this research focussed upon developing a scale to measure spatial self-concept, based upon previously published self-concept measures, before gathering data to establish its reliability and validity. Phase 2 of the research project employed a quasi-experimental design to compare the progress of children receiving a spatial skills intervention with a wait-list control group. Table 4 demonstrates the Phase 2 design, which used a convergent parallel mixed methods approach, where qualitative and quantitative data were gathered concurrently (Nair, 2017; Creswell & Plano Clark, 2011), and is illustrated in Figure 5. Qualitative data was gathered during the process evaluation conducted at the end of Phase 2, to explore participants' thoughts and feelings about the intervention, perceived changes to their individual spatial abilities, and views about mechanisms of change.

**Figure 5**

*Diagrammatic summary of the mixed-methods approach used in this research (based on Nair, 2017)*

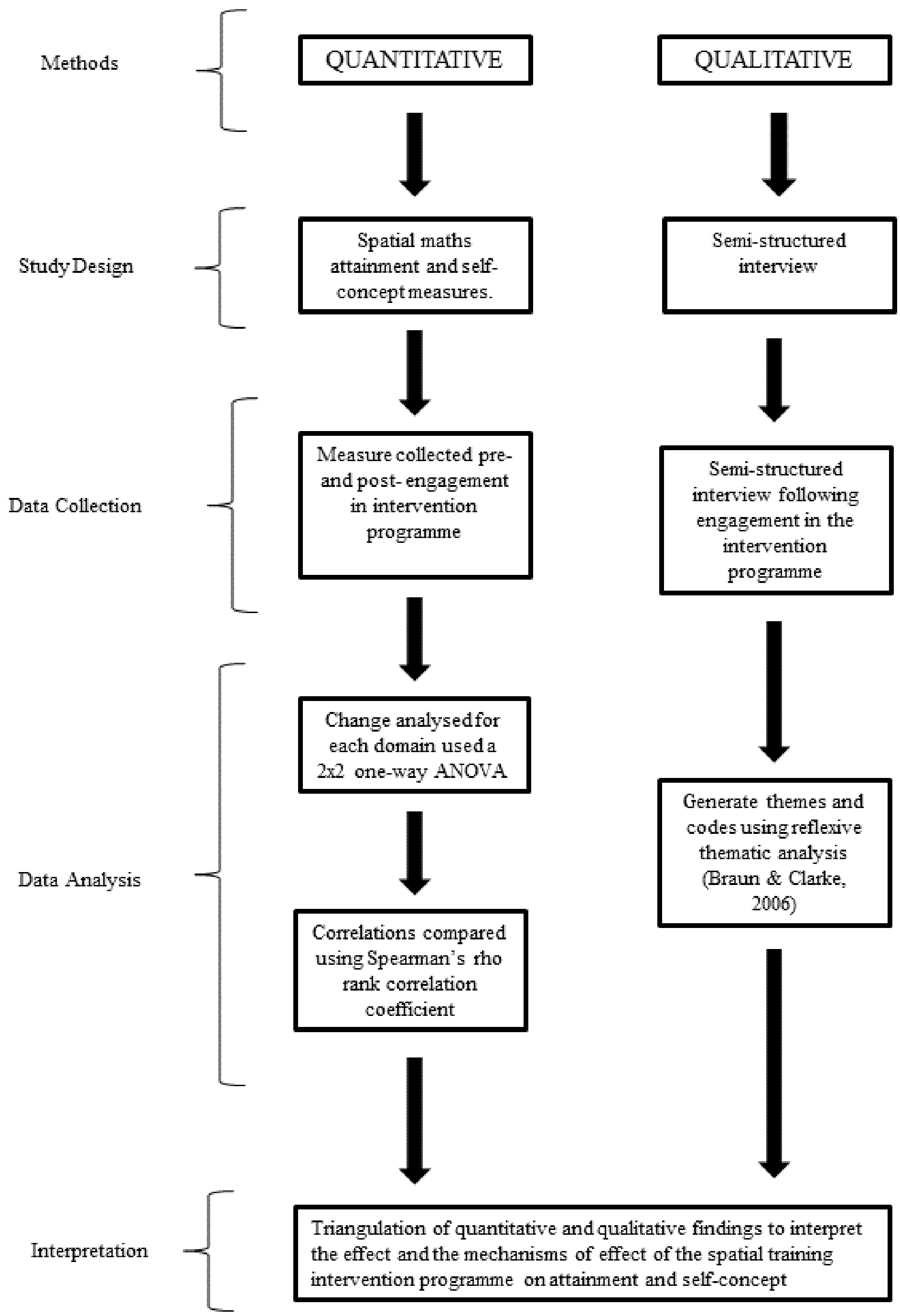


**Table 2**

*Research Project Design and Schedule*

| | Pre-measure assessment | Intervention | Post-measure Assessment |
|---|---|---|---|
| **Control Group** | 12/01/2022 | NO<br>13/01/2022 to<br>17/03/2022 | 23/03/2022 |
| **Intervention** | 12/01/2022 | YES<br>13/01/2022 to<br>17/03/2022 | 23/03/2022 |

**Reliabilty and Validity of the Spatial Self-Concept Measure**

As developing a spatial self-concept instrument is central to this study,  key psychometric principles were considered in relation to construction of a novel measurement scale. Psychometric instruments must demonstrate sound criterion-validity, content-validity, construct validity, and internal consistency (Hinkin, 1995). Germain (2006) outlined key processes that need to be undertaken during scale development.

Firstly, it is important to consider domain identification and item generation i.e. the relevance and sensitivity of items are the most important factor in  a reliable and valid measure (Hinkin, 1995). To develop a novel scale, an inductive, bottom-up process is one way to generate items. An alternative is to identify an established measure with good construct validity and adapt and modify the items. Chapter 2 outlines the changes that were made to Marsh's (1986) measure for use in this study. Furthermore, to establish construct validity with regard to a new measure, it is important to appraise the exisiting knowledge of participants, to ensure understanding of the constructs and also that items are sufficiently accessible, relevant and challenging. Further information about how this was achieved for the purposes of the study design can be seen in Chapter 2.

As well as establishing construct validity, it is important to establish the reliability of any new measure (Germain, 2006). Reliability refers to the consistency or reproducibility of scores from one assessment to another (Cook & Beckman, 2006). Hinkin (1995) summarised that the reporting of internal consistency reliability is an essential part of the development process of a psychometric scale. To assess the internal consistency of a measure, Cronbach's alpha should be used (Germain, 2006). Achieving internal consistency of .70 is recommended for research measures (Taber, 2018). Similarly, item intercorrelations should be calculated and be less than 1.00 to be "conceptually distinct" (Germain, 2006 p. 896). If the any item achieved a correlation of 1.00, they would be measuring the exact same concept. Another important aspect in generating good reliability statistics for a psychometric measure is test-retest reliability (Aldridge et al., 2017). Inter-rater reliability is not relevant for this research project, as the measure is based on self -report.

There are important methodological concerns that need to be considered when developing a novel psychometric tool, which relate to establishing adequate reliability and validity.

## Participants

### *Phase 1*

This study selected participants from children attending mainstream primary schools. A total of 178 Year 4 & Year 5 students aged between 8 and 10 Years, from three schools within the Bracknell Forest Area, in the South East of England were recruited. Schools agreed to participate following e-mail communication with Special Educational Needs Coordiantors (SENCos). A total of six schools were contacted, but three schools opted not to take part in the research study. This represents a convenience sampling method, based on geographical location. This method of sampling has some limitations relating to bias and generalisability (Jager et al., 2017) which will be discussed in Chapter 4.

Calculation of an appropriate sample size was done using respondent-to-item ratios. A respondent -to-item ratio refers to the number of responses to a questionnaire (e.g., sample size) to the number of items in said questionnaire. Guidelines for respondent-items ratios range from a 5:1 – 30:1 ratio (Tsang et al., 2017). Whilst there are no absolute rules for the sample size needed to validate a questionnaire with suitable power (Osbourne & Costello, 2004), it is recommended that researchers use as large a sample as possible (Tsang et al., 2017). There are 9 items on this novel questionnaire, and based on the limitations of this study, a 15:1 ratio was targeted. Using a 15:1 ratio, a minimum of 150 participants were required for this phase of the research project. The 178 recuited represents a respondent-to-item ratio of 19.78:1, a larger sample size than strictly necessary.

One school (School 2) with 61 participants were followed up two weeks after initial data collection to repeat the measure in order to establish the test-retest reliability of the spatial self-concept measure. Due to absence, only 55 pupils were present for retest measures. Information about the participants were provided by their parents, when written consent was obtained. Table 1 outlines the gender and number of pupils from each year for each school.

**Table 3**

*Phase 1 School Participants: Year Group Breakdown*

| | **Year 4** | **Year 5** | **Total** |
|---|---|---|---|
| **School 1:** | 37 | 0 | 37 |
| **School 2:** | 61 | 0 | 61 |
| **School 3:** | 43 | 37 | 80 |
| **Total** | 141 | 37 | 178 |

***Phase 2 – Experimental Groups***

For the second phase of this research project, participants were 57 Year 5 students aged between 9 and 10 Years. The sampling procedure followed was similar to that of Phase 1. Participants were from two mainstream primary schools within the Bracknell Forest Area, in the South East of England. Participants were recruited from the local area and through e-mails to school SENCos. A total of four schools were contacted. All four schools were two form entry schools, to facilitate the quasi-experimental design used. Only three schools expressed an interest in participating in this phase of the research study; these were the three schools that had been involved in Phase 1. As there was only capacity and time to work with two schools to deliver the intervention, random selection was undertaken, through drawing names out of a hat. Thus two schools were recruited for Phase 2. Consent forms were sent home with the all children in the Year 5 classes. 116 consent forms were sent home to the four Year 5 classes at the two schools. Of the families initially contacted, *N*=64 consented to take part in this second phase. The intervention was delivered to classes of children, randomly assigned (as a whole class) either to an intervention or control condition. Each intervention class received the spatial skills programme during January, February and March 2022. Although a total of 64 consent forms were returned, seven participants were withdrawn from the study due to absence from school on the days of the pre- and post-measures being administered.

**Table 4**

*Phase 2 School Participants: Year Group and Group Breakdown and Assignment*

| | **Intervention** | | | **Control** | | |
|---|---|---|---|---|---|---|
| | **Total Sample** | **Male** | **Female** | **Total Sample** | **Male** | **Female** |
| **School 1:** | 21 | 10 | 11 | 17 | 7 | 10 |
| **School 2:** | 11 | 5 | 6 | 8 | 4 | 4 |
| **Total** | 32 | 15 | 17 | 25 | 11 | 14 |

***Phase 2 – Process Evaluation***

Participants were selected for this part of the research project from each school. 11 participants were interviewed, and one teacher. Seven participants and one teacher were recruited from one School 1, and four participants were recruited from School 2. The inclusion criteria for the process evaluation was any participant who engaged in the spatial skills intervention. Only one teacher was interviewed, as a staff member was only present for the intervention sessions in one of the experimental groups. Participants were identified at different levels of academic attainment. Teachers drew on school data to identify each participant as either working towards (WT), working at (W), or working above (WA), age-related expectations in maths and literacy. Table 9 below outlines the academic attainment level for each of the process evaluation participants.

**Table 5**

*Teacher Identified Attainment Levels of Process Evaluation Participants*

| | | Literacy | | |
|---|---|---|---|---|
| | | **WT** | **W** | **WA** |
| | **WT** | 2 | - | - |
| Maths | **W** | 1 | 4 | 1 |
| | **WA** | - | 1 | 2 |

*Note.* WT indicates working towards age related expectations. W indicated working at age related expectations. WA indicates working above age related expectations.

As demonstrated by Table 9, pupils with differing levels of academic attainment were interviewed for this process evaluation. A range of research questions were developed for the semi-structured interviews. Twelve participants were selected for interview, but one opted to not engage in the interview process, resulting in the involvement of 11 pupils.

*Demographics of Participants in Both Phases*

School 1 and School 2 engaged in both phases of the research project. Data regarding the demographics of the participating schools in each phase is combined into Table 6.  This shows that demographic data from schools involved in this study is comparable to national averages.

**Table 6**

*Participating Schools Demographic Data*

| | School 1 | School 2 | School 3 | National Average |
|---|---|---|---|---|
| **Girls on roll:** | 50.9% | 46.9% | 51.1% | 49.1% |
| **Boys on roll:** | 49.1% | 53.1% | 48.9% | 50.9% |
| **Pupils with an SEN Education, Health and Care Plan (EHCP):** | 2.1% | 1.2% | 2.2% | 2.0% |
| **Pupils with SEN Support:** | 8.5% | 10.1% | 15.4% | 12.6% |
| **Pupils whose first language in not English:** | 16.4% | 24.9% | 18.2% | 20.9% |
| **Pupils eligible for free school meals at any time during the last 6 years:** | 14.2% | 16.4% | 20.4% | 23.5% |

*Note: This data has been sourced from the GOV.UK website (HM Government, 2022a) and data regarding the pupil population in 2020/2021.*

## Materials

### *Video*

In both phases of this research project, it was important to ensure that participants had a satisfactory understanding of the definition, nature, and examples of spatial abilities to answer a questionnaire based on them. A video with a runtime of 4 minutes and 57 seconds was developed which provided a verbal definition of spatial abilities, followed by a visual demonstration of four different examples of tasks which heavily involve spatial skills. Due to the wide application of spatial skills across many different domains (Lowrie et al., 2017), a range of different tasks were selected to be shown. Two school-based tasks were demonstrated, and two home-based tasks. The two school-based spatial tasks included a net of solids task and a symmetry task. The two home-based tasks involved following visual instructions to build a LEGO set, and playing on video games, specifically the video game Tetris. At the end of the video, other skills which involve spatial abilities were listed (for instance, sports and map reading), but these were neither explained nor demonstrated in detail. The video was uploaded to and hosted on the website, www.YouTube.com. To see a transcript and screenshots, or access a link to see the video in full, please see Appendix A.

***Measures***

*Self-Concept Measures:* An adapted version of the Self-Description Questionnaire 1 (SDQI) (Marsh, 1990) was administered to each participant during both phases. The SDQI was developed to measure self-concept in three academic areas (reading, mathematics, and general school). The SDQ was intended for use in grades 4 through 6 (USA school system), which corresponds to ages 8 to 12 years (Marsh, 1990). For this study, a fourth area of academic self-concept was added to the measure – spatial self-concept. The items used for the reading and maths self-concept measures were adapted to develop the spatial self-concept measure. Examples of the amended items can be found in Table 2 below. The self-concept measure consists of a statement, following which the participants are asked rate how true they feel that statement is for them, on a five-point Likert scale. The five points listed are: True, Mostly True, Sometimes True/Sometimes False, Mostly False, and

False. This novel spatial self-concept measure can be found in Appendix B. Additionally, Marsh's (1990) reading, and maths self-concept measures were used during both phases of this research, taken from the SDQI (This can also be found in Appendix C). These measures have frequently been shown to be a reliable and valid measure of reading and maths self-concept (Marsh et al., 2011). The novel spatial self-concept scale was developed for use in Phase 2, once adequate internal consistency and test-retest reliability of the measure were established, following analysis of Phase 1 results.

**Table 7**

*Examples of amended spatial self-concept items alongside relevant Marsh (1990) self-concept item*

| Original Marsh (1990) Self Concept Item | Novel Spatial Self Concept Equivalent Item |
|---|---|
| I like maths | I like spatial activities |
| I learn things quickly in maths | I learn things quickly using spatial activities |
| I am not very good at reading | I am not very good at spatial activities |

*Maths Attainment Measure (See Appendix D):* In order to measure spatial abilities during Phase 2, a novel maths attainment measure was developed. The proposed spatial abilities intervention was designed to be supplementary to the Year 5 curriculum. Therefore, it was important to identify the areas of the Key Stage 2 curriculum which address or are related to spatial abilities. The national curriculum for Key Stage 2 in England was accessed from the GOV.UK website (2022). The only relevant curriculum areas which directly relate to spatial skills are from the maths curriculum. Table 6 outlines the relevant targets which relate to spatial skills in the Year 5 maths curriculum in England.

**Table 8**

*Outline of Key Stage 2 maths curriculum targets which relate to spatial abilities (adapted from the GOV.UK website, HM Government, 2022b)*

| Heading | Specific Target |
|---|---|
| *Geometry – properties of shape* | • Identify 3-D shapes, including cubes and other cuboids, from 2-D representations<br>• Recognise, describe, and build simple 3-D shapes, including making nets |
| *Geometry – position and direction* | • Identify, describe, and represent the position of a shape following a reflection or translation, using the appropriate language, and know that the shape has not changed |

Using these specific identified targets, 20 Key Stage 2 past Statutory Assessment Tests (SATs) were read, and questions which related to these specific targets were identified. Overall, eight questions were selected from these past papers. Each of the eight questions could be awarded one or two marks. Five questions consisted of two marks, with three questions consisting of one mark. Thus the maximum total score that could be achieved when completing the Maths Attainment measure was 13 marks. The questions selected, and their source is outlined in Table 6. All past papers were accessed from the GOV.UK Wesbite (HM Government, 2022c).

**Table 9**

*Maths attainment measure question sources*

| Question Number | Past Paper Source |
|---|---|
| 1 | SATs paper A 2015 (level 3-5) |
| 2 | SATs paper B 2015 (level 3-5) |
| 3 | SATs paper B 2015 (level 3-5) |
| 4 | SATs paper A 2013 (level 3-5) |
| 5 | SATs paper B 2011 (level 3-5) |
| 6 | SATs paper A 2011 (level 3-5) |
| 7 | SATs paper A 2011 (level 3-5) |
| 8 | SATs paper A 2012 (level 3-5) |

Participants were given an appropriate amount of time to answer the questions. This was calculated by considering the proportion of marks in the measure (13 marks) in relation to the time awarded in a Key Stage 2 Maths Paper for children to achieve a maximum score of 40 marks. Children are given 45 minutes (HM Government, 2022c) to answer for 40 marks. Therefore, an appropriate amount of time to complete this worksheet was considered to be 15 minutes. Pupils completed that same spatial maths assessment for both the pre- and post- assessment periods. The reason the same questions were administered twice was to ensure that there was no difference in the average score between different measures. Similarly, the participants were not given the answers to the questions used following pre-measures. Finally, the significant time gap between pre- and post- administration (11 weeks) was deemed long enough to adequately conclude that there would be no practice effects.

**Ceiling and Floor Effects**. One important consideration regarding the quality of the measures used are the impact of ceiling and floor effects. Ceiling and floor effects occur when there is an extreme score for a response to items in a scale (e.g., Likert statement), which in turn limits the observed variability of responses (Allen, 2017). In this research, participants could only respond to questionnaire statements at the extremes using the 'Strongly Agree' and 'Strongly Disagree' options. Therefore, should many of the participants respond in a unidirectional manner to all of the statements presented to them, their responses would be limited and show a ceiling (overall questionnaire score of 9) or a floor (overall questionnaire score of 45) effect.

Ceiling and floor effects were considered by Marsh (1984) when designing the SDQ-I. He determined that for scores on each of the sub-scales (including maths and reading), ceiling and floor effects were not a significant mathematical and statistical issue. Due to this, it is reasonable to hypothesise there will be similar effects for the novel spatial self-concept measure. Nonetheless, it was decided to take considerations regarding floor and ceiling effects into account when scrutinising the data. Similarly, it was decided to undertake tests of normality at each phase of the research project to ensure adequately distributed data (Mann-Whitney tests), and to compare sub-scale scores to ensure consistent distribution of scores on each of the sub scales.

### *Intervention*

The spatial skills intervention programme was designed between January and May 2021. The intervention followed a template of intervention topics used by Lowrie et al. (2018). Each intervention session maps on to a different subtype of spatial skills including (1) Mental Rotation, (2) Spatial Orientation, and (3) Spatial Visualisation. The intervention was designed to have as low a reading and writing demand as possible, to ensure accessibility for participants with literacy difficulties. Any words or sentences presented to participants were first read to them by me, the researcher. All intervention sessions were delivered by me, the programme designer. Each intervention session used a Microsoft PowerPoint Presentation and a print-out work sheet. Some sessions used physical materials e.g., wooden blocks, nets of solids print outs. An outline of each session can be found in Table 8 below. Further details about the resources used in each session of the intervention can be found in the Appendix E.

**Table 10**

*Outline of spatial abilities intervention sessions*

| Intervention Topic | Aim of Session |
|---|---|
| *2D Mental Rotation* | Participants to understand and become familiar with 2D mental rotation tasks and strategies that can be used to approach them. |
| *3D Mental Rotation* | Participants to understand and become familiar with 3D mental rotation tasks and strategies that can be used to approach them. |
| *Rotational Symmetry* | Participants to understand and become familiar with rotational symmetry tasks and strategies that can be used to approach them. |
| *Drawing Maps* | Participants to be able to draw a basic map of a small familiar room, so that they understand how 3D areas can represented in 2D form. |
| *Perspective Taking* | Participants to understand and become familiar with perspective taking tasks and strategies that can be used to approach them |
| *Nets of Solids* | Participants to understand what a net of a solids is, and how it can be put together to make a 3D shape. Participants to become familiar with the nets of solids of familiar 3D shapes. Participants were able to anticipate what 3D shape a novel set of solid will make. |
| *Reflection and Symmetry* | Participants to able to identify the number of lines of symmetry of any given shape. |
| *Navigating Maps* | Participants to understand cardinal directions and changing angles cardinal point can impact on directions and perspectives. |
| *Revision of Topics* | Revision of Topics – with a focus on a task involving mental rotation, spatial orientation, and spatial visualisation. |

## Research Procedure and Data Analysis

This section outlines the research procedure for each phase of the research project, before outlining the data analysis methods used upon the data which has been gathered.

### *Phase 1 Research Procedure*

In March 2021, the video defining, and demonstrating examples of, spatial skills was developed. It was shot over 3 days using a video camera mounted above the tasks being shown. Similarly, screen recording software was used to demonstrate the spatial skills used in video games. During March and April 2021, the video was edited and a voiceover was recorded. Ethical approval and fieldwork approval was granted in July 2021. Between September and December 2021, consent forms were sent out to parents by recruited schools. Between October 2021 and March 2022, data was collected for Phase 1 of the research project. Data was collected in person, in the classroom setting. All students in Year 4 and/or 5 classes that had been recruited watched the video together on a projector or television. All students, regardless of consent status were able to watch the video. At this point, the students were asked if any of them would like to opt-out of watching the video. No students at any point in the research project chose not to watch the video. After the video had been shown, consenting students were handed a paper copy of the spatial, maths and reading self-concept measures (see Appendices B & C). Questionnaires had randomly allocated numbers written on them which corresponded to the participant's identity recorded on a password protected spreadsheet. Next, children were verbally addressed by me, the researcher, and informed that they could now answer a short questionnaire asking for their thoughts and feelings about spatial skills, and other skills they use in school such as reading and maths. Finally, participants were informed that they would have to rate how true or false they felt a series of statements was for them, on a five-point scale. At this point, they were asked if they had any questions about the video, or the questionnaire. They were also given the opportunity to withdraw from the study should they choose to. Each statement on the measure was then read out and the participants were asked to select their answer with a tick or cross in the relevant box. The statements were read out loud in order to control for and support pupils with literacy difficulties. This part of the procedure was in line with the original Marsh (1986) procedure for the SDQI. Whilst the statements were read out, the mainstream class teacher and classroom teaching assistant circulated around the classroom to ensure that the students were filling out the questionnaires in an appropriate way, and to answer any questions that they posed. After all 27 items were read out, participants were given another opportunity to ask questions, or to have any statements repeated to them. After this, all paper questionnaires were collected. After two weeks, School 2 (*N*=55) was returned to, and the same procedure was followed exactly, to gather and collect questionnaire data.

***Phase 1 Data Analysis***

The student self-report measure included the SDQI (Marsh, 1990) sub-scales for reading and maths self-concept. Also included was the novel spatial skills self-concept sub-scale. Each sub-scale included 9 statements and participants rated how true each one was for them. Response options ranged from True to False. Five options were available to select (True, Mostly True, Sometimes True/Sometimes False, Mostly False & False). Each selected answer corresponded to an associated number. These were 1 for True, 2 for Mostly True, 3 for Sometimes True/Sometimes

False, 4 for Mostly False, and 5 for False. Seven of the nine statements were worded positively (e.g., I like maths, or I get good marks in lessons with maths), whereas two of the nine statements were negatively worded (e.g., I hate maths, and I am not very good at maths). Reverse scoring was used for the negatively phrased statements. Therefore for these statements, the selected answer corresponded to a different associated number. These were 1 for False, 2 for Mostly False, 3 for Sometimes True/Sometimes False, 4 for Mostly True, 5 for True.

All statistical data analysis was undertaken using IBM SPSS Statistics 27. To determine the internal reliability and consistency of the novel spatial skills measure, Cronbach's alpha was used. Cronbach's alpha is a measure of internal consistency, and it is expressed as a number between 0 and 1. Internal consistency refers to the extent to which all the items in a test, or questionnaire, measure the same concept or construct, and therefore it is connected to the inter-relatedness of the items within the questionnaire (Tavakol & Dennick, 2011). In other words, statistically a high Cronbach's alpha indicates a high degree of correlation between each of the items on a scale. In order to establish the test-retest reliability of the spatial skills self-concept measure, one of the schools was returned to two weeks after the initial data collection to collect additional data by asking the same children to complete this measure once more. Test-retest reliability is method to measure the reliability of a test and it refers to the extent to which a measure produces similar results over time. Spearman's rho is a statistic which was designed for the purpose of measuring the strength of a basically linear association between two continuous variables (Kinnear & Gray, 2006). A Spearman's rho test of correlation is appropriate as the same group was subjected to a repeated measure over two time points (pre and post two weeks). Essentially, the within-subjects variable in this test was time. A linear relationship between these two variables would be expected as the hypothesis expects participants responses to remain relatively static. Pearson's R was not used as the assumption that the data is normally distributed cannot be met. This is due to the small sample size and possibility of positive or negative skew to the data. A perfect positive association (i.e., all participants gave the exact same response at both data collection points), would be reflected by a Spearman's rho of +1 (Kinnear & Gray, 2006). A Spearman's rho of 0.5 to 0.75 would indicate moderate test-retest reliability, whereas 0.75 to 0.9 would indicate good test-retest reliability (Portney & Watkins, 2009). For the purposes of this research project a Cronbach's Alpha scored of >0.7, and a Spearman's rho of >0.7, would demonstrate acceptable internal consistency and test-retest reliability, in order to establish the novel spatial self-concept measure as a suitable instrument for use in Phase 2 of the project. Spearman's rho correlation coefficient allowed for the testing of hypotheses related to research questions 1 and 2.

### ***Phase 2 Research Procedure***

Between September and December 2021, consent forms were sent out to parents by recruited schools. Between January 2022 and March 2022, data was collected for this phase of the research project. Data was collected in person, in the classroom setting. All students in both control and intervention groups completed four measures before the delivery of the intervention sessions. The four measures were, the spatial maths attainment measure, the novel spatial self-concept measure (developed in Phase 1 of the project), reading self-concept and maths self-concept measure (Marsh, 1990), respectively. The same procedure as Phase 1 was followed for each of the self-concept measures (spatial, maths and reading).

All participants in both the control and experimental classes watched the video together on a projector or television. As in Phase 1, the students could opt out of watching the video, if they wanted to. However, no individual chose not to watch the video. Consenting students were handed a paper copy of the spatial, maths and reading self-concept measures (Please see Appendices B & C), after the conclusion of the video. In contrast to Phase 1, any non-consenting students were not present in the room for data collection. The same research procedure was followed for the collection of self-concept data as outlined in research procedure for Phase 1 (see relevant section above for further details), including arrangements for  watching the video, opportunities to ask questions, and the anonymisation of participant identifying data by substituting names with numbers, and retaining the key on a on a secure spreadsheet.

The maths attainment measure was administered pre-intervention. This was completed after the self-concept measure so that there was no impact on responses based on performance, or the perceived difficulty of the test. Participants were provided with pencils and rulers and asked to complete the measure within 15 minutes. They were informed that they should put their hand up and ask an adult if they struggled to read any of the questions. No guidance or prompt was given that would support interpretation of the question. After the 15 minutes had elapsed, all papers were collected. The maths attainment measure was scored based on the related mark scheme for each question, to give a score between zero and 13. Scores were recorded in an SPSS 27 database.

Following pre-intervention data collection, 10 weekly intervention sessions were delivered by myself between January 2022 and March 2022 in the classroom setting. The only individuals present during the sessions were the consenting participants, and for one of the intervention classes, a teacher was present. This was due to a lower number of consenting participants in School 2, so the teacher stayed with non-consenting members of the class, of which there were a greater number. Each session was delivered using a Microsoft PowerPoint presentation and an associated worksheet. Participants were given relevant physical materials that related to each session. They were informed that they could put up their hands to ask questions at any point throughout the sessions. The length of the sessions were all between 20 and 30 minutes. Each session was conducted on consecutive weeks, with the exception of one break due to the February half-term break.

The intervention sessions followed a consistent, similar structure. Each session began with an introduction which identified to focus of the session. Key language terms were clarified for meaning when the were relevant for the learning aim of the session. For instance, prior to the 2D and 3D mental rotation sessions, the intervention group was asked “Is anyone able to tell me what it means when you rotate a shape?”. Participants were encouraged to put up their hand to answer about their knowledge of the key word. Another example related to the 2D and 3D mental rotation was that the intervention group was asked “What is the difference between 2D and 3D shapes?”. After some participants shared their answers to each question, a clear definition of the key word was given to the participants. Appendix E includes the key words used in each session, the prompt question asked, and the definition read to the participants afterwards. After key words had been clarified, participants were asked if they had anymore questions related them, or if they were unsure about what it meant. Following this, the participants were provided with the worksheets and materials. After this, each session followed a slightly varying structure depending on the topic of focus. Nonetheless, each session started with a worked example, to clarify the nature of the spatial task. After participants had completed the tasks as presented by the Microsoft PowerPoint presentation and worksheet, the answers were provided. At the end of each session, participants were informed of the name of the following session.

The pre-intervention measures (maths attainment measure and self-concept measures) were collected one day prior to the initiation of the intervention, and the post-intervention measures were collected one day after its conclusion. Pre- and post- intervention data collection procedures were parallel to ensure similarity of conditions across the two data collection points. After the conclusion of the research, both intervention and control groups were given an opportunity to ask any final questions. The teacher of the control classes were then provided with all of the Microsoft PowerPoint Presentations and associated worksheets, and materials to use. The decision about whether to use the resources as part of the Year 5 maths curriculum was left to staff in the participating schools. After the conclusion of Phase 2, participants in the intervention group were informed that some of them would be given the opportunity to express some of their thoughts and feelings about the programme, in an audio-recorded interview.

### *Phase 2 Data Analysis*

A pre/post control group design was used. Students completed all the measures (maths attainment measure and self-concept measures) at both pre-intervention and post-intervention. A mixed model analysis of variance (ANOVA) was conducted. The mixed-design one-way ANOVA can be used to test for differences between two independent groups when subjecting participants to repeated measures (Kinnear & Gray, 2006). A mixed-design one-way ANOVA was considered the most appropriate statistical test to use as there were two independent groups (control and intervention group), who were subjected to repeated measures during two different time points (pre-intervention and post-intervention). The within-subjects variable was time (pre-intervention and post-intervention), and the between-subjects variable was group (control or intervention group). As such, a mixed-design one-way ANOVA is the appropriate test to address the hypotheses related to RQ3 and RQ5, as it they address comparing performance between control and intervention groups, at different time periods. In order to use a mixed-design one-way ANOVA, certain assumptions need to be met. For that reason, it was decided to use Levene's test to assess for homogeneity of variance, the Mauchley's test of Sphericity, and the T-test for Normality of Distribution in order to ensure that the data is independent, that the variances between each groups are somewhat equal, and that errors are normally distributed (Lumley et al., 2002). These assumptions are standard when conducting an ANOVA (Lumley et al., 2002). For RQ3, should an significant interaction be determined between experimental group (control vs. intervention) and time (pre- and post- measures), for either spatial maths attainment or spatial self-concept, the data will be separated into individual spreadsheets for each group. Following this, follow-up repeated measures t-tests will be completed on each data set. This will allow to determine whether the is a significant difference between scores pre- and post- for each individual group following engagemenet with the intervention programme (or no engagement i.e., control). For RQ5, new independent groups must be established in order to differentiate those with high and low reading self-concept. To achieve this, quartiles were calculated for those in the intervention group. Participants were assigned a number from 1 to 4 based upon which quartile they are in. Comparisons were made between quartiles 1 and 4 (those with high vs. low reading self-concept).

A comparisons were made between those groups in spatial maths attainment and spatial self-concept using a mixed design one-way ANOVA. Quartiles in reading self-concept was used as an alternative to measuring high and low reading ability through other assessment. Post-hoc tests will not need to be conducted on the data on each of the one-way ANOVAs in this research design. The justification is due to the use of only two experimental groups, the intervention group, and the control group. Post-hoc tests are only required when there are three or more variables in the ANOVA, when using repeated measures. This study adopts a 2x2 experimental design. As such, there is no post hoc-test available in IBM SPSS 27 between the present measures from one time to the next. If an alternative design had been used with, for example, a 3-month follow up measure, then post-hoc tests, such as the Bonferroni correction would have been appropriate. The Bonferroni correction can be used in various experimental contexts, including when “examining more than one endpoint” (Armstrong, 2014, p. 502).

To evaluate the relationships between variables, correlational analyses can be used. Spearman’s rho rank coefficicent was used to complete correlational analyses in both Phases 1 and 2. Spearman’s rho is a statistic which was designed for the purpose of measuring the strength of a basically linear association between two continuous variables (Kinnear & Gray, 2006). Spearman’s rho allows hypotheses related to RQ4 to be investigated, as it is studying the relationship between self-concept (perception of aptitude) and spatial maths attainment (actual aptitude). A perfect positive association (i.e., all participants gave the exact same response at both data collection points), would be reflected by a Spearman’s rho of +1 (Kinnear & Gray, 2006). It is worth noting that either Correlation Coefficient (Pearson’s R and

Spearman's rho) can imply causation. Whilst causation may be present correlations do not prove causality (Kinnear & Gray, 2006).

**Process Evaluation**

These semi-structured interviews sought to understand how the intervention worked, its perceived quality, details relating to implemention, and the perceived outcomes. Table 10 below outlines each subsection and the associated research questions.The process evaluation questions (PEQs) outlined at the beginning of Chapter 2 formed the basis of the interview schedule. The PEQs and related prompts for the semi-strucuted interviews for teachers and Year 5 pupils respectively are outlined in Tables 11 and 12.

**Table 11**

*Teacher Semi-Structured Interviews Questions and Related Research Questions*

| Process Evaluation Questions | Related Prompt Questions |
|---|---|
| **PEQa: How well was the programme implemented? What are the barriers and facilitators of delivery?** | • What was the quality of the intervention sessions like?<br>  ○ How clear was the content of the intervention sessions?<br>  ○ To what extent were the pupils engaged in the programme?<br>• How well was the programme designed?<br>• What were some of the factors that made the delivery of the programme more challenging?<br>  ○ What were some of the factors that were successful about the design of the intervention? |
| **PEQb: What are the perceived student outcomes from engagement with the programme?** | • What has been the observed impact of the intervention on:<br>  ○ academic attainment<br>  ○ engagement of the children in other lessons?<br>  ○ Self-perceptions of abilities?<br>  ○ What about other outcomes? |
| **PEQc: What are the perceived mechanisms that are taking place in the intervention, that brought about change in any identified outcomes?** | • What aspects of the intervention programme brought about the above specific outcomes? |
| **PEQd: To what extent does the intervention appear to facilitate children's engagement?** | • How well were the children able to engage in the intervention?<br>• How would you describe their enjoyment of the sessions, and would they like to do more?<br>  ○ What aspects of the intervention do you think facilitated/did not facilitate engagement? |
| **RQe: To what extent can teachers deliver this programme?** | • How accessible would this intervention be for you to teach as part of the curriculum?<br>  ○ Which parts are especially easy?<br>• Which parts are particularly difficult? |

**Table 12**

*Participant Semi-Structured Interviews Questions and Related Research Questions*

| Process Evaluation Questions | Related Prompt Questions |
|---|---|
| **PEQa: How well was the programme implemented? What are the barriers and facilitators of delivery?** | • Can you describe to me what spatial skills are?<br>  ○ Any examples?<br>  ○ Have you understood more or the same about spatial skills since doing these lessons on spatial skills?<br>• How easy/hard were the sessions to understand?<br>  ○ What could have been better? |
| **PEQb: What are the perceived student outcomes from engagement with the programme?** | • How could some of the skills you have learned during the spatial skills lessons help you in school?<br>  ○ Which lessons or subjects especially?<br>• What have you got better at since doing the spatial skills session?<br>  ○ Spatial Abilities?<br>  ○ Mathematics lesson-related spatial tasks?<br>  ○ What have you learned about yourself and what you can do well and not so well?<br>  ○ How good you feel you are at Spatial Skills? (Spatial self-concept).<br>• Are you especially good or not so good at spatial skills?<br>  ○ Can you explain your answer? |
| **PEQc: What are the perceived mechanisms that are taking place in the intervention, that brought about change in any identified outcomes?** | • Of all the skills you have practiced and learned during the spatial skills sessions, which one do you think will help you the most?<br>• What was it about the programme that resulted in your learning? |
| **PEQd: To what extent does the intervention appear to facilitate children's engagement?** | • To what extent were the spatial skills lessons fun/boring or neutral?<br>  ○ Which sessions did you like the most and why?<br>• How easy/hard were the sessions to understand?<br>  ○ What could have been better? |

The semi-structured interviews were audio-recorded and transcribed. The questions were sent to the teacher participant ahead of time so that they could begin to prepare responses. All participants were conducted on-site at the recruited schools. Reflexivity was a key consideration when approaching this part of the research project, as it should be with any piece of qualitative research (Dodgson, 2019). This is especially relevant as in this study, the same individual delivered the intervention and also conducted the semi-structured interviews. Important considerations such as the influence of power imbalances (Grove, 2017) on the trustworthiness of the data need to be considered. This is reflected on in the Discussion section of this thesis. Participants were reassured that their data was fully anonymised and that they would be able to withdraw from the research project at any stage should they want to. After the data was gathered, the audio files were transcribed.

### ***Process Evaluation Data Analysis***

The texts of 12 transcripts were analysed using a qualitative approach which was based upon thematic analysis procedures outlined by Braun and Clarke (2013). Braun and Clarke (2013) suggested six stages to follow for effective thematic analysis. These six phases are “1) data familiarisation and writing familiarisation notes; 2) systematic data coding; 3) generating initial themes from coded and collated data; 4) developing and reviewing themes; 5) refining, defining and naming themes; and 6) writing the report” (Braun & Clarke, 2013, p. 331). For the purposes of this research, this was the exact procedure which was followed. More specifically, **a** hybrid process of both inductive and deductive thematic analysis was used (Fereday & Muir-Cochrane, 2006). The initial pre-determined coding system was deductive and linked to the over-arching themes reflecting the focus of the research questions about the perceived quality, implementation, and perceived impact of the intervention. New codes were developed based on the data, and established new inductive sub-themes within the coding hierarchy (Guest et al., 2012). This data driven methods involved assigning a label to a theme, then defining the theme and writing a descriptive statement which is related to each theme to assist the coding process (Boyatzis, 1998; Dunsmuir et al., 2017).

Credibility of the analysis was ensured through consultation between myself and my research supervisors in order to try and diminish researcher bias and selective attention. Dependability or auditability was ensured by the audio-recording and transcribing the data in its entirety (Dunsmuir et al., 2017). The software package NVivo12 was used to analyse, organise and review the data, and create a conceptual network from which quotations could be accessed. This process allowed for review of the thematic structure to be undertaken by supervisors, as experienced qualitative researchers. This also helped establish the internal consistency of the codes. This NVivo 12 programme supported the process of thematic mapping (Braun & Clarke, 2006). The NVivo enables “generation of concept maps in which network relationships are derived from co-occuring codes that highlight where individual code quotations are in close proximity, embedded overlapping or following each other” (Dunsmuir et al., 2017, p.12). This concept map was again reviewed by supervisors. Due to the participants’ age, it was not appropriate for transcripts to be returned to establish the accuracy of the transcript in representing their views, and to affirm that the coding system captured key themes. This procedure was followed for the one adult participant, the teacher, who also acted as an advocate for the participants views, where they were from children from their educational setting.

**Ethical Consent**

All parents of Year 4 & 5 students from one of the three schools were sent an information letter outlining the aims of the research, the study procedure, and notification that their child, along with the rest of their class had been selected for involvement in the study, for both phases of the study. For Phase 1, only parents of Year 4 students in school 1 and school 2 were provided with this information. This was due to the involvement of the Year 5 cohort in those schools in the Phase 2 of this research project. Parents were also sent home a consent form (Please see Appendix F for Parent/Carer Information Sheets and Consent Forms). Assent was also sought from participants at two separate points during the data collection in each Phase. Details of the information they were provided with is explained in detail in the procedure section. In addition, participants were verbally explained the nature and purpose of the research and were given the opportunity to ask any questions they may have about the research. Furthermore, participants were informed that they had a right to withdraw from the research project at any time. Confidential information was captured about each participant as part of the consent form (full name). Participants were allocated with a randomly generated number which was recorded against their name. These numbers and actual names are recorded on a password protected spreadsheet that is uploaded on to the University OneDrive. Exeter data protection guidelines have been followed in full throughout this research project.

Regarding Phase 2, consent for all pupils to be interviewed for the process evaluation was obtained as part of the consent form, even though not all participants would be interviewed post-intervention. Parents were informed in the information sheet that their child may be interviewed as part of the research project. Before conducting any interview, assent and consent was sought from each of the participants verbally, to both be interviewed and to be recorded. Participants were verbally explained the nature and purpose of the research and were given the opportunity to ask any questions they may have about the research. As before, participants were informed that they had a right to withdraw from the research project at any time. Before they were interviewed, participants were randomly allocated a number, and this information was then cross-referenced with the attainment data provided by the teacher. All audio files were recorded to an SD card, before being uploaded onto the University OneDrive and deleted at source. Each interview was fully transcribed, and transcriptions were also stored onto the University OneDrive. Just as they were for the quantitative data collected, Exeter data protection guidelines have been followed in full during this research project.

# Chapter 3

## Results

In this section, the results for each phase will be summarised by research question.

### Phase 1 - Establishment of a Novel Spatial Self-Concept Measure and the Exploration of Correlation of Other Forms of Self-Concept Results

#### *Reliability and Validity of the Spatial Self-Concept Scale*

*RQ1:* Does the novel self-concept measure show satisfactory reliability and validity, in relation to internal consistency, test-retest reliability and criterion validity?

In order to measure the reliability of the novel spatial self-concept measure based on Marsh (1990), two statistical tests were used. Cronbach's alpha was used to measure the internal consistency of the scale. The questionnaire was completed by 178 students, and good internal consistency was obtained ($\alpha = .858$). An alpha score between 0.70 and 0.90 is considered good (Streiner & Norman, 2008). Spearman's rho correlation coefficient was used to measure the test-retest reliability of the measure. Of the 178 students who completed the questionnaire 55 were followed up for test-retest reliability after 2 weeks. The mean spatial self-concept score from the 55 students initially was $M = 19.01$. After a 2 week gap, the means was $M = 19.39$. The Spearman's rho correlation coefficient overall was ($r = .86$, $p < .001$). All Spearman's rho correlation coefficients were calculated for each individual item on the spatial self-concept scale. These ranged from between $r = .63$ to $r = .74$. Intercorrelational scores of between 0.5 and 0.75 indicate moderate reliability, whereas scores between 0.75 and 0.9 indicate good reliability (Portney & Watkins, 2009). Therefore, this measure has good overall reliability, and moderate reliability on the item level. In summary, satisfactory Cronbach's alpha and Spearman's rank correlation coefficient scores were obtained for the novel spatial self-concept measure to determine good internal consistency and test-retest reliability.

***Relationship between Spatial, Maths and Reading Self-Concept***

*RQ2:* What is the nature of the relationships between spatial self-concept and other aspects of academic self-concept, specifically maths self-concept and reading self-concept?

In order to measure the relationships between spatial self-concept, maths self-concept and reading self-concept, an analysis using Spearman's rho correlation coefficient was conducted. An average overall self-concept score was calculated for each student for each of the self-concept subtypes. Table 13 outlines the Spearman's rho correlation coefficients between each of the subtypes of self-concept. The Spearman's rho correlation coefficient indicated a statistically significant moderate positive linear relationship between participant's 'spatial self-concept' and participants 'maths self-concept' scores, ($r$=.435, $p$<.01). There is a slightly stronger positive correlation between spatial self-concept and maths self-concept, than between spatial self-concept and reading self-concept. As seen in Table 13, students with higher levels of overall 'spatial self-concept' tended to have higher levels overall of 'maths self-concept'.The Spearman's rho correlation coefficient indicated a statistically significant moderate positive linear relationship between participants' 'spatial self-concept' and 'reading self-concept' scores ($r$=.318, $p$<.01). The Spearman's rho correlation coefficient indicated no statistically significant relationship between participant's 'maths self-concept' and participants 'reading self-concept' scores, ($r$=.123, $p$=.101). As seen in Table 13, students with higher levels of overall ‘spatial self-concept’ tended to have higher levels overall of ‘maths self-concept’. As seen in Table 13, students with higher levels of overall ‘spatial self-concept’ tended to have higher levels overall of ‘reading self-concept’. As seen in Table 13, there is no relationships between students’ levels of overall ‘maths self-concept’ and overall of ‘reading self-concept’

**Table 13**

*Spearman’s Rank Correlation Coefficicent Comparison between each of the subtypes of self-concept.*

| | *Relationships between Self-Concept Subtypes* | | |
|---|---|---|---|
| | *Spatial and Maths* | *Spatial and Reading* | *Maths and Reading* |
| *rho* | *.435* | *.318* | *.123* |
| *p* | *<.01* | *<.01* | *.101* |

**Phase 2- Evaluation of the Spatial Self-Concept Intervention**

***The Impact of a Spatial Skills Intervention on Maths Attainment and Self-Concept***

*RQ3*: How effective is the novel spatial skills intervention programme at improving spatial skill maths attainment and spatial self-concept, compared to a control group?

In order to evaluate whether the novel spatial skills intervention is effective at improving spatial skill maths attainment, a 2 (time: pre-intervention, post-intervention) x 2 (intervention group: intervention and control group) one-way ANOVA was used. The mean overall spatial maths attainment scores as measured by the spatial skill maths attainment measure for each time point and each group are shown in Table 16.

There was no significant main effect of intervention group overall ($F(1,56) = .789$, $p = .378$. However, a significant main effect of time was found ($F$ (1, 56) = 21.264, $p>0.01$). Also, a significant interaction between intervention group and time was found ($F$ (1, 56) = 16.291, $p>0.01$). This interaction effect is illustrated in Figure 4. The control and intervention data sets were then separated into individual spreadsheets for further analysis. Follow up paired sample t-tests revealed that the intervention groups maths attainment scores increased significantly between pre-intervention and post-intervention ($t(32)=-5.50$, $p<.001$), whilst there was no effect in relation to the control group ($t(25)=-.267$, $p=.791$). Inspection of the means for each groups indicated that the scores on the maths attainment measure had increased significantly for the intervention group between pre-intervention ($M=5.16$), and post-intervention ($M=7.56$). The post measures suggest that the participants who received the spatial skills intervention were scored significantly better on the measure of spatial maths attainment, whereas the participants who did not receive the intervention showed no improvement in score.

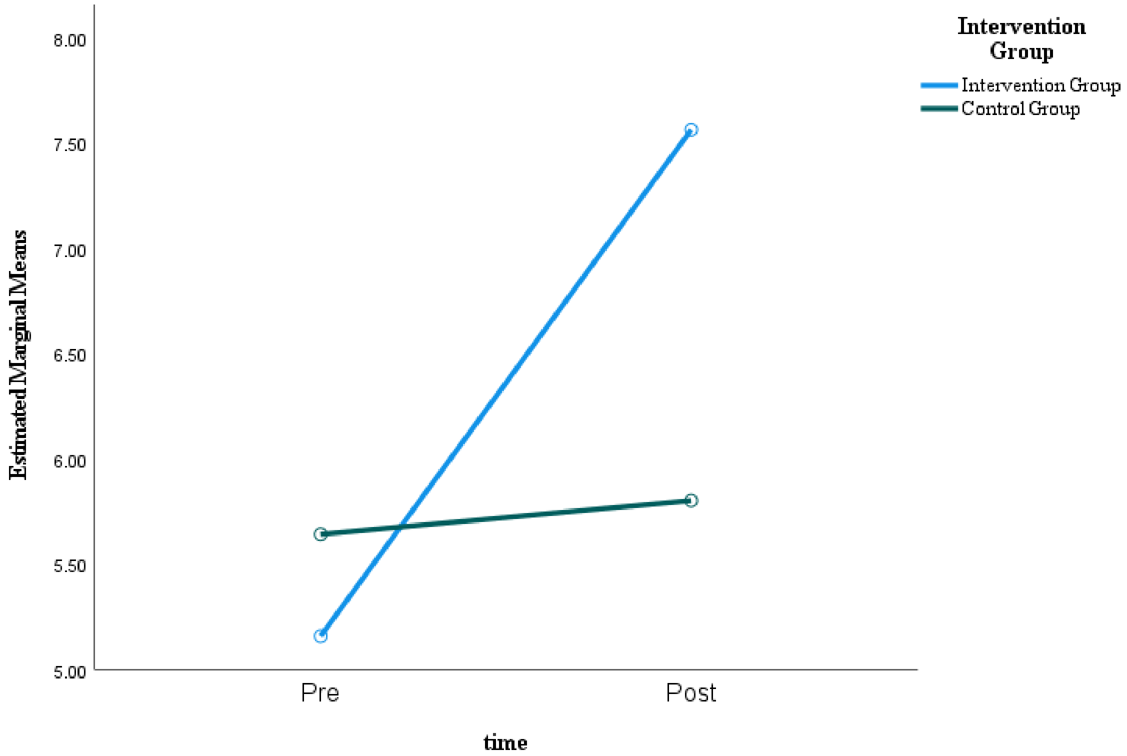
**Table 14**

*Descriptive Statistics for the Spatial Skills Maths Attainment Measure of the Intervention Group and Control Groups measured at two time intervals, Pre- and Post-Intervention (N=57).*

| *Spatial Maths Training Group* | *N* | *Pre-Intervention* | | *Post-Intervention* | |
|---|---|---|---|---|---|
| | | *Mean* | *SD* | *Mean* | *SD* |
| *Intervention* | 32 | 5.16 | 3.08 | 7.56 | 2.68 |
| *Control* | 25 | 5.64 | 2.95 | 5.80 | 2.83 |

**Figure 6**

*Maths Attainment Score comparison between Intervention and Control Groups measured at two different time intervals, Pre- and Post- Intervention*



In order to evaluate whether the novel spatial skills intervention is effective at improving spatial self-concept, a 2 (time: pre-intervention, post-intervention) x 2 (intervention group: intervention and control group) one-way ANOVA was used. The mean overall spatial self-concept scores as measured by the novel spatial self-concept for each time point and each group are shown in Table 16. There was no significant main effect of intervention group overall ($F$(1,56) = 2.91, $p$ = .093. Likewise, no significant main effect of time was found ($F$ (1, 56) = .0.062, $p$= .804. Also, no significant interaction between intervention group and time was found ($F$ (1, 56) = .551, $p$=.461). The same 2x2 one-way ANOVA was used to investigate whether the novel spatial skills intervention had any impact on maths self-concept and reading self-concept. There was no significant interaction found between group and time for either maths self-concept (F (1,56) = 1.637, $p$=.206) or reading self-concept ($F$ (1,56) = .124, $p$=.726). This data does not show any significant impact from engagement in the novel spatial skills intervention programme upon self-concept scores in either control or intervention groups.

**Table 15**

*Descriptive Statistics for the Spatial Skills Self-Concept Measure (N=57).*

| *Spatial Maths Training Group* | *N* | *Pre-Intervention* | | *Post-Intervention* | |
|---|---|---|---|---|---|
| | | *Mean* | *SD* | *Mean* | *SD* |
| *Intervention* | 32 | 18.90 | 5.39 | 19.25 | 6.75 |
| *Control* | 25 | 17.15 | 4.73 | 16.46 | 5.47 |

Nonetheless follow-up tests were run to study to stability of the spatial self-concept measure following the intervention. To achieve this Spearman's rho correlation coefficient of the pre- and post- spatial self-concept for the intervention and control groups were compared. The control group achieved a moderate positive correlation (which is in line with the test-retest reliability analyses conducted as part of Phase 1), $r$ = .734, $p$ <*.001, N* = 25. The same analysis was conducted on the data for the intervention group, whilst a significant correlation was also found, the effect was weakened, $r$ = .526, $p$ = .002, $N$ = 32.

***Relationship between Spatial, Maths Self-Concept and Spatial Maths Attainment***

*RQ4:* Is there a significant relationship between student spatial and maths self-concept, and performance on the spatial maths attainment measure?

In order to measure the relationships between spatial self-concept and maths self-concept, and performance on the novel spatial maths attainment measure, an analysis using Spearman's Rho Correlation Coefficient was conducted. In order to control for the influence of the intervention on both spatial self-concept, maths self-concept and spatial maths attainment, these analyses was conducted using the data collected at pre-measure, for both control and intervention groups. A total overall spatial self-concept score, maths self-concept, and a total spatial maths attainment score was calculated for each student. The Spearman's rho correlation coefficient indicated a statistically significant relationship between participant's 'spatial self-concept' and participants 'spatial maths attainment' scores, ($r$=.298., $p$=.024). There is a weak positive relationship between students' levels of overall 'spatial self-concept' and overall, of spatial maths attainment. Similarly, the Spearman's rho correlation coefficient indicated a statistically significant relationship between participant's 'maths self-concept' and participants 'spatial maths attainment' scores, (*r*=-.328, *p*=.039). The relationship is negative as lower score on the spatial self-measure reflects a higher self-report of spatial self-concept. Therefore, as seen in Table 13, there is a weak positive relationship between students' levels of overall 'spatial self-concept' and overall, of 'spatial maths attainment.

***Impact of The Level of Reading Self-Concept on Research Findings***

*RQ5:* How effective is the novel spatial skills intervention programme at improving spatial skill maths attainment and spatial self-concept, for those who have low reading self-concept?

In order to evaluate whether the novel spatial skills intervention is more effective at improving spatial self-concept and spatial maths attainment, in participants with lower reading self-concept, compared to those with high and average reading self-concept, two 2(time: pre-intervention, post-intervention) x 2 (reading self-concept status: low, high/average) one-way ANOVAs were used. Each another used spatial self-concept and spatial maths attainment, as the between subjects' factor, respectively. Participants from the intervention group were divided into quartiles based upon their scores reported in the pre-measure of reading self-concept. The lowest reading self-concept quartile was compared with the highest reading self-concept quartile. The mean overall spatial self-concept scores as measured by the novel spatial self-concept for each time point and each group are shown in Table 18.

**Table 16**

*Descriptive Statistics for the Spatial Skills Maths Attainment Measure of the High and Low Quartiles measured at two-time intervals, Pre- and Post-Intervention (N=16).*

| *Reading Self-Concept Quartile* | *N* | *Pre-Intervention* | | *Post-Intervention* | |
|---|---|---|---|---|---|
| | | *Mean* | *SD* | *Mean* | *SD* |
| *High* | 8 | 5.50 | 3.16 | 7.00 | 2.45 |
| *Low* | 8 | 3.88 | 2.58 | 7.38 | 3.20 |

**Table 17**

*Descriptive Statistics for the Spatial Self-Concept of the High and Low Reading Self-Concept Quartiles measured at two-time intervals, Pre- and Post-Intervention (N=16).*

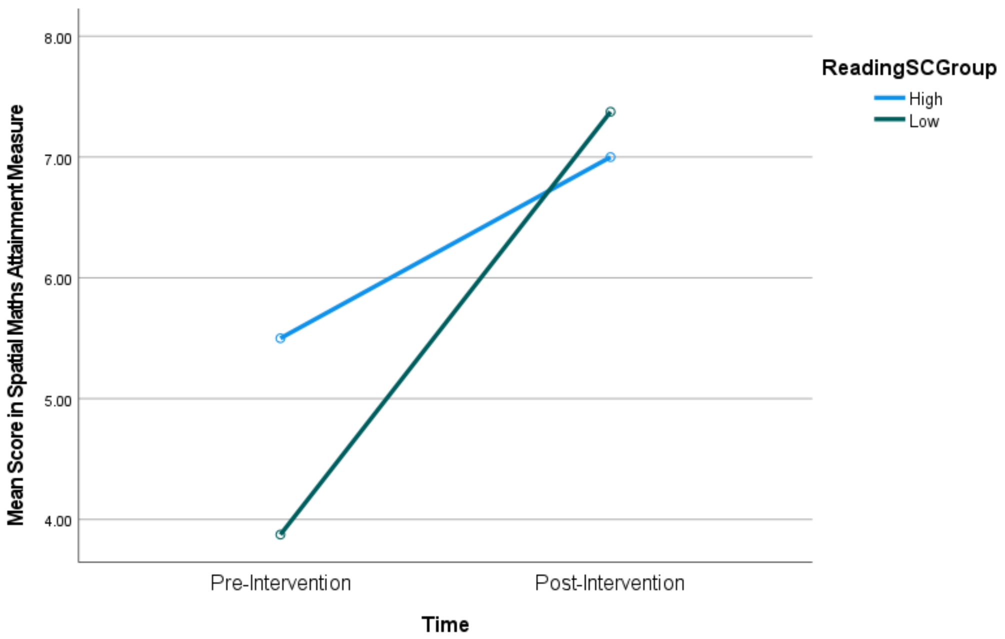
| *Reading Self-Concept Quartile* | *N* | *Pre-Intervention* | | *Post-Intervention* | |
|---|---|---|---|---|---|
| | | *Mean* | *SD* | *Mean* | *SD* |
| *High* | 8 | 15.88 | 3.91 | 13.75 | 2.96 |
| *Low* | 8 | 21.63 | 5.18 | 22.00 | 6.98 |

Regarding the impact on spatial self-concept, there was a significant main effect of reading self-concept quartile group overall (*F* (1,14) = 13.555, *p* = .002. However, no significant main effect of time was found (*F* (1, 14) = .298, *p*= .593. However, no significant interaction between reading self-concept group and time was found (*F* (1,

14) = .609, *p*=.448). On the other hand, regarding the impact on spatial maths attainment, there was no significant impact of reading self-concept group overall (*F* (1,14) = .222, *p* = .645). However, a significant main effect of time was found (*F* (1, 14) = 20.588, *p*<.001). However, no significant interaction between reading self-concept quartile group and time was found (*F* (1, 14) = 3.294, *p*=.091). Whilst no significant interaction was observed from the ANOVA, an tentative interaction can be seen from studying graphical data (see Figure 7. Below).

**Figure 7**

*Maths Attainment Score comparison between High and Low Reading Self-Concept Quartiles measured at two different time intervals, Pre- and Post- Intervention*




**Phase 2 – Process Evaluation of the Spatial Skill Intervention**

The process evaluation was designed to tap the experiences and views of the participants who received the intervention. The procese evaluation questions (PEQs) and associated verbal prompts can be found in Chapter Two section 2.2.4.

The first research question whicb was explored with participants, focussed on implementation and the barriers and facilitators of delivery. This question yielded different views and opinions about the research programme, which is outlined in the section below. The second inductive theme explored with participants was that of the perceived impact and outcomes of the spatial skills intervention by participants, and the associated perceived mechanisms that brought about any such change. The research questions were linked to associated research questions PEQB, PEQC and PEQD. Several themes emerged from this research question, and will be presented in section 3.3.2.

***Implementation***

**Polarisation of Views.** The first evaluative question (PEQa) was "How well was the programme implemented and what are the barriers and facilitators of delivery?". The theme that emerged from the data was varied across participants who evaluated their experiences in different ways. This theme was named 'Polarisation of Views'. Ten of the 12 participants (a majority of 83%) evaluated their experience of the intervention programme positively. For example, two participants reported:

> *"I don't think anything could be better really because I really enjoyed them."* (Participant 5)
>
> *"I think they were quite fun, because when you understand something, it becomes more fun."* (Participant 7).

On the other hand, some participants shared a different, more negative, view of the programme. Here are two examples:

> [I found the intervention] *"Kind of boring, when I don't get something, it just gets boring like this."* after which the participants clicked her fingers.  (Participant 12).

“*Some lessons I find boring because I already know them*.” (Participant 11).

Likewise, the teacher shared positive regard for the programme:

*“It was designed clearly, and there was a different focus for every week which the children enjoyed, and they knew what they were doing each week. Also, it was quite short which kept the kid’s attention. They’re obviously only 9 or 10, so their attention plan isn’t overly high. Um so I think the 20-minute sessions were useful, in that respect.”* (Teacher).

Throughout many of the interviews, participants struggled to construct responses and ideas related to changes that they would like to make regarding the intervention programme. For instance, three participants noted:

“*I thought the lessons were good anyway, I don’t think they needed anything more.*” (Participant 1)

“*I don’t really think anything, I can’t really think, I don’t really know*.” (Participant 5).

“*Errrm nothing really, no not really*.” (Participant 12).

There were some barriers identified by participants, but they were mostly related to sessions that the individual found difficult themselves and the associated materials. For example:

“*At first, I struggled with the symmetry, and the questions on that because yeah, and at first, I struggled with the maps because I would look at the lines and I didn’t know which way they were going?”* (Participant 7).

[I would like] *“Maybe more sessions on the mirrors and turning shapes.”* (Participant 3).

"*I wish we spent more time perspective taking or map reading*." (Participant 4).

Finally, there was an acknowledgement from some of the participants that small alterations to the learning materials and delivery of the sessions may improve the implementation of the programme:

*"I think what could have been better was the like words on the worksheets because they were really small words so they were a bit harder to read and get what you actually needed to do because it was only like one sentence so it was hard for me to understand like what actually are you asking, like you said this, but you haven't actually said how you are going to do it."* (Participant 9).

"*Maybe making things on the pictures like a little bit clearer, like making the lines darker, and using more things like blocks"* (Participant 1).

The range of different views related to this evaluative question made data saturation difficult. Nonetheless, there was a range of views and opinions were formed by the participants based on their experience of the programme. There were both positive and negative viewpoints related to quality of the implementation of the programme. Furthermore, different participants valued the quality and enjoyment of different intervention sessions, depending on their individual skills and differences. The subtheme of individual difference is evaluated in the following section.

**Perceived Impact and Mechanisms**

Participants expressed a range of different viewpoints and reports of experience of the programme, which have been organised into the following three superordinate themes: 'The Dynamic Nature of Spatial Skills', 'Transfer', and 'New Perceptions'. Table 18 presents each theme and associated subtheme, with an accompanying descriptor.

**Table 18**

*Perceived Impact and Mechanisms of Spatial Skills Intervention Themes and Subthemes*

| 1) The Dynamic Nature of Spatial Skills | 2) Transfer | 3) New Self Perceptions |
|---|---|---|
| The idenftification of spatial skills as a dynamic, non-static, group of individual subskills, in which individuals have varying profiles. | Acknowledgement from participants of impact on other areas of functioning separate to spatial skills following engagement in the intervention. | Identification from participants of a change in understanding and knowledge regarding spatial abilities. |
| **1a) Hands of Nature of Spatial Skills:** Valuing of the use of materials and heuristic approaching in the intervention programme. | **2a) Transfer to Maths:** Participants identifying improvements in their maths abilities following engagement in the programme. | **3a) Perception of Change:** Participants describing improvements in abilities following participation in the intervention programme. |
| **1b) Fragmental Nature of Spatial Skills:** Idenitifcation of spatial skills as a group descriptor of a set of different skills, opposed to a holistic construct. | **2b) Transfer to Literacy:** Participants acknowledging increases in their literacy abilities after intervention participation. | **3b) Identification and Understanding of a Novel Set of Skills:** Participants reported a new found understanding of their own abilities, in a form of functioning of which they were previously unaware. |
| **1c) Variations in Spatial Skill Profiles:** An recognition of varitation in ability of participant's skills in subskills (e.g., good at mental rotation & poor at spatial visualisation), leading to a development of a individual profile of skills by participants. | **2c) Transfer to Other Activities:** Any other improvements in skills that participants identified, including map-reading and video gaming. | |

**Theme 1: The Dynamic Nature of Spatial Skills**

The final theme 'the dynamic nature of spatial skills' refers to a perception of spatial skills as not a static, holistic set of skills, but rather a group of individual subskills in which individuals can have different aptitudes. Likewise, a value was observed by participants in the heuristic, hands-on nature of the programme and subject of spatial skills. The final theme comprised of subthemes ‘hands-on nature of spatial skills’ and the ‘fragmental nature of spatial skills’.

***Hands-on Nature of Spatial Skills Subtheme (1a)***

Many participants valued the consistent and regular use of materials and heuristic approaches to learning that were intentionally adopted throughout the intervention programme. For example, one participant reported:

> *“We didn’t just have to like for 15 minutes just write something down, we got to do it as a whole class, and see what we did and improve on it. Especially with like building the cubes and that, because it was hands on rather than just watching someone else do it.” “I find hand on more fun because you can see a lot more how you can improve like if you have another go you can see what you did wrong better.*” (Participant 10).

> [The sessions were fun because] *“you always had something to do, you weren’t just sitting there staring at a whiteboard.”* (Participant 2).

> [The sessions] *were pretty easy because of like all of the support, mirrors and cubes, it was actually pretty easy because you could see what colours there were and you could kind of like make things out of them and draw them on the sheet to see how they look like from underneath, top side back.* (Participant 3).

This view was shared the teacher too:

*“100% the physical resources, being able to move things, turn things around. We tell them to try and visualise things, but if they haven’t seen how to do it, how can they?*

*It has definitely given me ideas about how to teach these topics in the future."* (Teacher).

***Fragmental Nature of Spatial Skills Subtheme (1b)***

Following engagement in the intervention programmes, one key message relayed by many of the participants was the notion that Spatial Skills, rather than a holistic set of skills, were rather made up on many small subskills. For instance, participants reported that:

> *I don't think I'm the best at spatial skill because I still need a lot more practice, mainly with the perspective taking. I think I'm also pretty good since how I feel like how I can quickly rotate a shape in my mind without the physical block being there.* (Participant 10).

> *"So the things I can do as well and the mirrors and the line of symmetry, but one of the things I find the hardest is the rotation things, because mainly most of them look the same but some of them aren't."* (Participant 3)

> "*I can master most spatial skills."* (Participant 9).
> *"I know that im like okay at rotating shapes but not so good at like drawing them."* (Participant 8).

***Variations in Spatial Skill Profiles Subtheme (1c)***

Finally, participants spoke of their individual differences in relation to their personal spatial skill profiles, for instance, their varying patterns of strengths and difficulties. They identified new self-perceptions related to their understanding of their aptitudes in different tasks. For example, this participant recognises their strengths with tasks involving symmetry, but perceived challenges with mental 3D rotation:

> *"So, the things I can do as well and the mirrors and the line of symmetry, but one of the things I find the hardest is the rotation things, because mainly most of them look the same but some of them aren't."* (Participant 3).

This participant recognises their difficulties with spatial visualisation:

> *"I don't think I'm the best at spatial skill because I still need a lot more practice, mainly with the perspective taking. I think I'm also pretty good since how I feel like how I can quickly rotate a shape in my mind without the physical block being there."* (Participant 10)

*The following quote shows that this participant was aware of what they understood in relation to spatial skills covered during the intervention sessions, whilst also acknowledging that there were aspects of learning about which they were not yet secure:*

> *"Because half the things I was good at, whereas the other half of things I was not good at."* (Participant 6).'

**Theme 2: Transfer**

The final theme 'transfer' refers to an acknowledgement by many of the skills in which participants learned and practiced in the spatial skills intervention may have additional subsequent impact upon their attainment in other areas. The next theme is focussed around these areas, comprised by the subthemes, 'transfer to Maths', 'transfer to Literacy', and 'transfer to other skills'.

***Transfer to Maths Subtheme (2a)***

Most participants identified that many of the skills learned and practiced throughout the spatial skills intervention programme were either directly related to maths, or that newfound abilities and aptitudes in spatial skills may impact upon their future maths attainment. For example, one participant spoke about the impact it may have on their maths skills:

> *"I think has especially helped with maths, because I've never been good at shape in maths so doing some of that 3D mental rotation actually helped me with my shapes, because when you do 3D it kind of helps you with 2D because 3D is going to be harder, so if you master 3D, you can easily do 2D." "I think doing spatial skills actually helped me understand maths and other bits in maths helped me understand it more, so it helped me get the hang of it. It will still be a bit tricky obviously, but I think that I will get the hang of it a bit better now.*" (Participant 9).

> *"Maybe in maths there might be a question about perspectives. Maybe when I am playing with my friends. We might play a game that involves spatial skills*." (Participant 6).

> *"It can help with my technique in learning maths, it could be like a way to remember erm like er how to work out other questions. It could be like an easier way."* (Participant 5).

There was a wide agreement that spatial skills were linked to maths:

> *I am not that good at Maths. Maybe* [it has helped] *in symmetry, I never used to really get symmetry, I tried doing it at home and never really got it, but I tried now, and I think that I got it now.* (Participant 7).

Equally some participants explicitly referred to spatial skills as maths skills:

> *"I just quite enjoyed doing them, I am not really sure why. I just enjoy doing maths really."* (Participant 6).

***Transfer to Literacy Subtheme (2b)***

There was also an identification from some participants (six of twelve) that it may support them in English lessons. For example,

> "*The main thing is the writing because it helps with my handwriting and to get my pen license."* (Participants 11).

> "*If you were like in English or something, and you were given something that you had to move, then like you could just move it in your head instead*." (Participant 2).

That notwithstanding, many of the responses were related to the linguistic skills used to communicate knowledge that may be required in English lessons.

> *"English like when you're trying to see someone's perspective and give them directions?"* (Participant 10).

> *"I think English maybe because, sometimes in English tests or reading tests they might ask, okay so what spatial skill might this person be using. So, I think they might help me in the future."* (Participant 7).

***Transfer to Other Activities (2c)***

Finally, there was a reflection from many participants that the spatial skills intervention programme may support them in activities beyond subject domains in school, such as maths and literacy. Reflection on spatial skills used outside of the classroom environment related mainly to video gaming and map reading:

> *"Maybe like a mystery game where we are trying to solve a mystery. Like if we pretended there was a criminal, and they've got like a camouflage on the lock, and you have to use your spatial skills to know which box it is in."* (Participant 6).

*“Like in maths, um games sometimes, like video games pause, like a game where there’s like blocks in, like Minecraft or something.” (Participant 8).*

*“When you go onto your phone to use maps you’re using a spatial skill, if you go into your bedroom and look for something you’re using a spatial skill and when you play on video games you are using a spatial skill.” “Personally, I think like, looking at other points of view, like if I was with my friends and they were looking at something I would try and imagine their point of view and try and see what they are looking at.”* (Participant 7).

*“Probably map reading because I do that at my scout group, so I found that a bit easy because for the past 3 weeks I’ve been learning about map reading, and then you did it with us, so it was easier.” “Most of them were activities we do in school but not regularly. But it’s not something you do every day in school, but with these it did tell me a lot more about how spatial skills work.”* (Participant 9).

**Theme 3: New Self-Perceptions**

All participants in the process evaluation reported a newfound understanding about spatial skills,in general and also, their individual spatial skill set. The final theme is focussed on this, comprising the following subthemes: ‘perception of change’, ‘identification and understanding of a novel set of skills’, and ‘individual differences’.

***Perception of Change Subtheme (3a)***

There was an identification from most participants (ten of 12), that there was a positive improvement in their ability to complete tasks that had been focused on in the spatial skills intervention. Participants had a new self-perception in their spatial abilities. However, there were variations in the nature of change reported. Participants reported a range of perceived improvements in different subskills related to spatial abilities. Examples of quotes have been organised related to the following subthemes: ‘mental rotation’, ‘spatial orientation’, spatial visualisation’ and ‘general spatial improvement’, and are presented below:

Spatial Orientation Subtheme:

> *“Before every time we would read a map, I would have no idea where we were, I couldn’t read a map at all, but now I can read a little bit of a map.”* (Participant 10).

Mental Rotation Subtheme:

> *“Quite good, because first I didn’t quite know how to move things in my head but now, I feel quite good at it.”* (Participant 2).

Spatial Visualisation Subtheme:

> *“Looking at other points of view, like if I was with my friends and they were looking at something I would try and imagine their point of view and try and see what they are looking at.”* (Participant 7).

General Spatial Improvement Subtheme:

> *“I think a bit more about spatial skills because I didn’t really know much about spatial skills before, but now I feel like I know more.”* (Participant 1). general

***Identification and Understanding of a Novel Set of Skills Subtheme (3b)***

Participants also often identified that Spatial Skills were a set of skills which they did not know they had, or were using:

> *“I think a bit more about spatial skills because I didn’t really know much about spatial skills before, but now I feel like I know more.” “I learnt that I am actually very good at spatial skills because like I said before I had no idea what they were*

*before but now I feel like I understand it a lot more because I actually know what they are, I know when I am using them and it's just a lot easier."* (Participant 9).

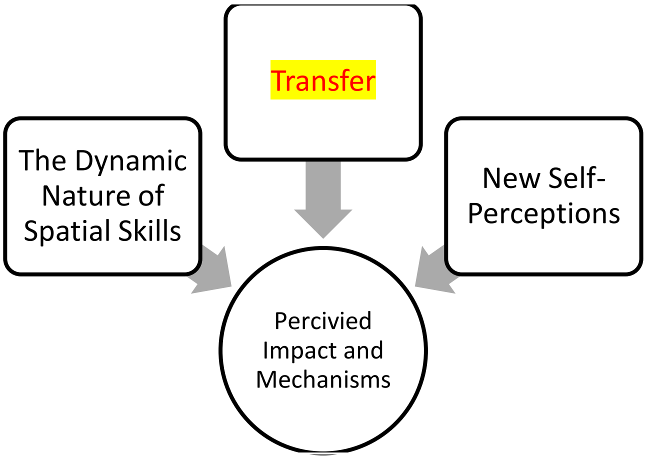
*"I didn't really know spatial skills were a thing before, so I think that I have learned a lot more about them."* (Participant 7).

*"Well, I think it's just because I have mainly been learning and I have begun to learn more about them, because I hadn't really heard about them before. I don't think I have really heard about them before."* (Participant 5).

Figure 8 demonstrates the thematic map which was developed which illustrates the inter-relationships between themes. All of the themes reported above relate to the perceived impact (and related mechanisms) that the intervention had brought about change upon the participants understanding and ability to complete spatial tasks. This means that each theme contributes to the overall inductive theme of perceived impact and mechanisms.

**Figure 8**

*Perceived Impact and Mechanisms of the Spatial Skills Intervention Programme Final Themes*



# Chapter 4

## Discussion

This discussion section is divided into subsections based upon each phase of the research project, and their associated research aims. Additionally, each of the research questions which were outlined in Chapter 2 will be evaluated with reference to the related hypotheses, to analyse and interpret the findings. Then I will outline the strengths and limitations of the research project and address potential directions for future research and the implications for professional educational psychology practice.

### Development of the Spatial Self-Concept Scale

*Research Aim One:* To develop a brief measure of spatial ability self-concept with good criterion validity and internal reliability for year 4/5 pupils (aged 9 to 10-years-old) in mainstream primary schools. The research questions related to this research aim were as follows:

*RQ1:* Does the novel self-concept measure show satisfactory reliability and validity, in relation to internal consistency and test-retest reliability?

RQ1 evaluated the reliability of the spatial self-concept measure. The novel spatial self-concept measure was based upon the Self-Description Questionnaire (SDQ-I) (Marsh, 1990). It shared similarities with the measure including both the wording and the order of the items. Reliability refers to the consistency or reproducibility of scores from one assessment to another (Cook & Beckman, 2006). Two statistics were used to determine the reliability of the measure, Cronbach's alpha for internal consistency and Spearman's rho correlation coefficient for test-retest reliability. Data collected demonstrated that the internal consistency of the measure was good (α= .858). Equally, the test-retest reliability of the measure was demonstrated by a strong correlation between scores obtained following a two-week gap (*r*= .865). Taken together, these statistics suggest that these measures are a suitably reliable measure. These findings are in line with similar ones made by Marsh (1990) when he validated his scale. Marsh (1990) reported good internal consistency reliability estimates for each of the individual self-concept and total scores (.80≥α≥.94). As such, this data demonstrates that Hypothesis 1 has been confirmed and the new scale is reliable. Furthermore, this allows for subsequent hypotheses to be tested, using the spatial self-concept scale.

**Relationships Between Subtypes of Self-Concept**

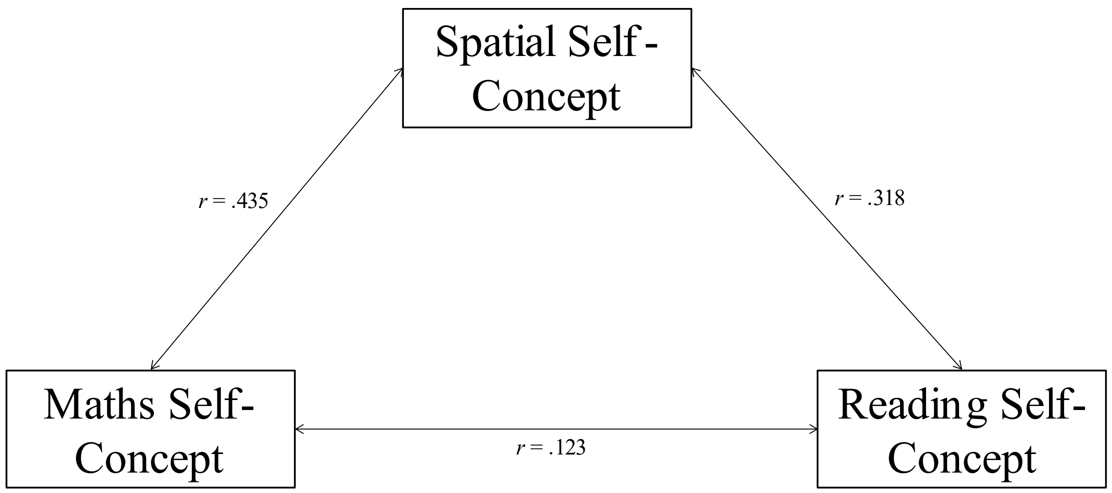
*Research Aim Two:* To explore the relationships between spatial self-concept and other academic self-concept measures (reading, maths & general academic ability) in year 4/5 (aged 9 years and 10 years) pupils in mainstream primary schools in the UK. The research questions related to this research aim were as follows:

*RQ2:* What is the nature of the relationships between spatial self-concept and other aspects of academic self-concept, specifically maths self-concept and reading self-concept?

Data collected demonstrated varying correlations between each measured subtype of self-concepts. Figure 9. below visually presents each of the correlation coefficicents. The following section discusses each of the three correlations in order, and the implications it has for the existing literature.

**Figure 9**

*Summary of the Spearman's Rho Correlation Coefficicents Between Each Subtype of Self-Concept*




***Maths Self-Concept and Reading Self-Concept***

This study replicated the correlational relationship between maths self-concept and reading self-concept initially reported by Marsh (1990). Marsh (1990) found that all the correlation coefficients between each of the individual measures of self-concept (e.g., maths, reading, physical ability, peer relations and parent relations) were relatively low (r= .17). Similarly, in this study there were low correlations between maths self-concept and reading self-concept observed (*r*=.123, *p*=.101), as predicted in hypothesis 2c. This supports Marsh's (1990) conclusion that the individual measures of maths self-concept and reading self-concept are distinct from one another. Additionally, it provides more evidence for the Shavelson et al. (1976) conceptualisation of self-concept as a multidimensional model. If self-concept was unidimensional, in other words individuals have a linear view about themselves related to all aspects of life, then you would expect a strong correlation between maths self-concept and reading self-concept. This would be due to all self-concepts being influenced from the same root self-concept value. If this were the case, global self-concept would be the root perception of self from which all other self-concepts were evaluated (i.e. an individual with low global self-concept would consistently have low maths and reading self-concepts, and one with high global self-concept would consistently have high maths and reading self-concepts).  This effect was not observed in Marsh's (1990) original findings, nor in this study.

***Spatial Self-Concept and Maths Self-Concept***

In contrast to the relationship between reading and maths self-concepts, a significant relationship was observed between spatial self-concept and maths self-concept. The Spearman's rho correlation coefficient indicated a statistically significant moderate positive linear relationship between participant's 'spatial self-concept' and participants 'maths self-concept' scores, ($r$=.435, $p$<.01), confirming the expectations outlined in hypothesis 2b. The literature into spatial abilities clearly established the mediatory role it plays performance in maths-based tasks (Lowrie et al., 2017). Those who demonstrate aptitudes in relation to spatial abilities, usually perform better in maths tasks (Lowrie et al., 2017). Furthermore, an individual's level of underlying spatial ability is highly predictive of future maths attainment (Holmes et al., 2008; Rasmussen & Bisanz, 2005). As such, it is unsurprising that individuals that perceive themselves to perform better on spatially-based tasks, also perceive themselves to be perform better in maths tasks. The Reciprocal Effects Model (REM) suggests that previous academic attainment leads to boosts in academic self-concept (Marsh, 2011). The REM could explain the correlation between maths and spatial self-concept. It is likely that the participants score higher in a measure of spatial self-concept because they do have underlying aptitudes in spatial tasks. Therefore, these aptitudes give them a cognitive basis to perform better in maths tasks, which in term boosts their self-concept related to maths. Figure 10. is a visual representation of the reciprocal effect between the two domains.

**Figure 10**

*The Dual Reciprocal Effects Model of Maths and Spatial Self-Concept*

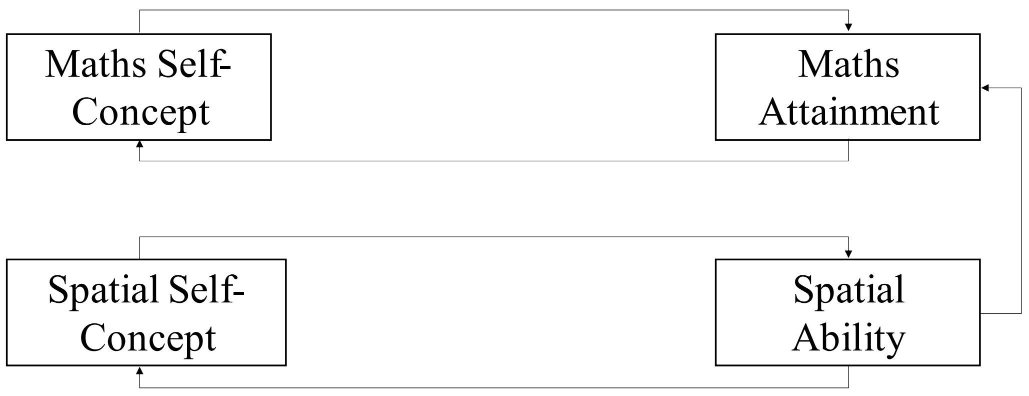



Figure 10 visually demonstrates the expected reciprocal relationship between maths self-concept and maths attainment, and spatial self-concept and spatial ability. Additionally it incorporates research that demonstrated clear links between spatial ability and maths attainment (e.g., Holmes et al., 2008), for instance that individuals with high spatial ability tend to achieve more highly in maths. Within this model, spatial self-concept and maths self-concept are not directly related or connected, but spatial skills play a mediatory role in supporting maths attainment. This model offers a potential explanation for the correlation between the two domains observed in the data.

Whilst model provides one explanation for the correlation observed, there are some possible alternative hypotheses. Marsh (1990) argued that the lack of correlation between the individual items on the SDQ-I (r=.17) was an indicator that individual self-concepts were distinct from one another. The moderate positive correlation found between the spatial self-concept and maths self-concept could be interpreted as evidence that spatial self-concept and maths self-concept are not adequately distinct. In other words, spatial self-concept and maths self-concept are so closely linked that they are conceptually inseperable. Likewise, the video which was developed to describe and inform participants about the nature of spatial skills included visual examples of two maths-based tasks (net of solids activity and symmetry activity), potentially suggesting to participants that spatial abilities and maths attainment are interlinked. It could be argued that participants may have had experience engaging in these specific tasks in maths lessons and for that reason, view spatial tasks as conceptually similar to maths tasks. Nonetheless care was taken in the design of the video to detail a range of spatial based tasks (including two non-maths based tasks, such as video games) to try and correct for these effects.

It is important to consider the nature of the correlational relationship between maths self-concept and spatial self-concept in the context of Shavleson et al.'s (1976) hierarchal and multidimensional model. If spatial self-concept is a distinct but related self-concept domain to maths, it raises the question of where spatial skills, or indeed any cognitive skill self-concept (e.g. memory self-concept, processing speed self-concept) sit within such a model. This will be revisited and discussed later in this section.

### ***Spatial Self-Concept and Reading Self-Concept***

The Spearman's rho correlation coefficient indicated a statistically significant moderate positive linear relationship between participant's 'spatial self-concept' and participants 'reading self-concept' scores ($r$=.318, $p$<.01). This means that the expectations of hypothesis 2b have been met. Reading and spatial ability have also been shown to be associated, with individuals with high spatial abilities often sharing aptitudes in reading (Giovagnoli et al., 2016). The casual link of this effect has been suggested to be due to spatial abilities being involved with decoding and symbolic recognition skills (Giovagnoli et al., 2016). As previously mentioned, the REM suggests that previous academic attainment leads to boosts in academic self-concept (Marsh, 2011). The REM could again explain the correlation between reading and spatial self-concept. It is likely that the participants score higher on a measure of spatial self-concept because they have underlying aptitudes in spatial tasks. Therefore, these aptitudes underpin better performance in reading, which in term boosts self-concept relating to reading. This is a parallel effect to that shown with regard to maths self-concept, so the following model is proposed (see Figure 11).

**Figure 11**

*The Dual Reciprocal Effects Model of Reading and Spatial Self-Concept*

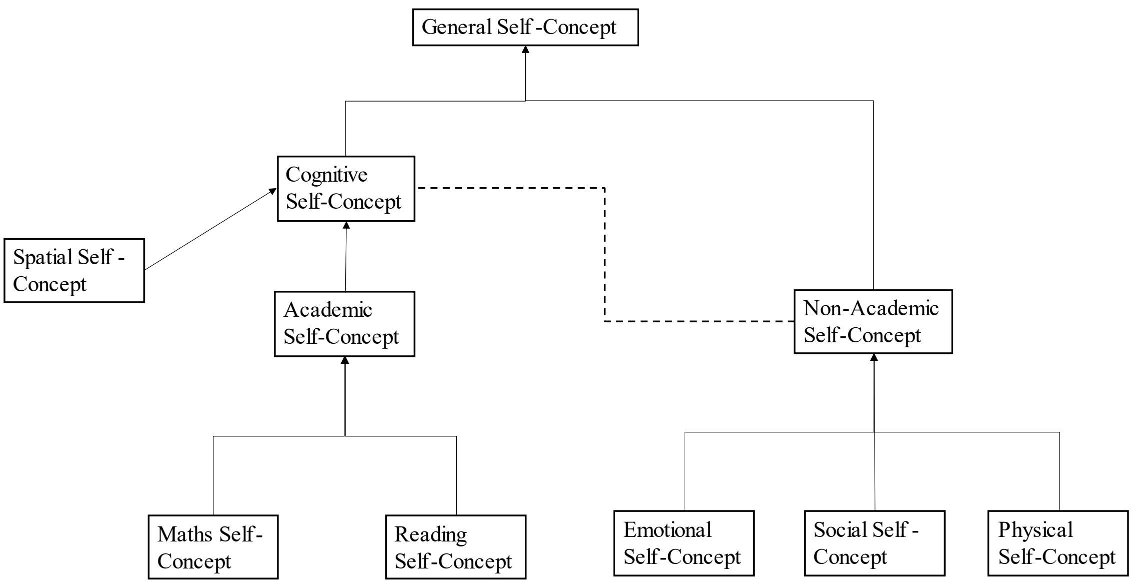

The results provide more evidence of the mediatory role that spatial ability may have in linking spatial self-concept with reading self-concept. The data showed a slightly stronger correlation of maths self-concept ($r$= .435) compared to reading self-concept ($r$=.318), with spatial self-concept. These means that hypothesis 2d has been met. This finding is in line with the stronger body of evidence showing links between spatial attainment and maths attainment, compared with spatial attainment and reading attainment (Uttal, Meadow et al., 2013). Perhaps most interesting of all is that despite correltions between spatial self-concept and maths and reading self-concept, there was no correlational relationship between reading self-concept and maths self-concept, either in the data gathered as part of this research study, or in previous research (e.g., Marsh 1990). I will now discuss the implications of this observation within the context of the multidimensional and hierarchal conceptualisation of self-concept proposed by Shavleson et al. (1976).

***Implications for the Shavelson et al. (1976) Hierarchical Model of Self-Concept***

The Shavelson et al. (1976) model of self-concept posits a segmented view of different forms of self-concept (see Introduction and Figure 1 for details). All self-concepts are hierarchically organised, with general self-concept at the apex, and some types of self-concept, such as academic and non-academic self-concept, separated and distinct within the model. Spatial Skills refers to an overarching set of skills that help to navigate and interpret the world, with clear transfer effects into performance in maths tasks (Lowrie et al., 2017) and reading ability (Giovagnoli et al., 2016). I would argue that spatial self-concept, as a domain specific concept, raises a difficult question as to where it would sit within the Shavelson et al. (1976) model. The challenge that spatial self-concept brings is that this underpins different domains of functioning, which makes it is impossible to assign as a purely academic self-concept.  In this study, spatial self-concept was correlated with both maths self-concept and reading self-concept, yet neither maths self-concept nor reading self-concept were correlated with one another. Another example that challenges the positioning of spatial self-concept within the Shavelson et al. (1976) model comes from video games. Spatial skills play a key role in mathematical cognition (Lowrie et al., 2017), but have also been shown to be linked to performance in video games (Milani et al., 2019). Maths self-concept clearly sits underneath academic self-concept in the Shavelson et al. (1976) model, whereas I would argue that video game ability (or self-concept) is more closely linked to non-academic self-concept. This suggests that the Shavelson et al. (1976) model will need to be modified to incoprporate spatial self-concept. Figure 12 is a visual representation of the newly proposed hierarchal model. A key difference between this and Shavelson et al.'s original model is an overarching self-concept domain sits above academic self-concept within the model, linked to cognitive self-concept. The addition of cognitive self-concept would take into account the values and beliefs an individual holds about their overall cognitive ability, that extend beyond academic self-concept. Some individuals may refer to themselves as not “book-smart”, evaluating themselves critically in academic terms, but still have aptitudes related to other cognitive skills, such as spatial skills. This conceptualisation would allow for values and beliefs about other cognitive skills to be taken into account, including, but not limited to, spatial self-concept, memory self-concept and processing speed self-concept. Under this conceptualisation, non-academic self-concepts, such as the emotional self-concept and social self-concept domains outlined by Shavelson et al. (1976) would also be linked to cognitive self-concept.

**Figure 12**

*The Interactionist Hierarchical Model of Self-Concept*



This proposed hierarchical model of self-concept provides a more interactionist stance and considers how different domains in self-concept may be interlinked. This model provides a visual conceptualisation of how spatial self-concept may be linked to academic self-concept, and thus reading and maths self-concept. As such it would explain the relationship between spatial self-concept, maths self-concept, and reading self-concept observed in the data. Other self-concepts linked to cognitive skills, for instance memory, would sit in a similar position to spatial self-concept. Memory is likely to have a similar role to spatial skills within the self-concept hierarchy, as like spatial skills, it has been shown to be malleable following training (von Bastian et al., 2019), and linked to performance in other cognitive abilities such as maths (Szczygiel, 2021). Similarly, memory has been shown to play an important role in developing effective social interaction and communication skills (Spreng & Mar, 2012), and individuals with aptitudes in memory have been shown to have improved social cognitive abilities (Ferreira & Adleman, 2020). Whilst there is no empirical evidence for a link between the newly developed domain of cognitive self-concept, a theoretically link is plausible, as there is crossover between some cognitive skills and non-academic tasks.

This new conceptualisation of self-concept primarily provides a new first-order domain of self-concept, cognitive self-concept. Nonetheless, it is important to base this theory within more recent research on the structure of self-concept. Marsh et al. (2012) argued that self-concept may be better measured at a level of consistency which is more consistent with specific issues (in the case of this research, spatial self-concept). However, Marsh et al. (2012) also noted that self-concept should be considered in parallel with more general measures of self-concept, in which cognitive self-concept could be considered as. Even should the Shavelson et al. (1976) model of self-concept be considered over-simplistic in its conceptualisation, the new model I have posited considers the interactional relationships between sub-types, which could be linked through a higher order, cognitive self-concept.

In summary, under this conceptualisation there would be three kinds of classification of self-concept. First, academic categories, such as maths, literacy and science self-concepts. Additionally, there would be non-academic classifications, such as social, emotional, and physical self-concepts. Finally, the third classification would be psychological categories related to psychological functioning (i.e., cognitive self-concept), including spatial, memory and motivation self-concept. I propose that these three classifications are interrelated, but distinct, similar to the distinction which Marsh (1990) originally proposed.

## Impact of the Novel Spatial Maths Intervention

*Research Aim Two:* To investigate whether short weekly intervention sessions focussing on different spatial skills can impact upon spatial ability, maths attainment, spatial self-concept, and other academic self-concepts, specifically, maths self-concept and reading self-concept. The research questions related to the quantitative data collection are as follow:

*RQ3*: How effective is the novel spatial skills intervention programme at improving spatial skill maths attainment and spatial self-concept, compared to a control group?

### *Improving Spatial Skill Maths Attainment*

The spatial ability training programme was associated with an improvement in spatial skill maths attainment, indicated by the significant interaction between time and whether the pupil was in the intervention or control group. This indicates that the spatial ability training programme was effective at improving spatial maths attainment in the intervention group following engagement in a 10-week spatial skills intervention programme, where there was no significant change amongst the control group. This provides further evidence supporting the malleability of spatial skills. Previous research has also found improvements in spatial ability following engagement in short weekly intervention sessions (Uttal, Meadow et al., 2013; Lowrie et al., 2017), interventions that partically informed the content of the programme developed.

But was this change due to practice effects? Practice effects are "improvements in cognitive test performance due to repeated evaluation with the same test materials" (Duff et al., 2007, p. 15). Whilst the same measure was reused for pre- and post-measures (with a 10 week gap between administration), it is unlikely the improvements in spatial maths attainment performance were due to practice effects for two reasons. First, participants were not given the correct answers to the questions on the spatial maths attainment, so they would not have been able to practice the test and recall the correct answers between the measurement points. Second, the use of a control group in this quasi-experimental research design, provides robust evidence to attribute the improvements in spatial maths attainment to the novel spatial ability training programme. If practice effects were present, then the control group would be expected to demonstrate similar improvements in spatial maths attainment scores as observed in the intervention group.

Whilst the results from the spatial maths attainment measure provides evidence of an improvement in spatial maths attainment, it is also important to consider alternative explanations for the increase in performance. One possible explanation is that engagement in the intervention, rather than improving spatial abilities or spatial maths attainment, simply provided participants with the understanding of what skills the questions on the measure required them to demonstrate. For instance, a participant may have never completed a question that asked them to rotate a cube and therefore did not understand what was being asked of them during the pre-measure. Whilst the intervention provided participants with opportunities to practice 3D rotation skills, they were also exposed to sample questions. The presentation of sample questions within the intervention session may have indicated what had to be done to answer a similar question. One could argue that rather than the intervention improving underlying spatial abilities, it provided participants with coaching in how to interpret and answer questions in the measure.

***Improving Spatial Self-Concept***

In contrast to progress in spatial maths attainment, there was no significant improvement in spatial self-concept. No significant interaction was found between time and intervention group, thus failing to provide evidence that the novel spatial ability training programme was effective at improving spatial self-concept in an intervention group compared to a control group. There was no significant difference between the scores reported by either control or intervention group at pre- or post-intervention. This result is not in line with the research hypotheses. Due to the REM of self-concept (Marsh, 1990), it was expected that improvements to aptitudes regarding spatially based tasks (as demonstrated in the improvement of spatial maths attainment scores), would be associated with an increase in students' overall spatial self-concept. Previous research investigating the impact of reading interventions on reading self-concept yielded significant improvements (Higgins et al., 2015). Nonetheless this effect has not been observed in the case of spatial skills. Whilst there is no evidence to suggest that spatial skills training programmes can impact upon spatial self -concept, there are a few possible explanations to why a significant effect was not detected.

One explanation is that the engagement in the research programme may have resulted in a change in participants' thoughts and feelings regarding their own spatial ability, but not in a unidirectional manner. Engagement in the programme may have resulted in participants understanding more about what spatial skills are, and about the tasks where they are used. It is possible that some participants discovered that they are have good spatial abilities following engagement in the programme. However, some may have found the spatial tasks much harder than they were expecting. It could be argued that these different positive and negative experiences may have influenced some participants to rate themselves higher in spatial self-concept, whereas others may have rated themselves lower. Individual positive and negative experiences and events influence upon the construction of self-concept within the Shavelson et al. (1976) model of self-concept. Thus the direction of participants' self ratings varied (some positively, some negatively) which may have resulted in an overall non-significant change in spatial self-concept at the group level, despite possible changes at an individual level - a multidirectional effect. There was a strong correlation between the pre- and post-intervention spatial self-concept scores in the control group ($r$ = .734), which was congruent with the test-retest data obtained in Phase 1 ($r$= .865). However, in the intervention group, the correlation between pre- and post-intervention spatial self-concept scores was only modertate ($r$ = .526). This provides some evidence, that those in the intervention group were more likely to change how they rated themselves regarding spatial self-concept. Furthermore, there is some evidence from the process evaluation about different positive and more negative experiences reported by the participants following engagement in the spatial ability training programme. There was no consistent positive message from participants about their experiences of the programme, both from the programme, and from the individual sessions. There is some evidence of a similar effect reported by Stallard et al. (2012). They studied participants identified at high risk of depression who received weekly cognitive behaviour therapy (CBT) in schools. The researchers found that participants were more likely to report greater depressive symptoms 12 months after engagement in the programme. They attributed this to the development of greater understanding and self-recognition of depressive symptoms and negative thinking styles over the course of the intervention. In the current study, engagement in the spatial skills programme may have resulted in greater participant self-recognition of their own strengths and weaknesses in this area of functioning, which will have led to a wider range of responses on the post-intervention measures.

Another possible explanation for the absence of an effect in spatial self-concept is simply time. It may be that the post-intervention measures were conducted too close to the end of the intervention programme. Whilst there was a short-term impact upon spatial maths attainment, it may take time for these skill improvements to manifest in performance in other spatial tasks. Over a longer period of time, participants may find the new skills they have developed from engagement in the programme support them in spatial tasks in other areas of life, and lead to subsequent improvements in spatial self-concept. This is speculative however as there is no evidence for this hypothesis that can be derived from the data. This could be explored in future research, by collection of follow-up data at three or six months post-intervention.

***Impact on Maths and Reading Self-Concept***

There was no significant effect as a result of engagement in the spatial skills programme on improvements in maths self-concept. No significant interaction was found between time and intervention group, therefore there is a lack of evidence that the novel spatial ability training programme was effective at improving maths self-concept. There was no significant difference between the scores reported by either control or intervention group at pre- or post- intervention. As there was no impact of the spatial ability training programme upon spatial self-concept, it is unsurprising that there is also no impact upon maths self-concept. Maths as a subject involves people engaging in tasks that require a complex range of abilities such as attention, inhibitory control and working memory (Skibbe et al., 2011). Marsh (1990) also showed that maths self-concept generally remains static over time, so this study is consistent with that finding. However, engagement in the spatial skills programme may take a longer to influence changes in maths self-concept.

There was no significant effect as a result of engagement in the spatial skills programme on improvements in reading self-concept. No significant interaction was found between time and intervention group, therefore there is a lack of evidence that the novel spatial ability training programme was effective at improving reading self-concept. There was no significant difference between the scores reported by either control or intervention group pre- or post- intervention. As noted previously regarding maths self-concept, Marsh (1990) showed that reading self-concept generally remains static over time. Nonetheless, reading self-concept as a domain has previously been shown to be able to be influenced by targeted interventions. Higgins et al. (2015) used a similar quasi-experimental design to this research study to investigate the impact of a “Literacy Lift-Off” (a targeted reading intervention), delivered on a whole class basis. They found that the reading intervention led to statistically significant improvements on reading attainment and reading self-concept beliefs. The findings do not provide similar results in relation to reading, nor do they indicate  a similar relationship with regard to spatial self-concept.

**The Relationship between Self-Concept and Spatial Maths Attainment**

RQ4: Is there a significant relationship between student spatial and maths self-concept, and performance on the spatial maths attainment measure?

The findings from this research indicated weak positive correlations between both spatial self-concept and spatial maths attainment ($r$=.298), and maths-self concept and spatial maths attainment ($r$=.328), when measured pre-intervention. This demonstrates two key findings. First, that those with more positive thoughts and feelings around maths (i.e., with higher maths self-concept), tended, on average, to score more highly on the spatial maths attainment measure, than those with more negative cognitions (i.e., lower maths self-concept). There was a similar effect observed in spatial self-concept - those with higher spatial self-concept scored more highly on the spatial maths attainment measure, than those with lower spatial self-concept. This would have been expected based on the findings of RQ2, that maths self-concept and spatial self-concept are closely correlated and means that hypotheses 4a and 4b have been met. Two important conclusions can be drawn from this data. First, it provides more evidence for the REM model as proposed by Marsh and Martin (2011), showing an interlinked relationship between self-concept and attainment. Second, it provides tentative evidence for the criterion validity of the spatial self-concept measure. Criterion validity referes to a method of test validation on an scale correlates with an external, non-test criteria (Cohen & Swerdlik, 2017).

The justification for use of the spatial maths attainment measure as a suitable measure for spatial abilities was provided in Chapter 2. To map on to Cohen and Swerdlik's (2017) definition of criterion validity, the spatial self-concept measure is the 'scale' and the spatial maths attainment measure is the 'external non-test criteria'. Previous research has demonstrated the link between attainment and self-concept (Marsh, 2011). As spatial self-concept and spatial maths attainment are correlated, it could be argued that this is evidence that spatial self-concept measure is studying the phenomenon it is intending to (spatial self-concept). Additionally to the good internal consistency and test-retest reliability that had already been discussed, this provides more positive evidence for the quality of the novel spatial self-concept measure.

**The Impact of the Novel Spatial Maths Intervention on Participants with Low Reading Self-Concept**

*RQ5:* How effective is the novel spatial skills intervention programme at improving spatial skill maths attainment and spatial self-concept, for participants with low reading self-concept?

The comparisons between the high and low reading self-concept (of the intervention group) yielded no differences in improvements in either spatial maths attainment or spatial self-concept. This suggests that engagement in the research project did not allow those with reading difficulties to discover a previously unknown ability related to spatial tasks. Similarly, if those with reading difficulties had an underlying aptitude in spatial tasks, it would have been expected to see a greater increase in spatial attainment following intervention. This effect was not observed.

Therefore, this research provides no further evidence for the research which has previously demonstrated a link between spatial abilities and reading difficulties (e.g., von Karolyi et al., 2003; Burgoyne, 2010). Instead, the results are in line with evidence suggesting no such link is present (e.g., Winner et al., 2001). Nonetheless, there are some possible explanations for the lack of effect which was observed in the data. First, it may be that assuming those with low reading self-concept (as identified by being in the bottom quartile of reading self-concept) is an accurate measure of those with reading difficulties may be inadequate. The REM suggests that as reading attainment is interlinked with reading self-concept, therefore it was a reasonable assumption to draw. It is also worth noting that none of the intervention group had a diagnosis of a specific learning difficulty in reading. Nonetheless the true level of reading attainment cannot be guaranteed, and future research should consider evaluating reading attainment with a more accurate assessment measures as a comparison tool. Similarly, it is important to note that this analysis was only undertaken upon the data gathered for the intervention group. Furthermore, only the highest and lowest reading self-concept quartiles were compared, and therefore the sample size was halved. As such, a relatively small sample size was compared ($N$ = 16). It is possible that no effect was found due to insufficient power. Despite this, overall, these results provide no evidence that those with reading difficulties have any particular aptitudes or skills related to spatial abilities. Similarly, the quantitative data provides no evidence that the intervention programme led to those with reading difficulties identify a new, previously underknown skill or ability. Nonetheless, the idea of discovering a previously unknown ability was explored in more detail in the process evaluation.

**Process Evaluation**

The Results section reported the Phase 2 Process Evaluation, with themes and sub-themes illustrated with quotations and the provision of a thematic map. These findings will be discussed in relation to the existing literature on spatial abilities and self-concept, in the context of the process evaluation questions (PEQs):

*How well was the programme implemented? What are the barriers and facilitators of delivery?*

Overall, most participants evaluated their experiences derived from engagement in the spatial skills training in a positive way. Nonetheless, two of the eleven participants shared more negative experiences, noting the difficulty of the tasks as an explanation of why they did not enjoy it. Whilst it is difficult to draw conclusions, the teacher who was intereviewed as part of this research project also spoke positively about the programme and its implementation. Therefore, whilst it is difficult to make a judgement on the quality of the implementation of this programme, there was positive feedback from participants, providing an encouraging indication that this programme is an enjoyable one, that could be taken into consideration for extending its use to support children in developing spatial abilities.

*What were the perceived mechanisms which brought about change (if any) by participants following engagement in the spatial abilities training programme?*

The findings from this PEQ reported three key themes relating to perceived mechanisms of change following engagement in the programme, notably the dynamic nature of spatial skills, new perceptions of their own spatial abilities, and the transfer of their newfound spatial skill into other skills. I will now discuss each of these themes in relation to the research literature.

***Theme 1: The Dynamic Nature of Spatial Skills***

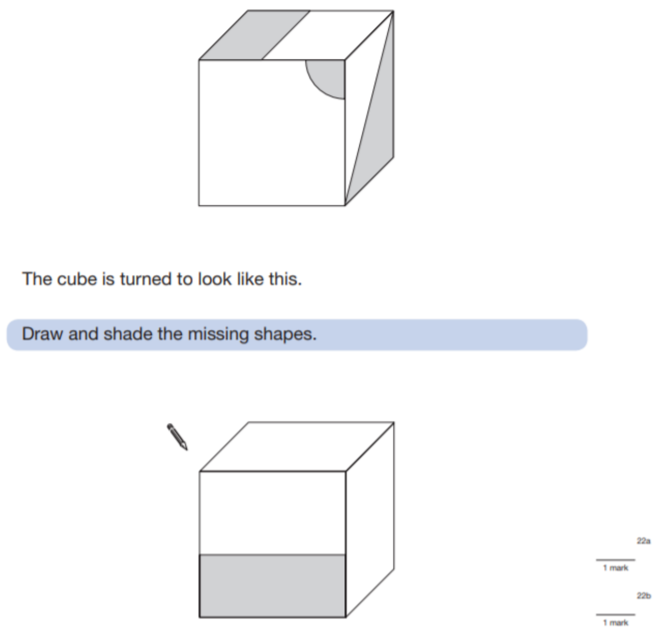
Participants valued the regular access to materials and heuristic approaches that was intentionally adopted throughout the intervention programme. This was done for two reasons. First, the intervention programme was designed to minimise demands on literacy skills, to control for any individual differences in reading attainment that could impact upon engagement in the programme. The use of concrete manipulatives in effective mathematics teaching is well documented. Both Piaget (1962) and Bruner (1964) outlined that concrete materials should be used to support younger learners when they begin to study abstract mathematical concepts. These materials allow teachers to represent abstract mathematical concepts with concrete manipulations. Carbonneau et al. (2013) conducted a meta-analysis which found that using manipulatives in mathematics instruction produces a small to medium effect size on student learning in comparison to instruction using abstract symbols alone. They also found that this effect was mediated by the use of instructional variables. They noted that,

> Instructional variables such as the perceptual richness of an object, level of guidance offered to students during the learning process, and the development status of the learner moderate the efficacy of manipulatives. The finding that specific instructional variables either suppress or increase the efficacy of manipulatives suggests that simply incorporating manipulatives into mathematics instruction may not be enough to increase student achievement in mathematics. (p 396).

Carbonneu et al. (2013) emphasise that whilst using instructional variables (e.g., manipulatives) are useful in mathematics instruction, it is important for them to be used in a directed and focussed way. The finding that participants valued the hands-on nature of the intervention may also guide a hypothesis to the positive impact of the spatial training intervention programme upon spatial maths attainment. Drawing on the Piaget (1962) and Bruner (1962) developmental frameworks, it could be argued that the use of materials in spatial training intervention programme allowed participants to understand how to relate an abstract mathematical concept to a concrete manipulation. This can be illustrated through the example of the 3-D mental rotation intervention session. The spatial maths attainment measure contained an item which required participants to shade the features of a cube, after it had been rotated. The question can seen in Figure 13 below.

**Figure 13**

*3-D Mental Rotation Item on the Spatial Maths Attainment Measure.*




During the 3-D mental rotation session, participants were given the opportunity to practice 3-D mental rotation tasks. They were given small wooden cubes with different shapes on them which they could manipulate and refer to, to answer the initial questions. Full details of the materials, procedure, and instruction used during the 3D mental rotation task can be found in Appendix E. In this case, participants were given manipulatives (the cubes provided) which were used to represent abstract concepts (rotating a 3-D cube such as Figure 13) in concrete representations. In this sense, the use of the concrete materials may have assisted the participants in developing the foundational mathematical concepts that has allowed them to follow up with improvements in spatial maths attainment performance in the post- measure scores.

The findings that participants valued the hands-on nature of the intervention provides further evidence that this approach is an effective and worthwhile approach for spatial ability training, especially in relation to specific spatial maths tasks. However, it is important to still acknowledge the importance of using adequate instructional variables. Future spatial interventions should make sure that the use of manipulatives is considered, and similarly that an appropriate level of guidance on how to use them to aid in learning is provided too.

Another identified subtheme related to the dynamic nature of spatial skills is the fragmented nature of spatial skills. This subtheme referred to the acknowledgement from participants that rather than spatial skills being a holistic concept that you are either ‘good’ or ‘bad’ at, they represent an overarching group of skills, which are made up of lots of different skills, in which individuals have varying aptitudes and profiles. For instance, some participants may perceive that they have strengths with mental rotation tasks but find that they struggle more when it comes to map reading or symmetry tasks. This idea that spatial abilities are made up of separate components is consistent with the literature. The different conceptualisaitons of spatial abilities were discussed in Chapter 1, where Figure 1 provides a summary of different conceptualisations mapped on to one another, alongside relevant skills, with examples of measures.  Some have argued that spatial abilities comprise three separate components: spatial visualisation, mental rotation, and spatial visualisation (Kozhevnikov et al., 1999; Linn & Petersen, 1985; Lowrie et al, 2017). Another conceptualisation was in a 2x2 schema for spatial skills which separated them based on two fundamental distinctions between types of spatial representations, intrinsic vs. extrinsic and static vs. dynamic (Newcombe & Shipley, 2015; Uttal, Meadow et al., 2013). Whilst there is some disagreement about how best to conceptualise the different components that make up spatial abilities, this study provides no evidence to support one classification system over another. However, participants did evaluate the nature of spatial skills as being made up as different components, as summarised the literature (Kozhevnikov et al., 1999; Linn & Petersen, 1985; Lowrie et al, 2017; Newcombe & Shipley, 2015; Uttal, Meadow et al., 2013). This idea has some important implications for the quality of the quantitative data of this research project. I have already identified that the reason there was no significant interaction between time and intervention group in changing spatial self-concept following engagement in the spatial abilities training programme. However, as mentioned, this effect could be attributed to a multi-directional change, with some participants having a new perception of skill, whether that be positive or negative (changes in perception is evaluated in the following section). It could be that referring to spatial skills as a holistic concept, as it is in the spatial self-concept measure, provided an unhelpful and inaccurate conceptualisation. Rather, it may have been better to explore thoughts and feelings regarding spatial skills by component, asking about mental rotation, spatial orientation and spatial visualisation, for example. Nonetheless, the spatial self-concept measure has been demonstrated to have good internal consistency and test-retest reliability. This suggests that, as a whole, participants had a consistent view of spatial skills. Nevertheless, exploring spatial skills on a component basis may be an interesting focus for future research. This idea will be explored in more detail in the future directions of research section.

***Theme 2: New Perceptions***

During the process evaluation, participants reported that the spatial skills training intervention provided them with a newfound understanding of what spatial skills were, but also about their own aptitudes regarding them. Most participants (nine of 11) identified that engagement in the programme resulted in a positive improvement in their ability to complete spatial tasks. Participants' reported improvements in spatial abilities was also found in the quantitative data, which showed a significant improvement in spatial maths attainment following the spatial training intervention. This finding is in line with research conducted by several researchers, which is evaluated in a meta-analysis by Uttal, Meadow et al. (2013) which showed that not only are spatial skills malleable, but also that even small amounts of training can improve spatial reasoning, in both males and females. Taken together, this research provides further evidence that spatial ability training improves spatial attainment, and that this improvement is acknowledged and identified by some participants.

Another theme from the process evaluation suggested that participants identified spatial skills as an unrecognised set of skills, which they were unaware they had. Burgoyne (2010) investigated spatial ability in pupils who were at risk of not being able to read in a longitudinal study and found that there were a number of students with Specific Learning Difficulties (SpLD) in reading, alongside high spatial ability. Burgoyne (2010) concluded that early identification of spatial ability as a perceived strength and a skill which can be used to support learning was important, as opposed to the identification of reading problems, which is a perceived deficit. The data gathered in this research project shows that spatial skills continues to be a relatively ‘invisible’ are of competence to most participants. Furthermore, engagement in the spatial training intervention programme allowed children to recognise spatial skills as a valuable set of abilities, from which they had a individual views about their own aptitudes. This intervention programme has the potential to have a powerful effect on a targeted population, such as children with reading difficulties with identified high ability in spatial related tasks. The intervention could allow them to develop a greater, positive understanding of their own skills related to spatial abilities, as outlined by Burgoyne (2010). I will discuss and evaluate this point, amongst others, in the future research section.

***Theme 3: Transfer***

Finally, participants identified that engagement may support them in other domains and lessons, including maths, English and geography. Performance and ability to engage effectively in learning in a classroom environment is complex and requires several different skills, including attention, inhibitory control and working memory (Skibbe et al., 2011). Nonetheless, research has shown that spatial ability is associated with attainment in other lessons, including maths (Lowrie et al., 2017) and literacy (Giovagnoli et al., 2016). This research study found that participation in the spatial training intervention led to improvements in maths attainment, where spatial tasks were involved. This improvement was noted by several of the participants. This research provides evidence that engagement in spatial training leads to a positive change in perceptions of spatial ability, and an acknowledgement that this change in perception may lead to increases in performance and attainment in other areas. Nonetheless, this research does not provide evidence that this effect is founded in actual attainment and performance, and whether these changes in perceptions and acknowledgement in transfer can remain consistent over time. Future research could investigate this and other possible directions will be explored.

## Strengths and Limitations

### *Phase 1*

This phase used sound statistical methods to demonstrate the internal consistency and test-retest reliability of the measure. This novel spatial self-concept measure was based on an well established tool (Marsh, 1986; Marsh, 1990; Marsh & Martin, 2011), was short and relatively easy to administer to large groups of participants within classrooms, which allowed participants to be at ease and give good responses. This contributed to the good sample size obtained for Phase 1 ($N$=178). Additionally, the use of well-published and validated sub-scales of the SDQ-I (maths self-concept and reading self-concept), meant that the correlations observed between spatial self-concept, maths and reading self-concept, were consistent with previous research and enabled more confident conclusions to be drawn.

One limitation of Phase 1 of the research was that participants were only recruited from three different schools, and all were involved in the English Key Stage Two curriculum.  Future studies that use the Spatial Self-Concept Scale should be conducted to extend evidence of its sound psychometric properties. Whilst a relatively large sample was obtained for the purposes of this research project (sufficient to generate statistically significant data), a larger sample size would have had greater power. Gathering a more diverse sample will be important, so to ensure the generalisability of the measure.

Another limitation is that it is difficult to conclude that participants had adequate understanding of what spatial skills are, after watching the video. This could be addressed in future research by gathering qualitative data from participants after watching the video regarding their ideas about spatial skills and definitions. This would also ensure better content validity of the spatial self-concept measure. Nonetheless the good internal consistency and test-restest reliability of the measure suggests that participants have a stable conceptualisation of what spatial skills are.

***Phase 2***

There are a number of methodological strengths involved in Phase 2 of this research project. First, this is an important and relatively underresearched area of study. Whilst there is more research within cognitive and developmental psychology journals, there are few published research studies investigating spatial abilities within British professional educational psychology journals (e.g., Educational Psychology in Practice & The British Journal of Educational Psychology). Likewise, much of the research evaluated for this research study was conducted using quantitative research methods. This current research uses both qualitative and quantitative research methods.

Arguably then, another strength is the quality of the research design. Phase 2 of this study involved mixed methods approaches, as both quantitative and qualitative data was gathered in order to evaluate the effectiveness of the spatial training intervention. Mixed methods research allows for research aims to be viewed from multiple different perspectives, which in turn gives a clearer picture of any issues (Harper, 2011). There are two main mixed methods approaches: sequential and parallel (Nair, 2017). For this research, I adopted a parallel approach as quantitative and qualitative data was gathered at the same time, post intervention. The quality of mixed methods approaches is not only highlighted in literature, but also recommended by the UK Government (2022) as an effective approach to research design which "can provide stronger evidence and more confidence in your findings" (para. 3). The mixed methods design allowed for the triangulation of information and has allowed conclusions to be drawn with more confidence.

Another strength relates to the applicability of this research to the English curriculum. Whilst there a good body of research which highlights the malleability of spatial skills (Uttal, Meadow et al., 2013), little research has investigated how spatial training interventions can be delivered in a classroom enivironment. In fact, one criticism of experimental studies investigating the malleability of spatial abilities, is that they have not been conducted within school environments (Uttal, Meadow et al., 2013). Teachers in schools in England (and the UK) must cope with many of the demands that are placed upon them by senior leadership teams, based upon meeting requirements of the school curriculum. This spatial intervention training programme was designed to be complementary to the Key Stage 2 Maths curriculum (UK Government, 2022). Furthermore, the impact of the spatial training intervention programme was measured using a spatial maths attainment measure that included items that were selected exclusively from past Key Stage 2 SATs papers. This provides a strong indication of the value of spatial ability training in directly supporting children in meeting English curriculum targets. Furthermore, combined with the evidence of strong links between spatial abilities and other cognitive abilities

(Lowrie et al., 2017; Giovagnoli, 2016), this suggests that there should be a greater focus on spatial abilities within the curriculum.

Another strength was the value of the findings from Phase 1, and their influence on Phase 2. In Phase 1, a spatial self-concept measure was developed, with good internal consistency and test-retest reliability. This allowed me to measure change in spatial self-concept over the course of the intervention delivered in the Phase 2.

A key limitation of this phase of the research project is that participants were only recruited from two different schools, and all were involved in the English Key Stage Two curriculum. Another key limitation is that the sample size is relatively small (N=57). Whilst this is enough to have demonstrated statistically significant data, a larger sample size would have been beneficial in order to demonstrate greater power.

Another limitation was linked to the fact that I as the researcher acted as both the intervention designer and deliverer, and the data collector and analyser. Over time, I developed relationships with the participants and their teachers, which may have indirectly influenced the content of the responses collected in the process evaluation. There was a risk of positive bias in the responses to the questions in the semi-structured interviews, as participants may have been unwilling to give negative responses or feedback to me, in case they felt they were insulting my design or delivery skills. Whilst that is an important consideration, rapport building between interviewer and interviewee has been shown to be effective in gathering richer data during interview (Prior, 2017). Similarly, there was not universally positive feedback reported from participants during interview. Nonetheless, my positionality and relationship with the participants is a key methodological concern in regard to the value claims made. This concern could have been ameliorated through and alternative interviewer conducting the semi-structured interviews. This could be achieved in future research designs.

One significant limitation of this research design is the quality and validity of the spatial maths attainment measure used. The measure was designed to measure maths attainment where it directly is linked to spatial tasks, related to targets from the Key Stage 2 English Maths curriculum (UK Government, 2022). Sullivan (2011) outlined several sources of evidence which are required to build an argument that a novel assessment instrument is a valid measure. The sources of evidence are content, relationship to other variables, and consequences. I would argue that I have provided evidence for two of these sources of evidence, content and consequences. Sullivan (2011) summarises that content can be achieved through outlining the steps used to develop the instrument. This has been achieved through the summary of the items used in the measure, the process of how they were selected, and the sources of information used, in Chapter 2. That notwithstanding, it is important to note that the items selected for the measure were not specifically designed to measure spatial ability. Instead, the items were selected based on their relationship to spatially linked English Maths curriculum targets. Furthermore, according to Sullivan (2011), evidence of consequences means that “if lower performers receive additional training and their scores improve, it will add to the validity of the instrument” (p. 120). In this study, there was an improvement in performance in the spatial maths attainment measure, following participation in the spatial skill intervention programme. This therefore provides more tentative evidence for the validity of the measure. The main limitation which challenges the validity of the spatial maths attainment measure is the absence of evidence which is related to the measure's relationship to other variables. Sullivan (2011) outlines that relationship to other variables includes the "correlation of the new assessment instrument results with other performance outcomes that would likely be the same" (p. 119). In this research study no other steps were taken to study the relationship between performance on the spatial maths attainment measure and performance on other, already well-published and validated scales of spatial ability, such as the Embedded Figures Test (Witkin & Goodenough, 1981), or Block Design tasks (Amaro & Barker, 2006). By measuring the relationship between the spatial maths attainment measure and other spatial skills measures also would provide greater evidence for construct validity (Germain, 2006). Ensuring greater validity of the spatial maths attainment measure is a possible direction for future research. The study could have benefitted from a stronger testing for appropriate validity and reliability (e.g., test-retest reliability, measure for normal distribution), prior the initiation of Phase 2, akin to the methodology used to develop the spatial self-concept measure.

There were some methodological concerns related to the research design. Whilst there was random allocation to which class in each setting received the spatial training intervention programme, participants remained within their own class groups for the delivery of the intervention. Both participating schools did however have a control group and an intervention group in order to try and ensure that groups were similar in terms of school characteristics. Furthermore, the fact that the intervention was delivered by the same researcher ensured a systematic and consistent approach to the programme's administration.

Finally, a key limitation of this research study is the lack of longer-term follow-up measures. Whilst there is good research to suggest that improvement in spatial abilities can sustain over time (Uttal, Meadow et al., 2013), it is unclear to whether improvements found in this research study will do so. Similarly, it is possible that the impact of the spatial training intervention programme upon self-concept may take longer to result in positive progress, as previously discussed. This longer-term impact could be investigated in future research.

***Reflexive Analysis***

Braun and Clarke (2006; 2019) frequently refer to the importance of reflexive approaches involved when completing a thematic analysis of qualitative data. Reflexive approaches involve later theme development, which have been derived from codes, and then "conceptualised as patterns of shared meaning underpinned by a central organising concept" (Braun & Clarke, 2021, p. 39). Braun and Clarke (2021) summarise that theme development that occurs during the process cannot be exist separately from the researcher, as they are generated by the researcher. The data engagement process is mediated by all of the experiences which the researcher brings to the process, including, their research values, skills, training and experience. The coding process is inherently subjective, and therefore it requires researchers to reflect on their own assumptions, and explicitly state how these assumptions may influence their coding. Transparency when approaching qualitative research is important, and especially when using reflexive thematic analysis (Braun & Clarke, 2019).

I know the amount of time, effort and work that went it to the design process of the intervention, including the construction of materials. Furthermore, I know that I myself enjoyed the delivery of the intervention and enjoyed the relationships that were developed with the children who received the intervention. I still critique my work, and I constantly reflect upon my own skills and practice in line with the Kolb Learning Cycle (Kolb, 1985), which led to a series of iterative changes during the process of intervention development.

Second, it is important to reflect on how my prior experiences may have impacted upon my analysis. I am a trainee EP, and prior to this I worked in special needs school for children with complex special educational needs. Within that setting, I worked with young people with social interaction and communication difficulties, including some who were non-verbal. During this time, I grew a strong understanding of strengths-based learning and individual differences, and the importance in supporting children and young people to be aware of their strengths, rather than focussing on difficulties. I believe that this experience aided me in devising not just the whole research project (particularly in relation to self-concept), but also supported the process of creating the interview schedules, theme choices, and wording, especially in relation to individual differences.

As the intervention was delivered over time, I became more aware of the impact and the learning process which the pupils were engaging with throughout. I kept a fieldwork journal, from which I recorded observations. One of the key observations was that I perceived an increased enthusiasm from the participants when more physical materials were introduced before sessions, for instance. Nonetheless, I did not allow this observation to change or impact upon my subsequent interview schedule questions.

It was important for me to undertake a piece of research which was interesting and engaging for me. I strong interests in mathematics, and the underlying cognitive processes which are used when engaging in mathematical tasks. I also have a keen research interest into specific learning difficulties in maths, such as dyscalculia. This was especially beneficial when exploring the different sources of knowledge and allowed me to research deeper into the nature of spatial skills. Furthermore, having seen both the positive impact the research had on spatial maths attainment, and the different responses the participants gave in response to the interview questions, I feel confident in the quality of the intervention which I designed. Whilst there are many strengths to this research, it is important to acknowledge the limitations. My consistent role as the intervention designer, deliverer, interview conductor, and data analyser provides a clear limitation to the research, which will be explored in more depth in the upcoming section.

**Originality of this Research and Suggestions for Future Research**

This research study has been able to establish spatial self-concept as a novel a worthwhile new subset and domain of self-concept, that belongs somewhere within already established models of self-concept (e.g., Brunner et al., 2008; Marsh, 1990; Shavelson et al., 1976). Future research could investigate how spatial self-concept relates to other forms subtypes of self-concept, especially overall academic self-concept. Likewise, some research has suggested that academic self-concept is correlated with the rate of by which spatial cognitive maps are formed (Burles et al., 2014). Future research could look at the relationship between spatial self-concept and spatial ability in more depth, using well researched, validated, and published measures of spatial abilities, for instance, Raven's Coloured Progressive Matrices (RCPM) (Raven & Raven, 2003), the Embedded Figures Test (Witkin & Goodenough, 1981), or Block design tasks (Amaro & Barker, 2006). These three spatial ability measures are suggested, but the list is certainly not exhaustive.

Similarly, future research could benefit from bolstered sample sizes in relation to the effectiveness of the newly designed spatial training intervention programme. Using larger, more diverse populations, would provide further information to whether this intervention would demonstrate effectiveness across greater populations. Similarly, future research could also investigate whether the increases to spatial maths attainment maintain over time. Equally, it would be worthwhile to investigate whether there was any change to spatial self-concept over a longer period of time.

**Professional Implications of the Current Study**

There are several professional implications that this research project has for educational psychology practice, in particular related to selection and recommendation of interventions, curriculum development, and assessment.

First, this research project demonstrates that the novel spatial training intervention programme is an effective intervention to support children who may struggle with spatial reasoning. Even in a non-targeted, general population, the intervention demonstrated a significant improvement in spatial attainment. As such, EPs may consider recommendation, this or similar programmes, for children who struggle in this particular area of learning.

This research contributes to the research literature regarding the importance of spatial ability, particularly in relation to maths attainment. EPs should ensure that they consider spatial abilities when engaging in an assessment. Furthermore, this research highlights that EPs should be willing to recommend spatial ability training programmes in their psychological advice, where particular difficulties are identified. The present spatial ability training programme outlines an intervention which is complementary to the Key Stage 2 mathematics National Curriculum for England

(UK Government, 2022), making it an ideal intervention for EPs to recommend. This research also highlights the importance of spatial ability in the learning process and future educational psychology research should investigate its role in the learning process.

It is important for EPs recognise that one of the unintended consequences of raising awareness about spatial abilities is that it for some, it may illuminate an area of strength, for others it may cause them to become aware of deficits in spatial ability. This therefore increases the need for targeted intervention for those who need it. Once pupils understand their own strengths and difficulties, they need to be supported to thrive in their strengths and be provided with targeted help regarding their difficulties. This strengths-based approach will support pupils in developing their self-concept and is likely to have consequential effects on not only their future academic attainment, but also perception of enjoyment from engaging in the learning process.

In summary, it is important that EPs consider all these aspects when developing and conducting future practice. In ever-changing and evolving societal and educational context, it is imperative for EPs to remain at the forefront of both educational and psychological research so to support young people in reaching their potential. This research provides more evidence of the importance of both spatial abilities and self-concept as mediating constructs in academic attainment within education. EPs need to champion the importance of spatial ability and spatial ability training. This can be through continual research investigating its importance within a classroom context, and the development and recommendation of appropriate intervention. Similarly, they must help support education providers in understanding the important role that self-concepts play in both attainment, and children and young peoples' experience of education. Finally, there are likely to be thousands of children and young people within the UK education system, that have a cognitive strength in spatial abilities, which they are completely unaware of. Even more significantly, their current experiences of education may have led them to believe that they have very little cognitive strengths at all. EPs have the influence and ability to help shape the education system to seek out these individuals and support them in developing a different and more positive idea of themselves, and as a learner.

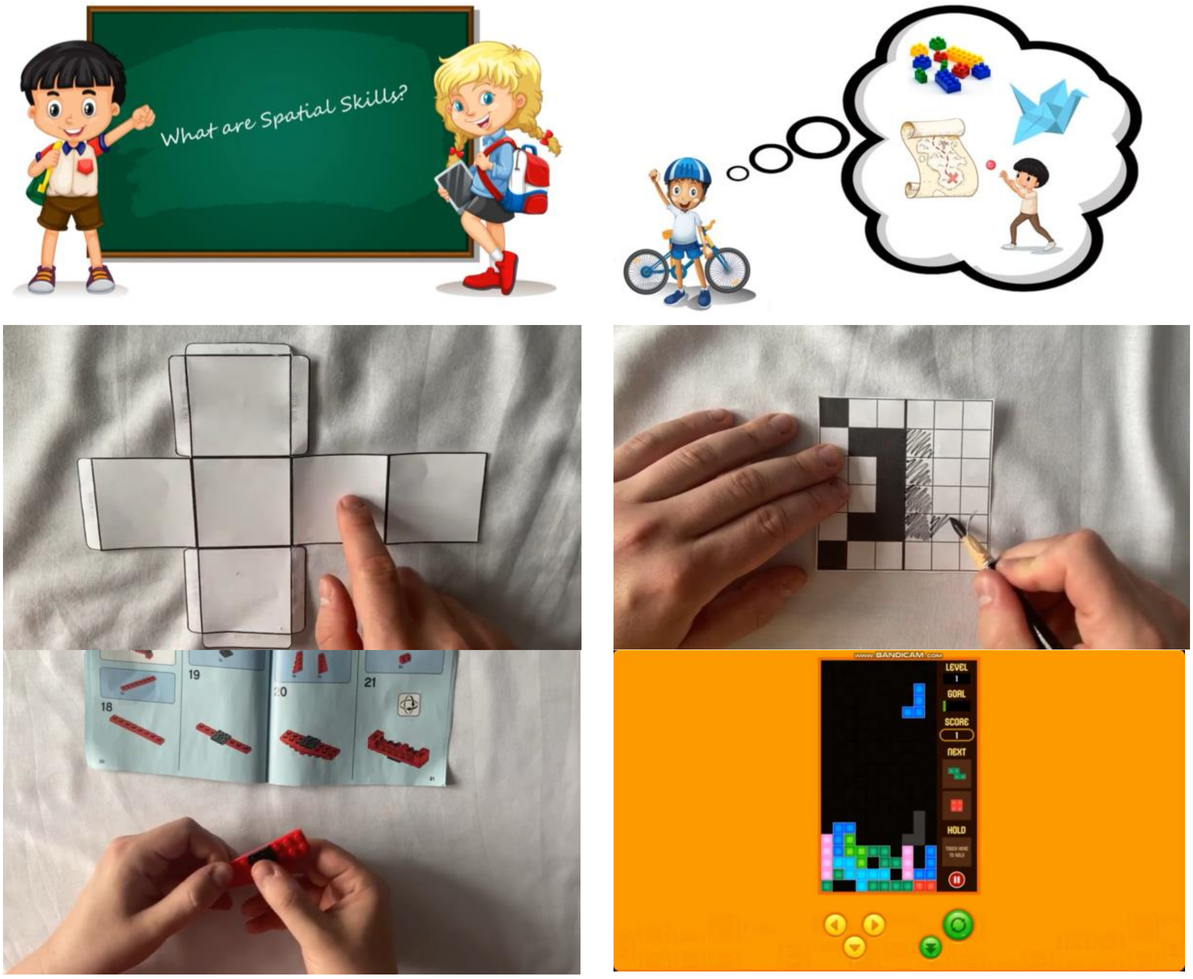
# Appendices

**Appendix A:** *Spatial Skills Video Transcript, Screenshots, and Video Link*

**Transcript**

Hello everyone. Today I am going to tell you about a new kind of skill, that you use every day, that you might not have heard of. These skills are called spatial skills. You use spatial skills when you are at home, when you are playing video games, and even in school. Now, lets talk about some of the examples where you might use spatial skills. I am now going to show you some tasks that you might have done in school that use spatial skills, just like this one. Could you have looked at that picture and understood what shape it was going to be? You can see that there are six sides, like a cube. Therefore, you could imagine, in your head, when the shape has been put together, that it will make a cube. This is another task that you may have done in school that uses spatial skills. Looking at this drawing, could you imagine what it would look like if it was in a mirror, in your head. This is another kind of spatial skill because you are thinking about the shapes in your head and working out what the shapes on the other side would look like. LEGO is a toy where using spatial skills is especially important. Some LEGO kits come with a booklet, just like this one. The booklet tells you how to build the set. When building the set, you must find all the correct bricks which the instructions tell you to. Then you look at the instructions and work out how to put them together. Even though there are no words in the instructions, you are still able to build the set using the pictures. This is because you are using your spatial skills. Another place where you commonly use spatial skills, is when playing video games, just like this one, Tetris. When you play Tetris, you have to do a number of things. As the shapes come down, you have to quickly look at the spaces below, and find an appropriate place that the shape will fit. As well as this, you must be able to rotate the shapes in your head, so that they fit in the spaces that you have selected. Both skills, spotting the spaces, and being able to rotate the shapes to fit, are spatial skills. These are just a few examples of where you might use spatial skills, at home or at school. They are not the only examples; others could include sports and map reading. I hope this video has helped you understand about spatial skills. You will now be given a questionnaire to answer. Thanks for listening.

**Screenshots**




**Video Link**

**[https://youtu.be/xzKI577UM8E](https://youtu.be/xzKI577UM8E)**

## **Appendix B:** *Novel Spatial Self-Concept Measure*

This is a questionnaire about how you feel about some of the skills that were demonstrated in the video you have just watched, and some of your thoughts and feelings about them. The questionnaire will also ask about some of your thoughts and feelings about maths and reading. If you have any questions, please put your hand up and ask an adult.

How true are the following statements about spatial skills for you? *Please tick the box which most applies to you.*

| | **True** | **Mostly True** | **Sometimes True/ Sometimes False** | **Mostly False** | **False** |
|---|---|---|---|---|---|
| **I look forward to lessons with spatial activities.** | | | | | |
| **I like spatial activities.** | | | | | |
| **I am interested in spatial activities.** | | | | | |
| **I enjoy doing work which use spatial activities.** | | | | | |
| **I hate spatial activities.** | | | | | |
| **I learn things quickly using spatial activities.** | | | | | |
| **Work which use spatial skills are easy for me.** | | | | | |
| **I get good marks in lessons with spatial activities.** | | | | | |
| **I am not very good at spatial activities.** | | | | | |

**Appendix C:** *Maths and Reading Self-Concept Measures*

How true are the following statements about maths for you? *Please tick the box which most applies to you.*

| | True | Mostly True | Sometimes True/ Sometimes False | Mostly False | False |
|---|---|---|---|---|---|
| **I look forward to maths.** | | | | | |
| **I like maths.** | | | | | |
| **I am interested in maths.** | | | | | |
| **I enjoy doing work for maths.** | | | | | |
| **I hate maths.** | | | | | |
| **I learn things quickly in maths.** | | | | | |
| **Work in maths is easy for me.** | | | | | |
| **I get good marks in maths.** | | | | | |
| **I am not very good at maths.** | | | | | |

How true are the following statements about spatial skills for you? *Please tick the box which most applies to you.*

| | True | Mostly True | Sometimes True/ Sometimes False | Mostly False | False |
|---|---|---|---|---|---|
| **I look forward to reading.** | | | | | |
| **I like reading.** | | | | | |
| **I am interested in reading.** | | | | | |
| **I enjoy doing work for reading.** | | | | | |
| **I hate reading.** | | | | | |
| **I learn things quickly in reading.** | | | | | |
| **Work in reading is easy for me.** | | | | | |
| **I get good marks in reading.** | | | | | |
| **I am not very good at reading.** | | | | | |

**Appendix D: Maths Attainment Measure**

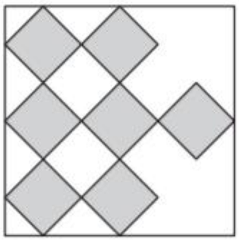
# Maths Worksheet

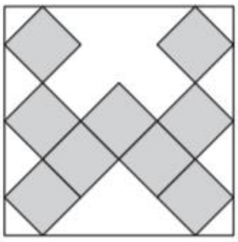
| 1) |
|---|

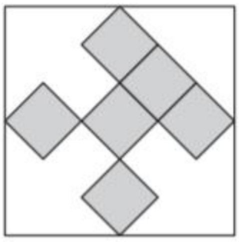
These three square tiles have symmetrical patterns on them.

Draw the line of symmetry on each tile.

Use a ruler.





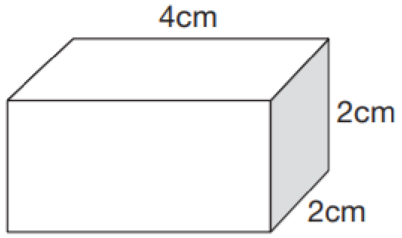


4i

4ii

2 marks

**2)** Look at the cuboid below.

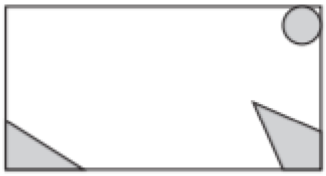



Draw **two** more faces to complete the net of the cuboid.

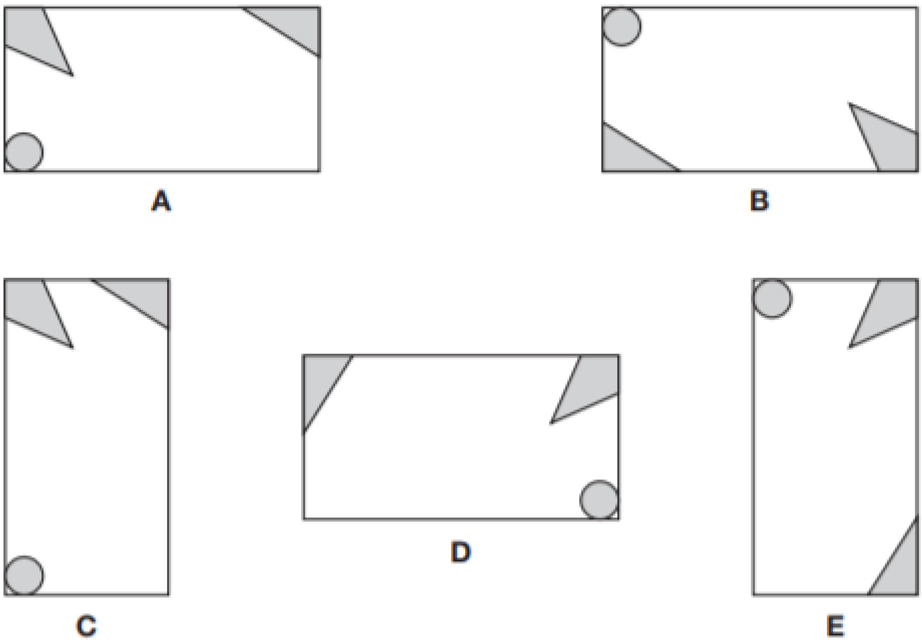
9a
1 mark

9b
1 mark

**3)** Megan has a rectangular tile with this design on it.



Here are five more rectangular tiles.




Write the letters of **all** the tiles that have the same design as Megan's tile.

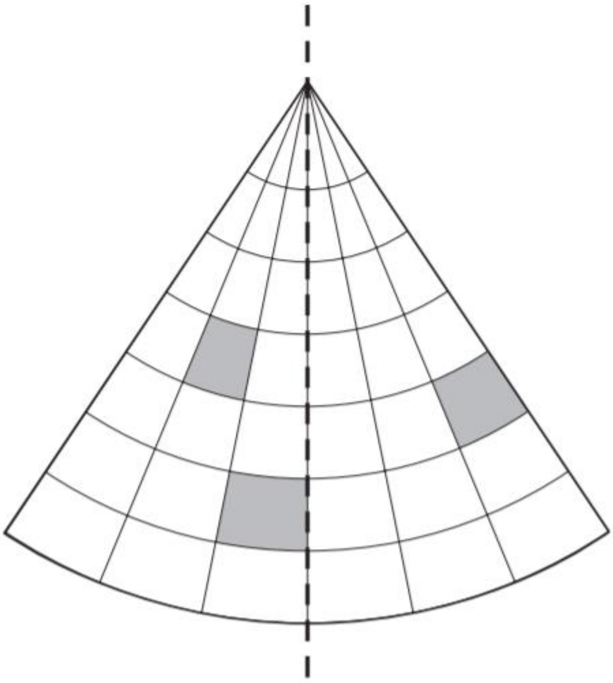
_______________

7i

7ii

2 marks

**4)** Draw the reflection of **all** the shaded shapes in the mirror line.




2

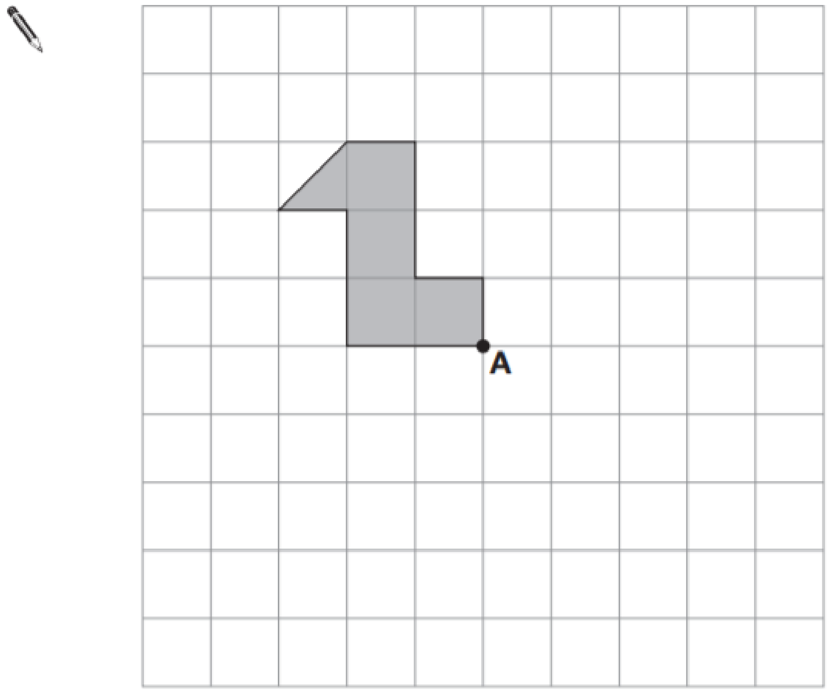
1 mark

**5)**

Here is a shaded shape drawn on a square grid.

The shape is rotated 180° about point A.

Draw the shape in its new position on the grid.



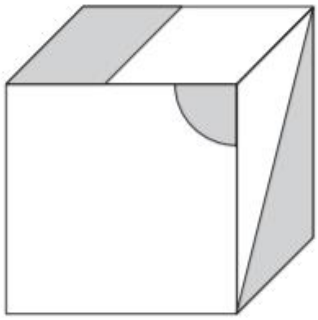

19i

19ii

2 marks

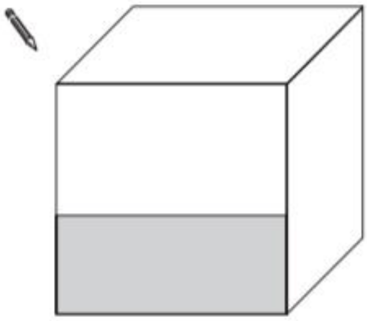
**6)**

This cube has shapes drawn on three of its faces.



The cube is turned to look like this.

Draw and shade the missing shapes.



22a

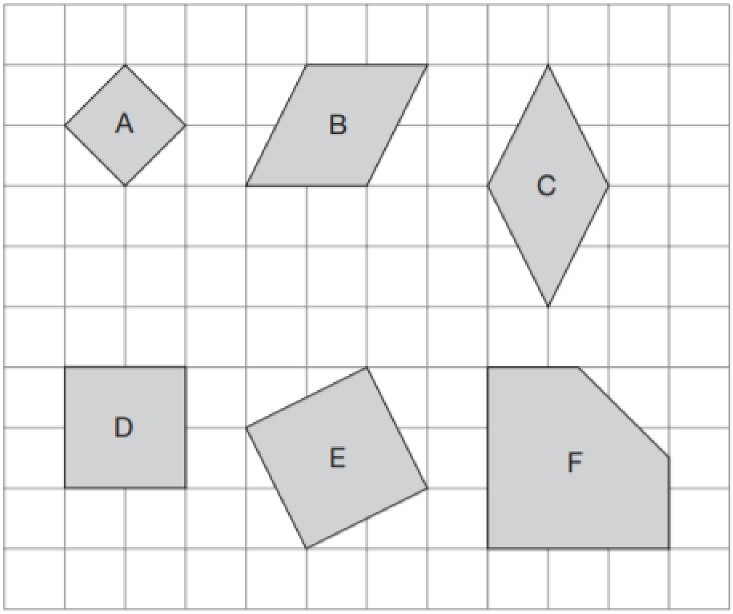
1 mark

22b

1 mark

**7)**

Here are six shapes on a square grid.




Write the letters of **all** the shapes that are squares.

_______________

5

1 mark

## Appendix E: Full Outline of Spatial Skills Intervention Sessions

### Outline

| Intervention Topic | | |
|---|---|---|
| 2D Mental Rotation | *Aim of Session:* | Participants to understand and become familiar with 2D mental rotation tasks and strategies that can be used to approach them. |
| | *Description:* | Participants were presented with a worked example and rotation was demonstrated on the whiteboard so that understanding of the task was clarified. Next, participants were given two examples to try out rotation. This was assisted with card shape of the stimuli so they could experiment with 2D rotation in physical format. Finally, participants were presented with 3 examples for 2D mental rotation – answers were provided after 2 minutes. |
| | *Resources:* | 2D Mental Rotation PowerPoint Presentation, 2D Mental Rotation Worksheet, 2 shapes cut in the shape of the stimuli in slides 6,7,8. |
| 3D Mental Rotation | *Aim of Session:* | Participants to understand and become familiar with 3D mental rotation tasks and strategies that can be used to approach them. |
| | *Description:* | Participants were presented with a worked example and rotation were demonstrated on the whiteboard so that understanding of the task can be clarified. Next, participants were given two examples to try out rotation. This were assisted with small coloured wooden cube that matches the stimuli so they can experiment with 3D rotation in physical format. Finally, Participants were presented with 3 examples for 3D mental rotation – with answers provided after 2 minutes. |
| | *Resources:* | 3D Mental Rotation PowerPoint Presentation, 3D Mental Rotation Worksheet, 2 wooden cubes with different coloured sides matching stimuli. |
| Rotational Symmetry | *Aim of Session:* | Participants to understand and become familiar with rotational symmetry tasks and strategies that can be used to approach them. |
| | *Description:* | Participants were presented with a worked example and rotational symmetry were demonstrated on the whiteboard so that understanding of the task can be clarified. The PowerPoint presentation is supported by animation to support understanding. Next, participants were given three examples to try out to count the number of symmetrical rotations. This were assisted with a card in the shape of the stimuli so they can experiment with rotational symmetry in physical format. Finally, Participants were presented with 3 examples for rotational symmetry – with answers provided after 2 minutes. |
| | *Resources:* | Rotational Symmetry PowerPoint Presentation, Rotational Symmetry Worksheet, 3 shapes cut in the shape of the stimuli in slides 7,8, 9. |

| | | |
|---|---|---|
| Drawing Maps | *Aim of Session:* | Participants to be able to draw a basic map of a small familiar room, so that they understand how 3D areas can represented in 2D form. |
| | *Description:* | Participants were presented with a worked example that shows a photograph of a bedroom from different angles alongside a basic floor plan of the room. A cross will mark a corner of the bedroom on the floor plan and participants were asked to select in which photograph would the X be visible (*see full lesson materials for more details).* Next, a whole intervention group activity was completed where a basic floor plan of the classroom is drawn on a whiteboard/flipchart. Finally, participants were asked to draw a floor plan of a familiar room in their home. |
| | *Resources:* | Drawing and Navigating Maps PowerPoint Presentation, Drawing and Navigating Maps PowerPoint Worksheet, Flipchart paper. |
| Perspective Taking | *Aim of Session:* | Participants to understand and become familiar with perspective taking tasks and strategies that can be used to approach them |
| | *Description:* | Participants were presented with a worked example and perspective taking were demonstrated on the whiteboard so that understanding of the task can be clarified. Next, participants were given two examples to try out how objects appear differently from different perspectives. This were assisted with coloured blocks that they can look at from a range of different angles. Finally, Participants were presented with 3 examples for perspective taking – with answers provided after 2 minutes. |
| | *Resources:* | Perspective Taking PowerPoint Presentation, Perspective Taking Worksheet, 4 coloured wooden cubes per participant. |
| Nets of Solids | *Aim of Session:* | Participants to understand what a net of a solids is, and how it can be put together to make a 3D shape. Participants werecome familiar with the nets of solids of familiar 3D shapes. Participants were able to anticipate what 3D shape a novel set of solid will make. |
| | *Description:* | Participants were presented with some cut-out nets of solids that they can fold and glue together into a 3D representation. Next participants were presented with some worked examples where they must answer what shape a net of solid will create, and then have to opportunity to fold and glue the net to see if they were right. Finally, participants were presented with some questions where they do not have the benefit of paper to fold and glue. |
| | *Resources:* | Nets of Solids examples, glue. |
| Reflection and Symmetry | *Aim of Session:* | Participants to able to identify the number of lines of symmetry of any given shape. |
| | *Description:* | Participants were presented with a worked example and reflective symmetry were demonstrated in the presentation so that understanding of the task can be |

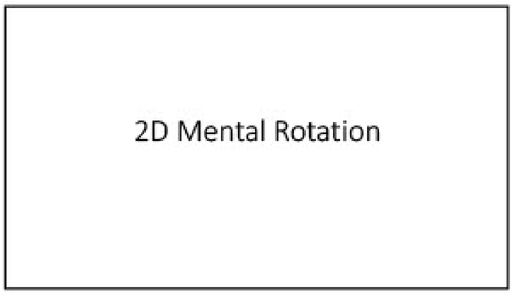
| | | |
|---|---|---|
| | | clarified. Next, participants were given two examples to try out how where they can use a mirror to identify lines of symmetry of shapes from their worksheet., Participants were presented with 3 examples for reflective symmetry – with answers provided after 2 minutes (per question). |
| | *Resources:* | Reflection and Symmetry PowerPoint Presentation, Reflection and Symmetry Worksheet, mirror. |
| Navigating Maps | *Aim of Session:* | Participants to understand cardinal directions and changing angles cardinal point can impact on directions and perspectives. |
| | *Description:* | Participants were presented with a worked example and map navigation was demonstrated on the whiteboard so that understanding of the task can be clarified. Next, participants were encouraged to come up with a set of directions to navigate across the local town. |
| | *Resources:* | Navigating Maps PowerPoint Presentation, Navigating Maps Worksheet, small print out of a compass with North, East, South and West. |
| Revision of Topics | *Aim of Session:* | Revision of Topics – with a focus on a task involving mental rotation, spatial orientation, and spatial visualisation. |
| | *Description:* | The participants could choose which activities they would like to choose to practice again. |
| | *Resources:* | All resources from previous sessions were available. |

| Intervention Topic | Key Words | Prompt Question | Definition Provided |
|---|---|---|---|
| 2D Mental Rotation | 2-Dimensional | What is the difference between a 2 and 3-dimensional shape? | 2D shapes are flat and only have two dimensions, length, and width. 3D shapes are solid objects with length, breath and width. Circles, squares and triangles are 2D shapes, and cubes, cylinders and cones are 3D shapes. |
| | Rotation | What happens when you rotate a shape? | Rotation is the movement of an object around a central point. Some examples of things that rotate is the steering wheel of a car or spinning top. |
| 3D Mental Rotation | 3-Dimensional | What is the difference between a 2 and 3-dimensional shape? | 2D shapes are flat and only have two dimensions, length, and width. 3D shapes are solid objects with length, breath and width. Circles, squares and triangles are 2D shapes, and cubes, cylinders and cones are 3D shapes. |
| | Rotation | What happens when you rotate a shape? | Rotation is the movement of an object around a central point. Some examples of things that rotate is the steering wheel of a car or spinning top. |
| Rotational Symmetry | Symmetry | What does it mean when a shape is symmetrical? | Something is symmetrical when it has two halves which are matching. If you drew a line down the middle of something, if both sides were the same, it would be symmetrical. |
| | Rotation | What happens when you rotate a shape? | Rotation is the movement of an object around a central point. Some examples of things that rotate is the steering wheel of a car or spinning top. |
| Drawing Maps | Maps | What is a map? | A map shows the locations of places, areas, or objects relative to each other. Maps can be used to make directions to follow. |
| | Bird's eye view | When you look at a map like this, why do people say it is from a bird's eye view? | Bird's eye view is a general view from above. It is what a bird would see when flying above an area. |
| Perspective Taking | Perspective | What does taking someone's perspective mean? | Perspective taking means seeing something as if you were somebody else, from their point of view. |
| Net of Solids | Net of Solid | What a net of solid? How could you make a 3D shape with this? | A net is a 2D shape that can be folded to make a 3D shape. |
| Reflection and Symmetry | Reflection | What does a reflection show? | A reflection shows a reversed image of whatever has been placed in front of it. A reflection can be found using a mirror. |
| | Symmetry | What does it mean when a shape is symmetrical? | Something is symmetrical when it has two halves which are matching. If you drew a line down the middle of something, if both sides were the same, it would be symmetrical. |
| Navigating Maps | Maps | What is a map? | A map shows the locations of places, areas, or objects relative to each other. Maps can be used to make directions to follow. |
| | Directions | How would you give somebody directions? Why? | Directions are the particular ways to get from one place to another. Some directions could be turn right or left, or go straight head when you reach the library, for example. |

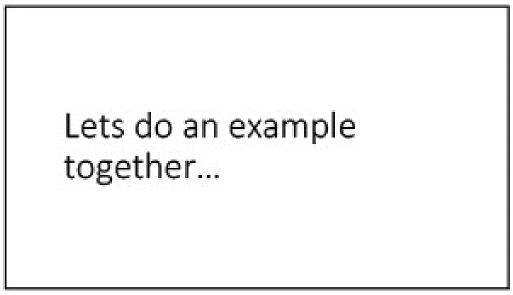
**Session 1: 2D Mental Rotation Materials**

*These following resources have been recreated from Stoet (2021).*

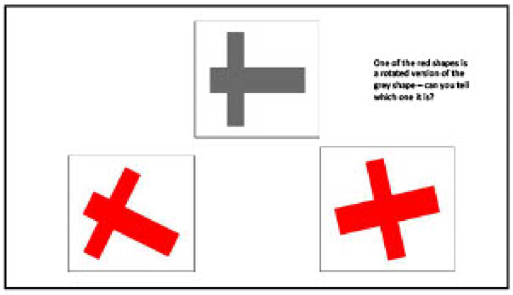
*Slid*



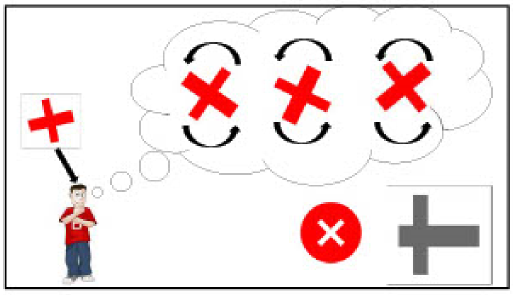

1



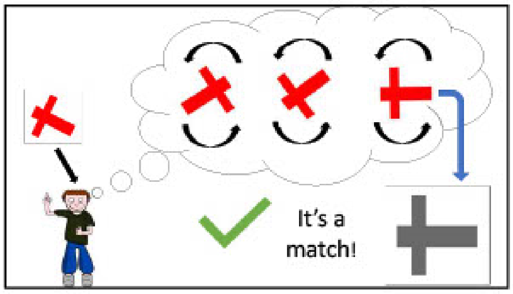

2



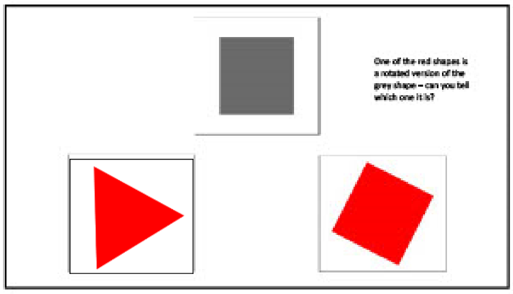

3



4

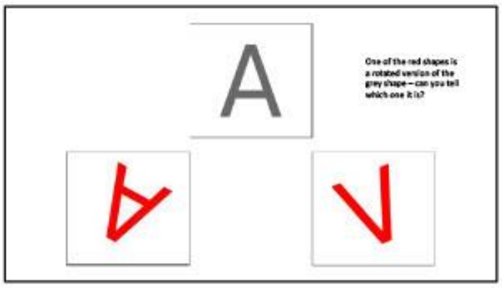



5

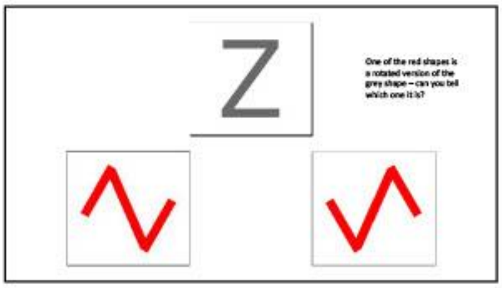



6

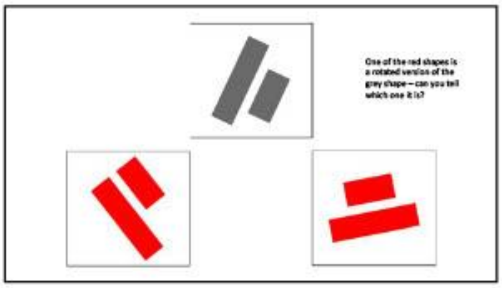
22/06/2022



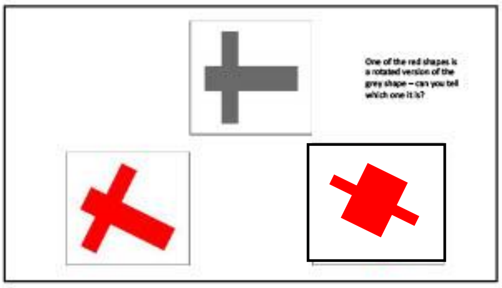
7



8



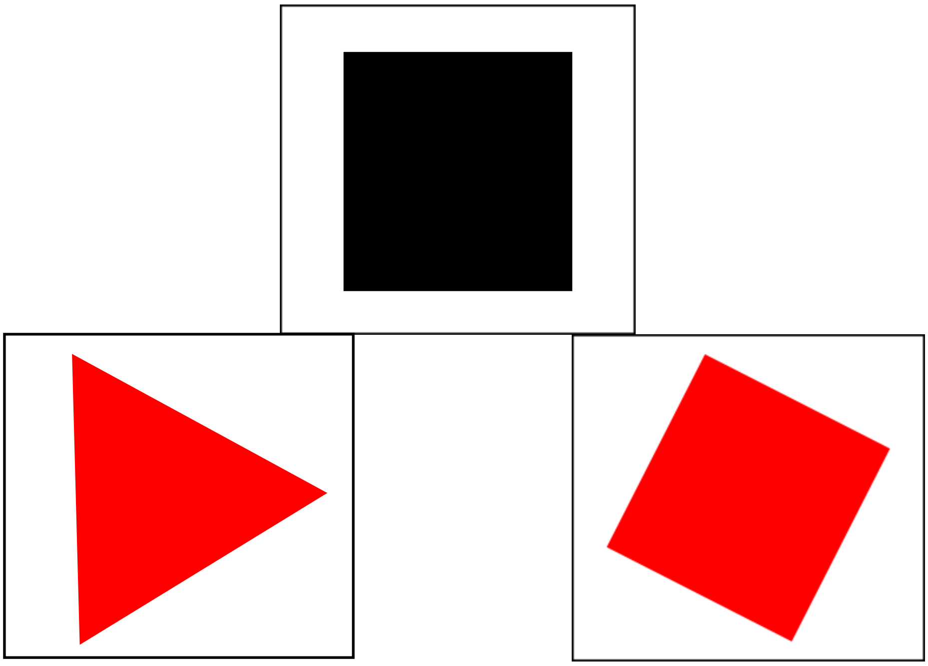
9



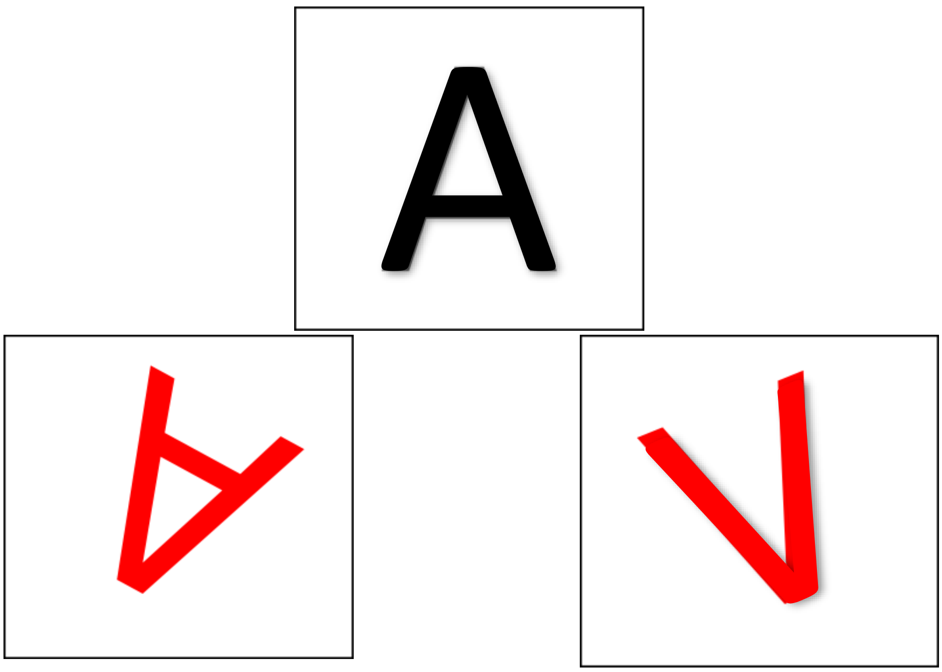
10

*Worksheet*

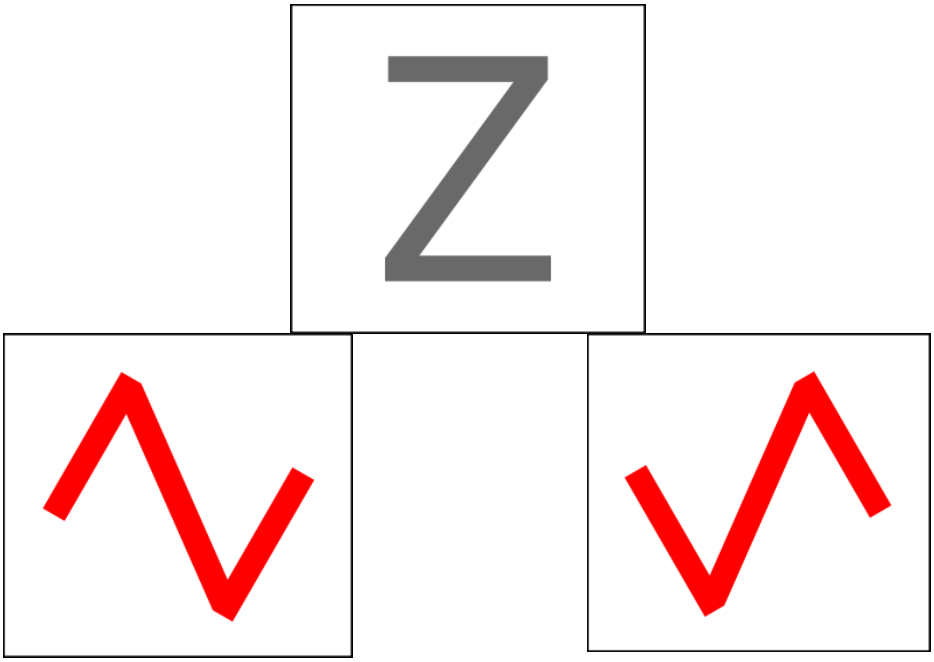
1)



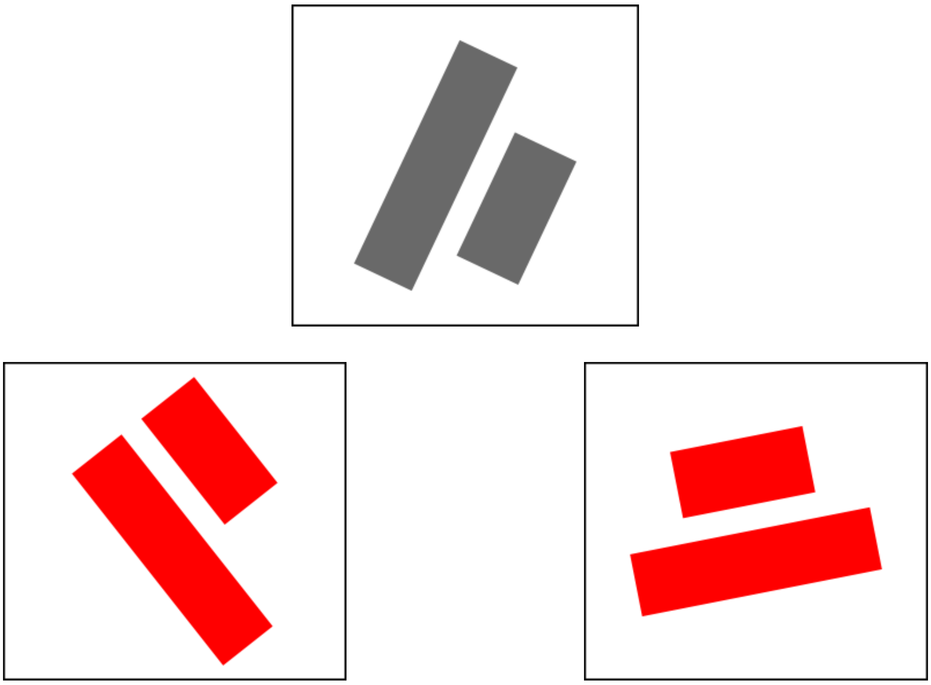
2)



3)




4)



**Session 2: 3D Mental Rotation Materials**

*Slides*

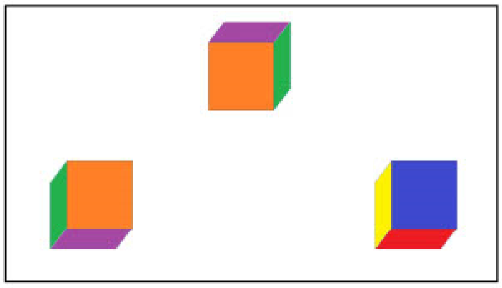
30/06/2022

3D Mental Rotation

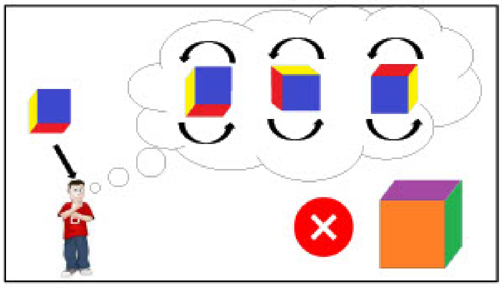
1

Lets do an example together…

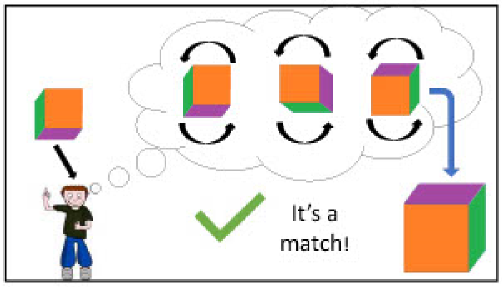
2



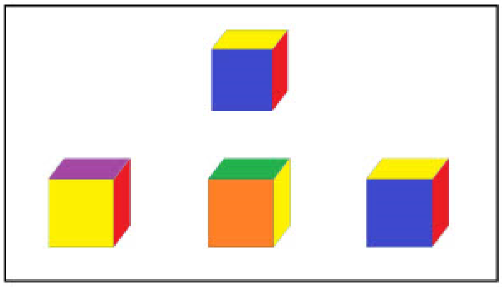
3



4

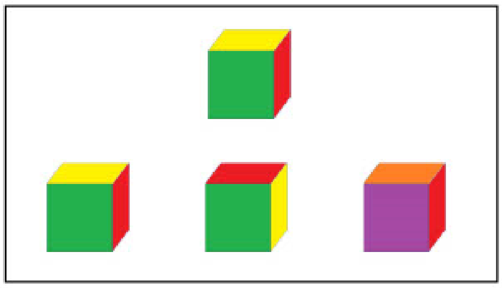



5

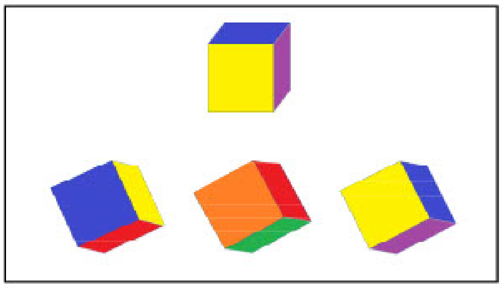


6

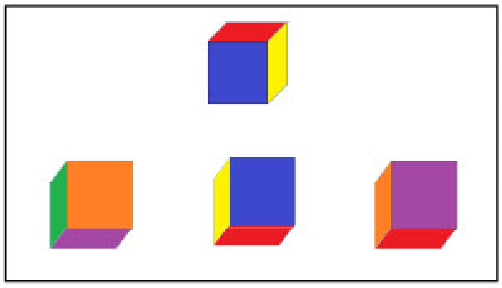
30/06/2022



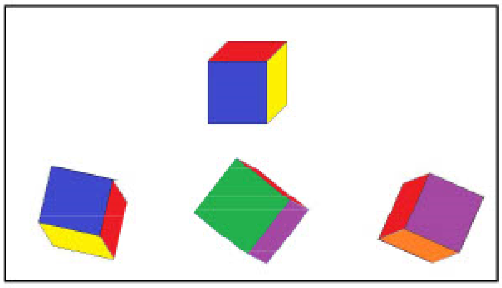
7



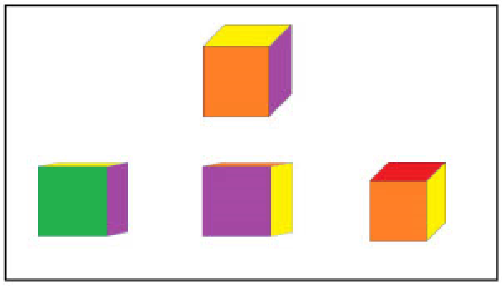
8



9



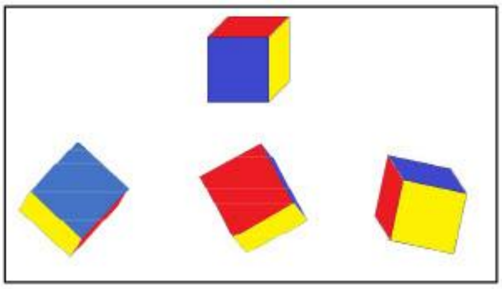
10



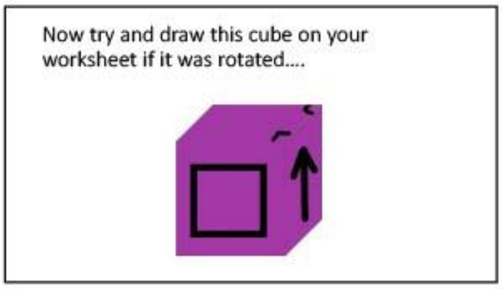
11

Time for a tricky one

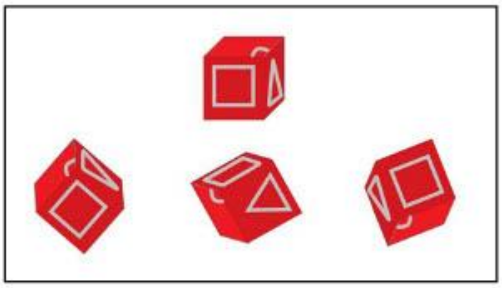
12



13


Now try and draw this cube on your worksheet if it was rotated....

14

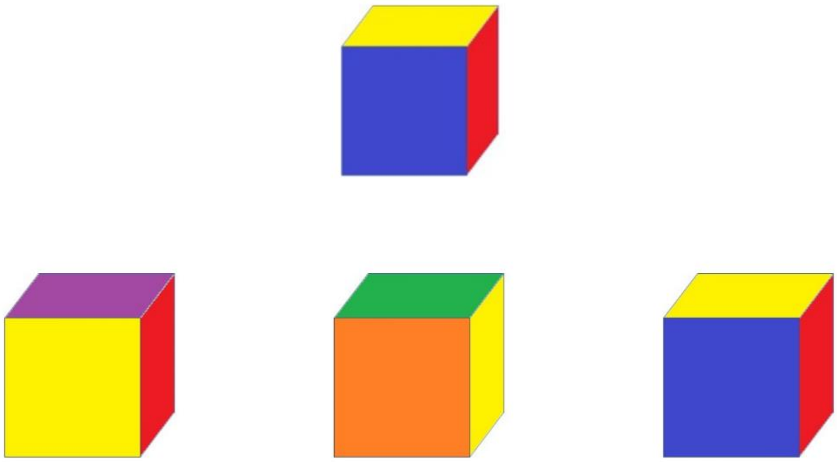


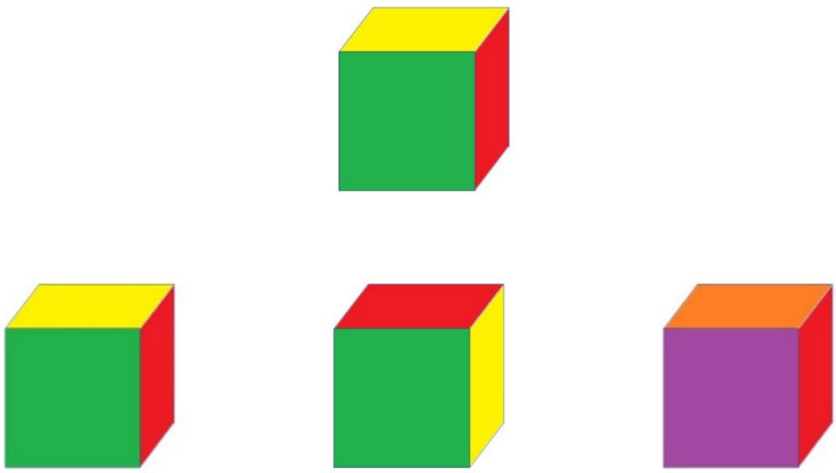
15

*Worksheet*

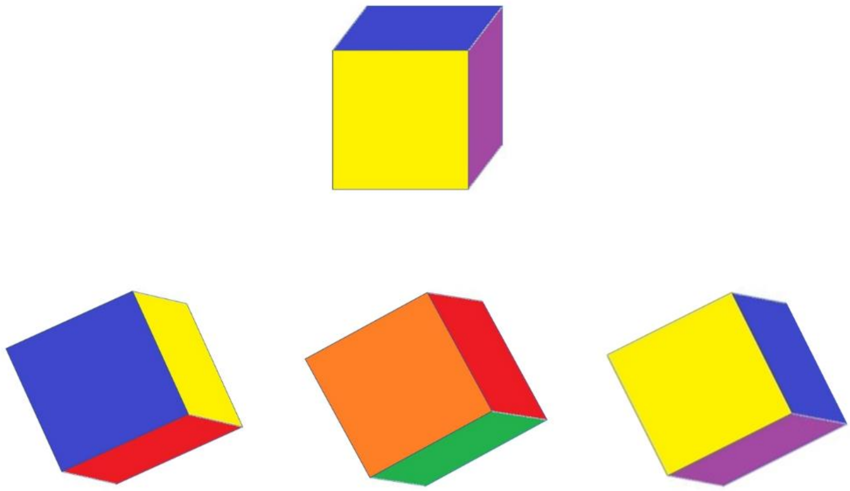
# 3D Mental Rotation Worksheet

1)

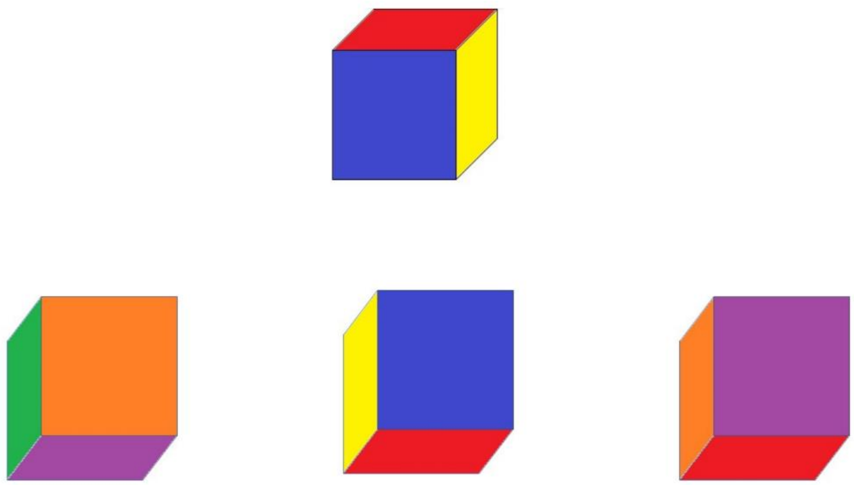




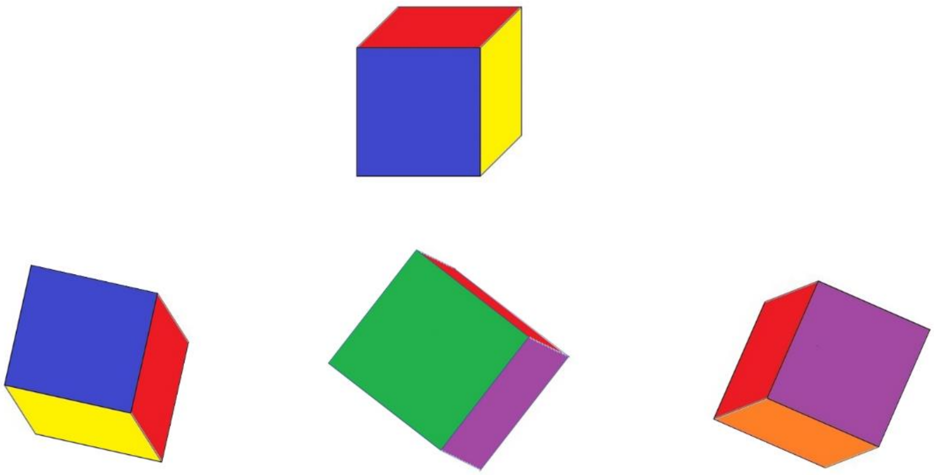
2)



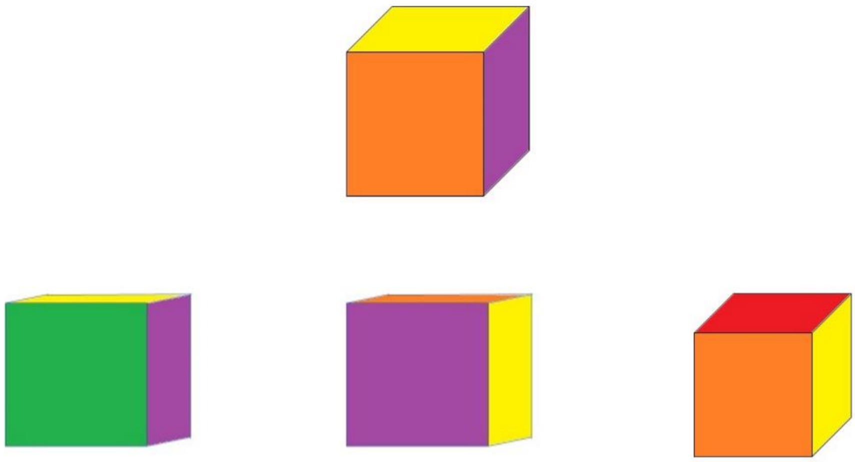
3)



4)

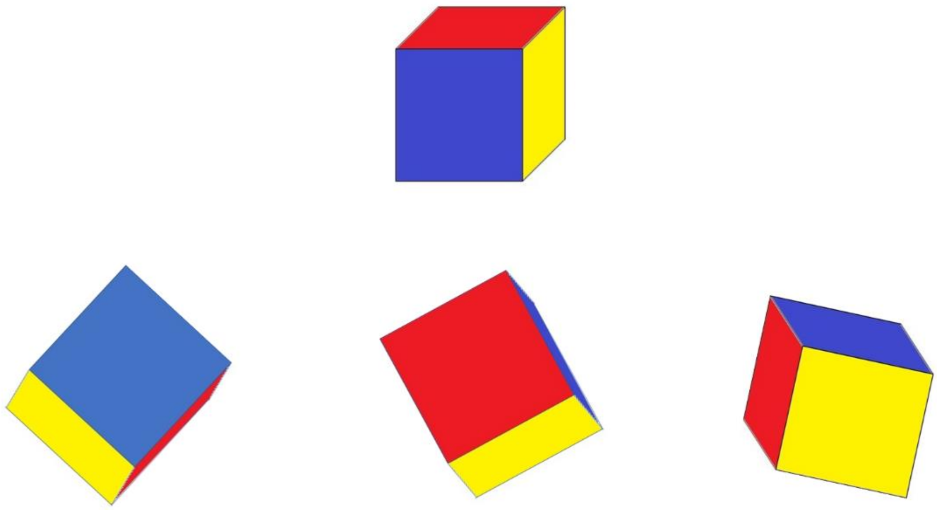


5)



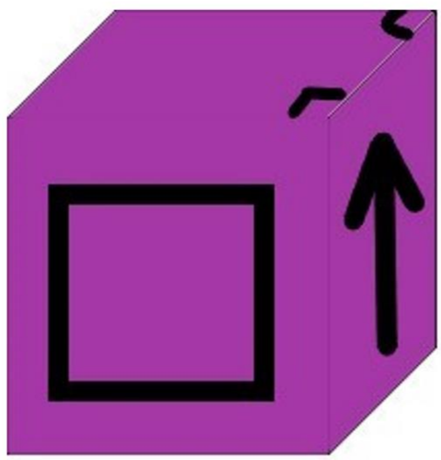
6)

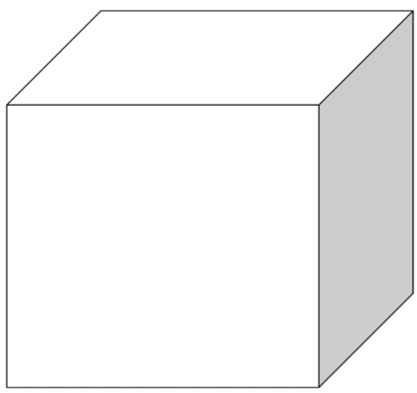
*Use your wooden cubes to help*



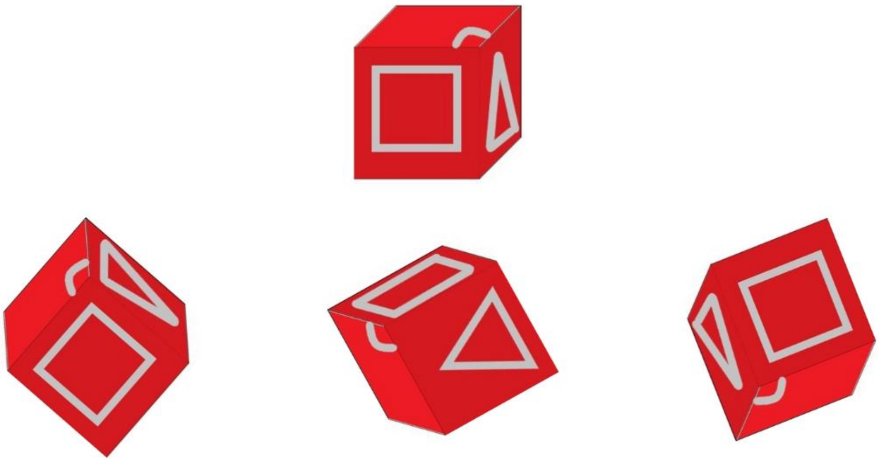
7)

8)

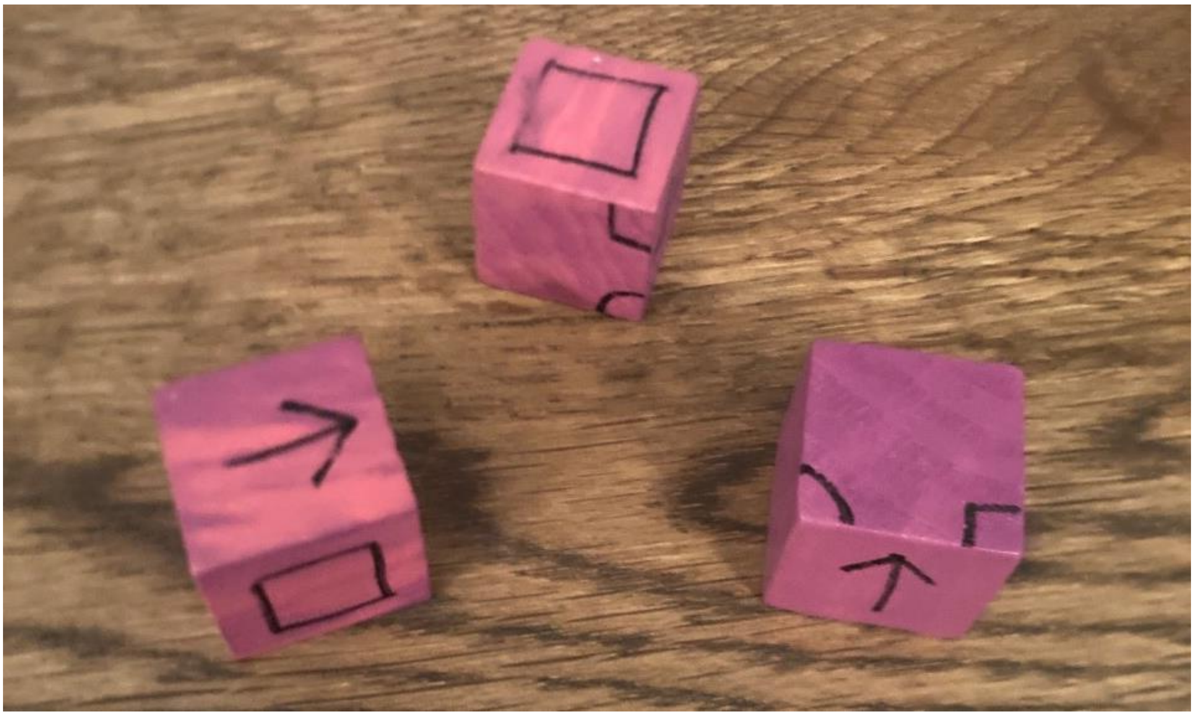


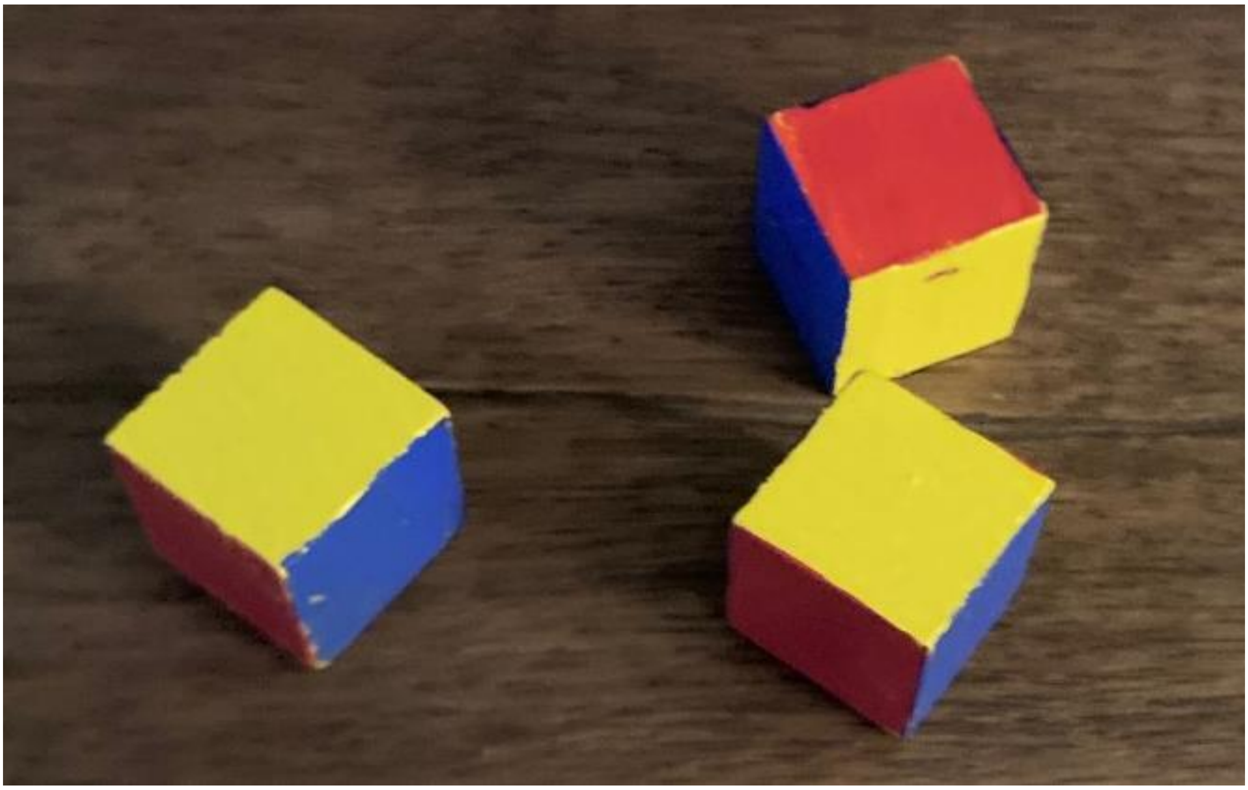


9)



*Materials*





**Session 3: Rotational Symmetry Materials**

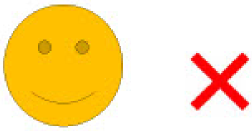
*Slides*

30/06/2022

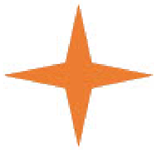
Rotational Symmetry

1

2



3



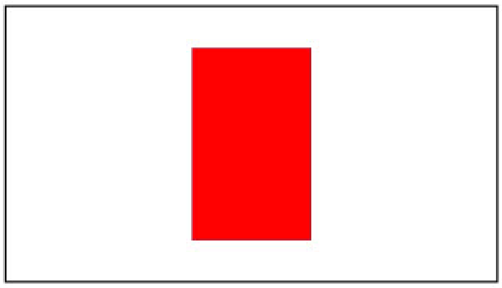
4

5

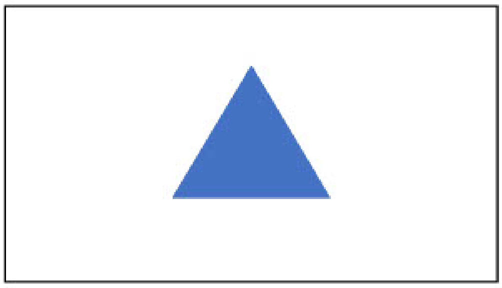
Now look at your worksheets at see if we can do some on your own...

TOP TIP: Use the shapes to help work it out

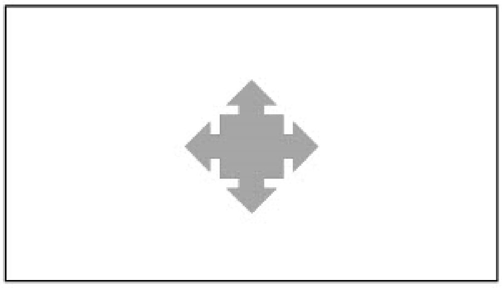
6



7



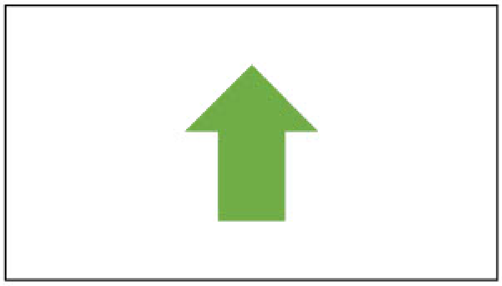
8



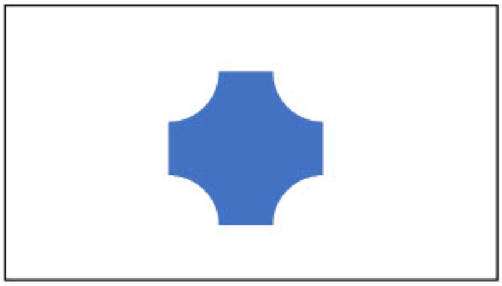
9

Now look let's see if you can do some in your head...

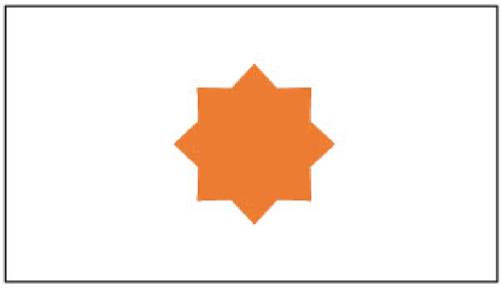
10



11



12



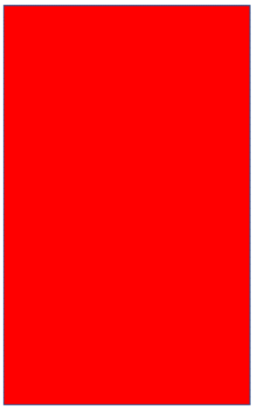
13

*Worksheet*

# Rotational Symmetry Worksheet

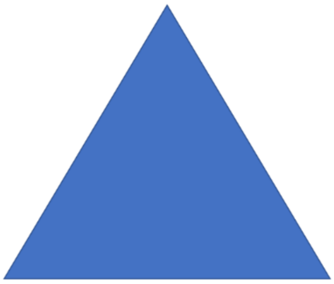
*Use your shapes available to help*

1)



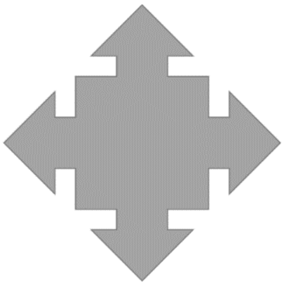
Answer:

2)



Answer:

3)

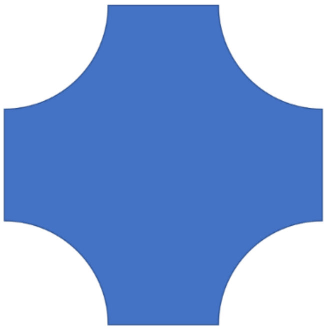


Answer:

4)

Answer:

5)



Answer:

6)

Answer:

## Session 4: Drawing and Navigating Maps Materials

*Slides*

30/06/2022

Drawing and Navigating Maps

1

Let me show you a bedroom…

2

3

4

5

6

30/06/2022

7


In which picture can you see the desk marked with the red X?

8

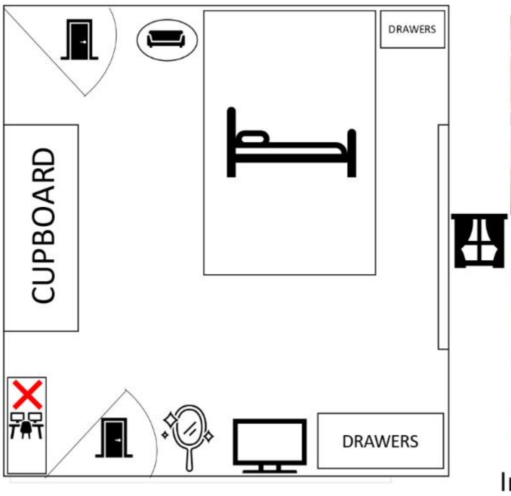
Now lets draw a floor plan of the classroom together…

9

Can you draw a floor map of a room in your house?

10

*Worksheet*




In which picture can you see the desk marked with the red X?

Can you draw a floor map of a room in your house?

## Session 5: Perspective Taking

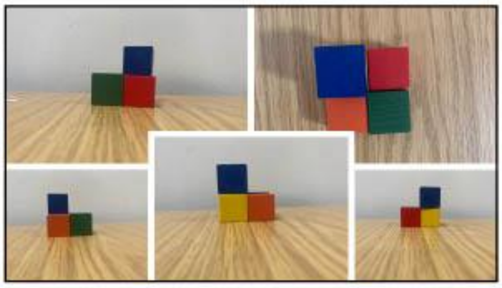
*Slides*



Perspective Taking

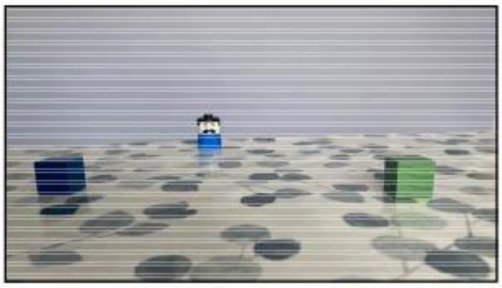
1

2

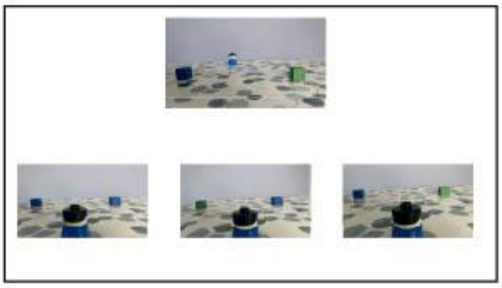


3


4

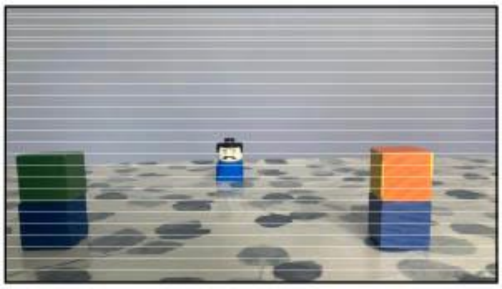


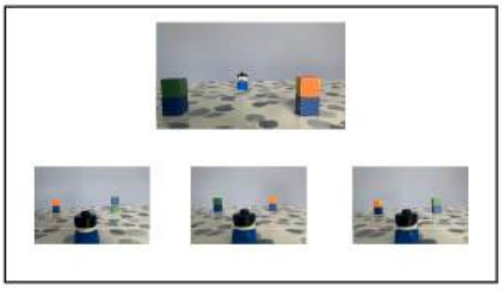
5

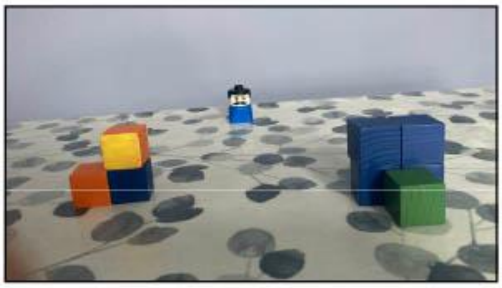


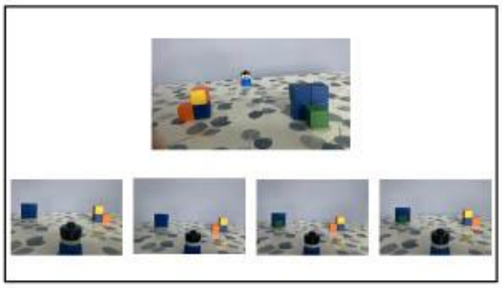
6

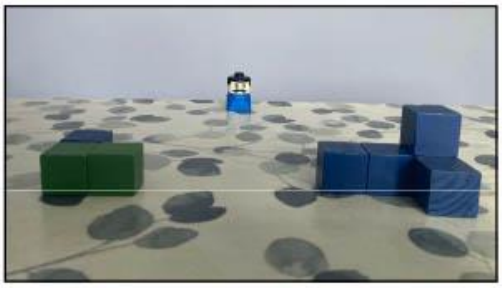
30/06/2022

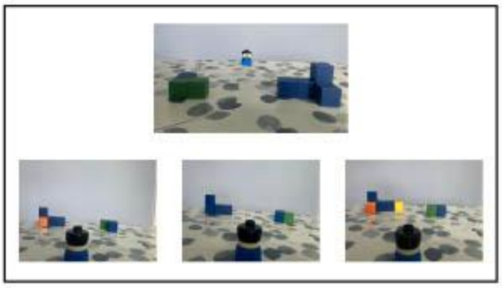

7


8


9


10


11


12

*Worksheet*

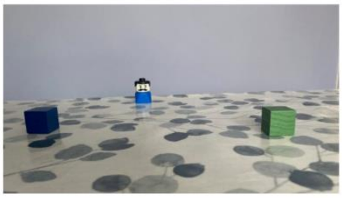
Perspective Taking Worksheet

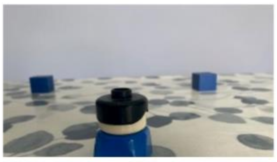
1. In pairs, use 5-6 blocks to make a small cube or tower.

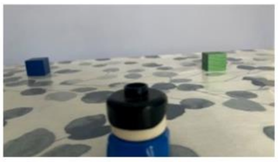
Now draw you cube or tower from 4 different perspectives below.

| | |
|---|---|
| | |
| | |

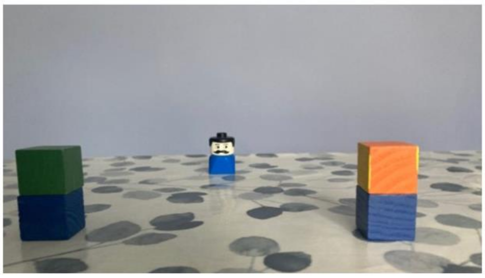
2. Which of these perspectives will Jeff see? Circle the correct answer.

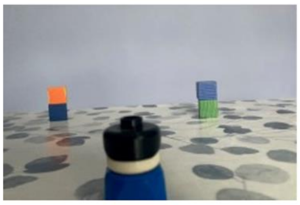


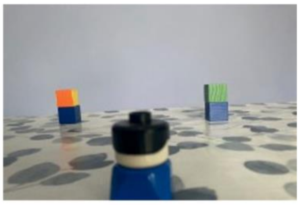




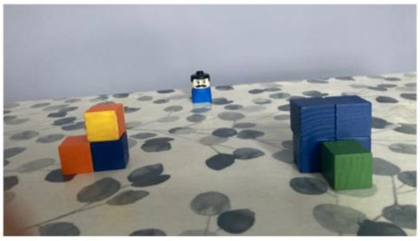
3. Which of these perspectives will Jeff see? Circle the correct answer.





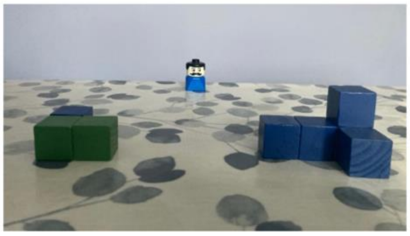


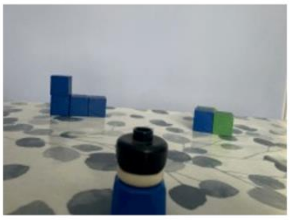
4. Which of these perspectives will Jeff see? Circle the correct answer.



5. Which of these perspectives will Jeff see? Circle the correct answer.

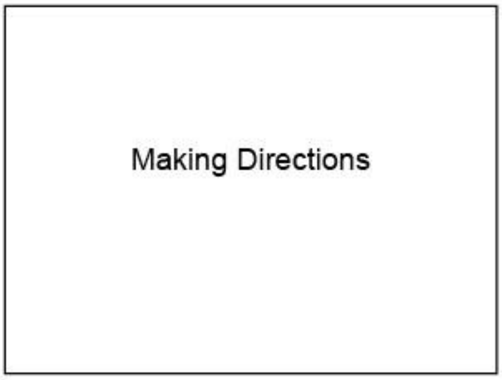


## Session 6: Making Directions

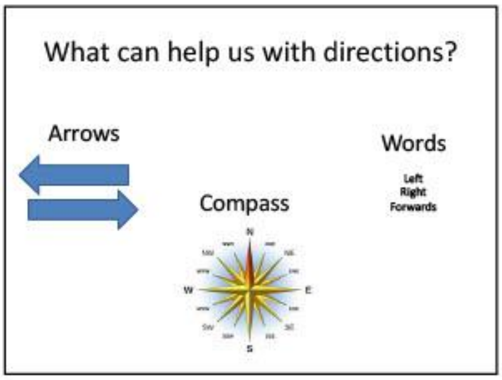
*Slides*

30/06/2022

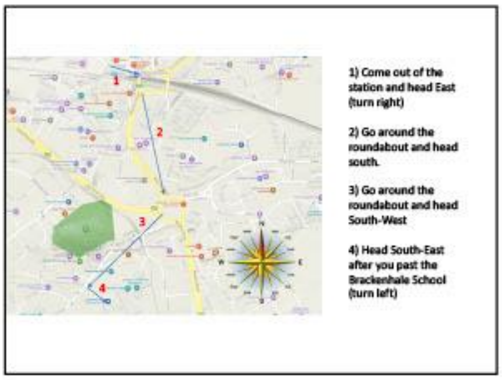



1

2




3



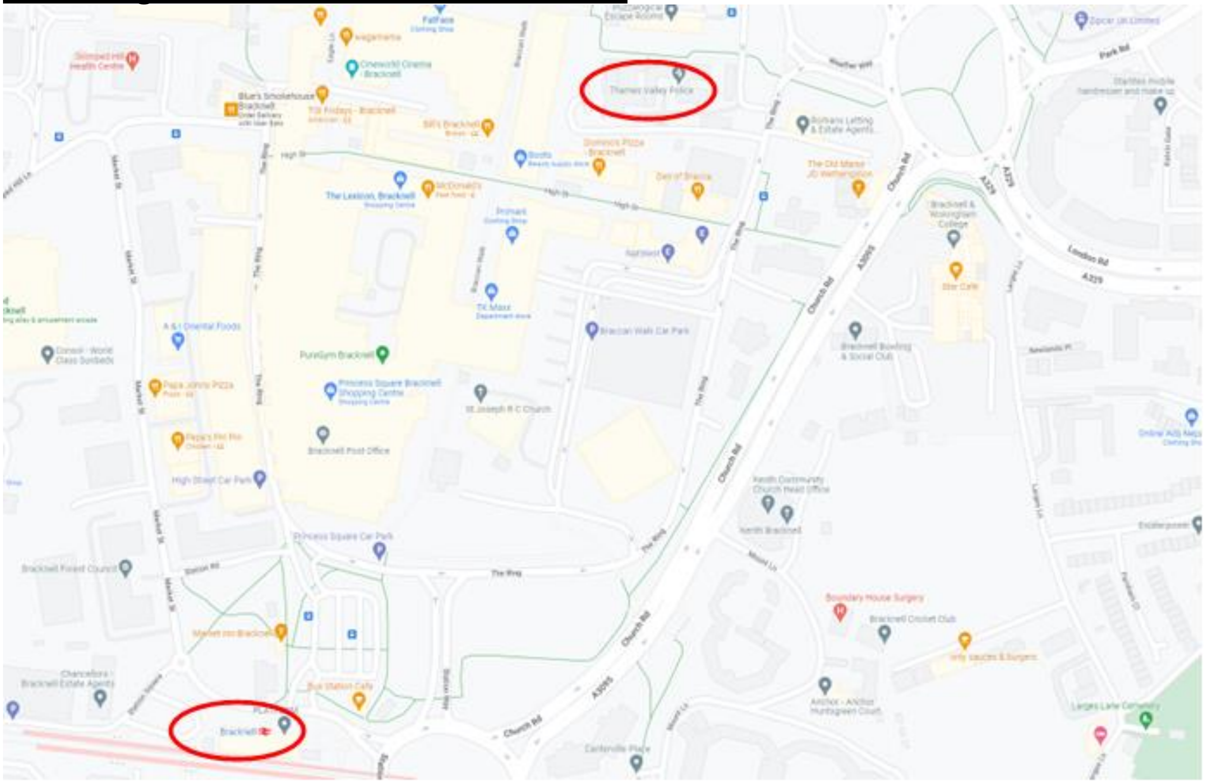

4


5


6

*Worksheet*

# Making Directions Worksheet



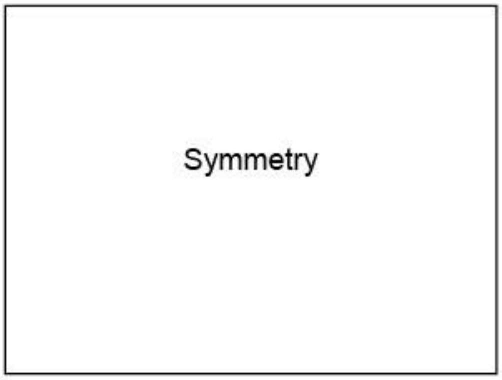
Can you write the directions from Bracknell Station to the Police Station?

| | |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |

## Session 8: Symmetry

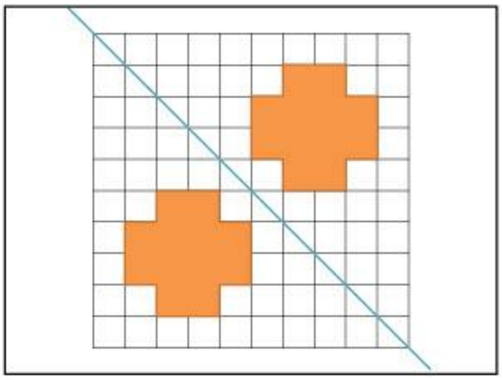
*Slides*



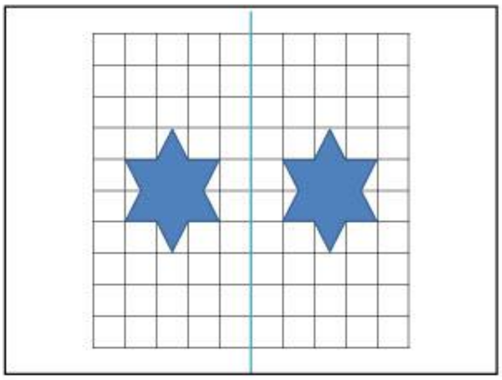



1

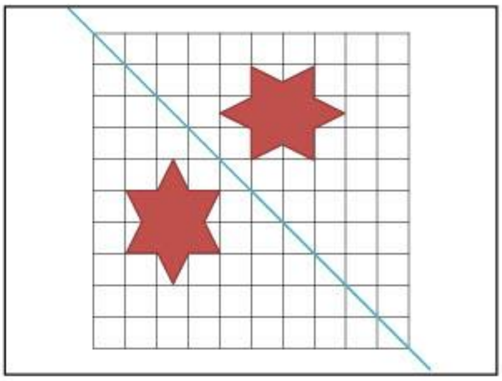

2



3



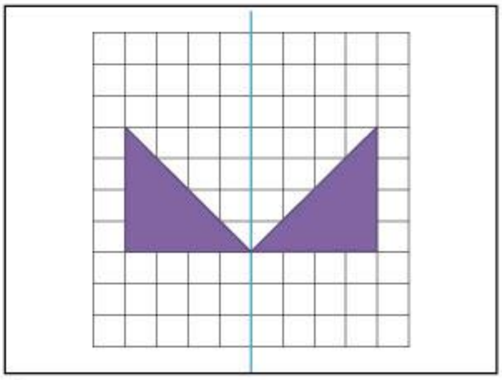
4



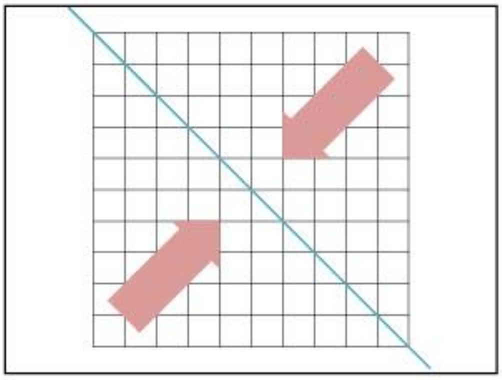
5


6

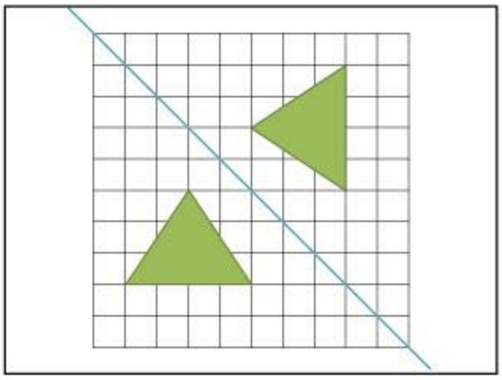
30/06/2022



7



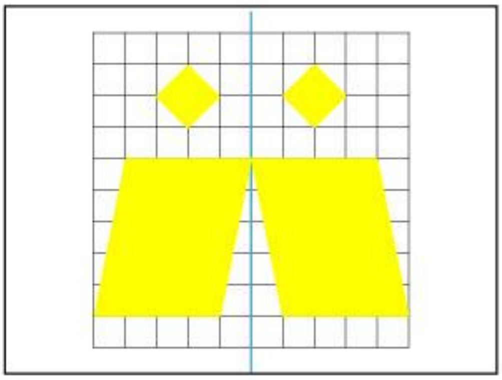
8



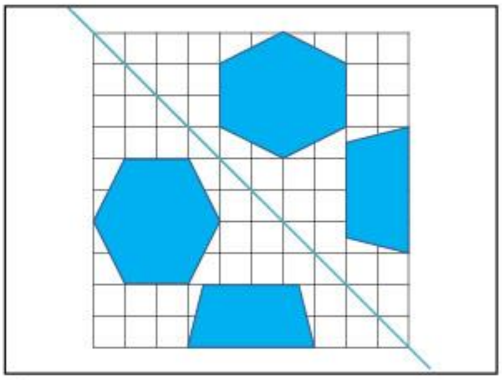
9

Now try these ones without the mirror
(you can use it to check afterwards)

10



11

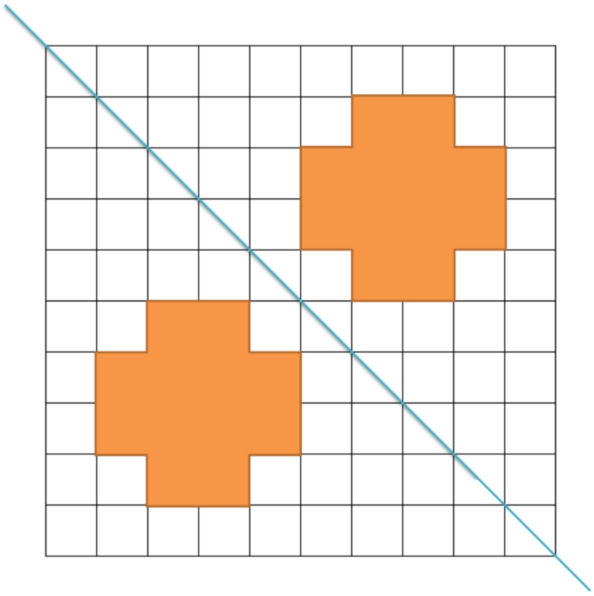


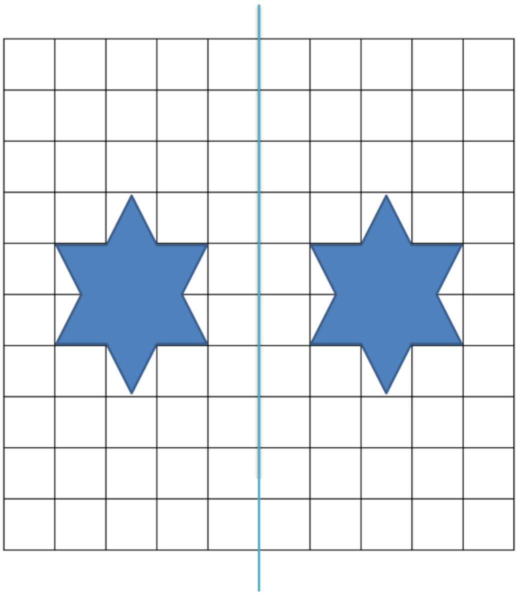
12

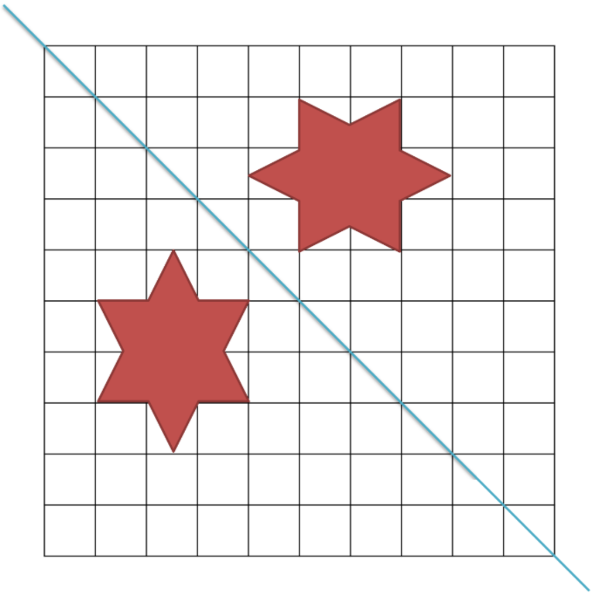
*Worksheet*

<u>Symmetry Worksheet</u>

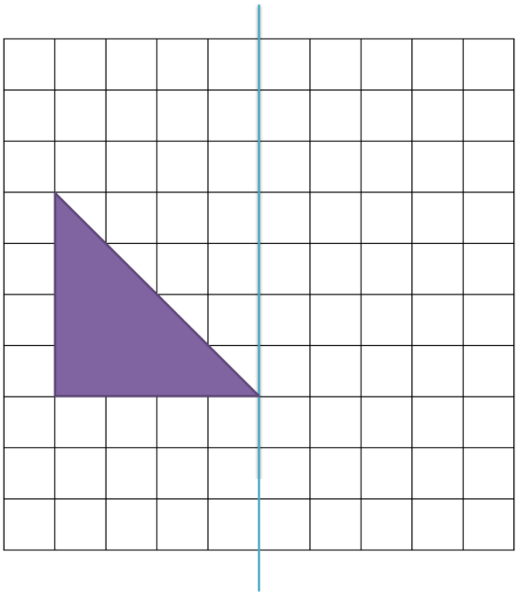
EXAMPLES

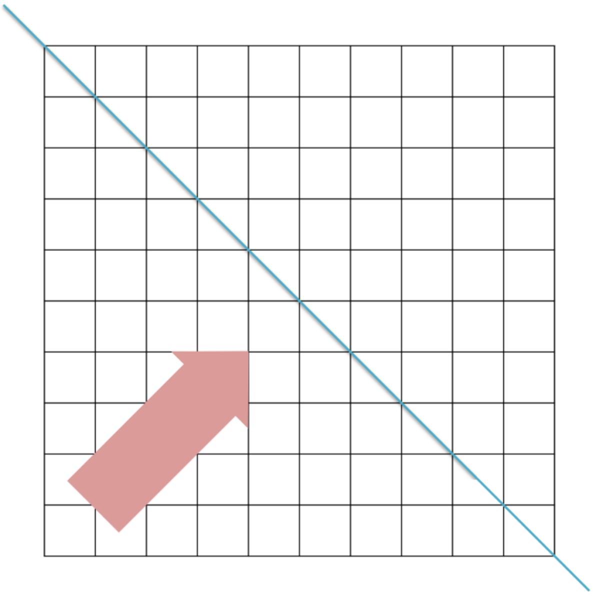


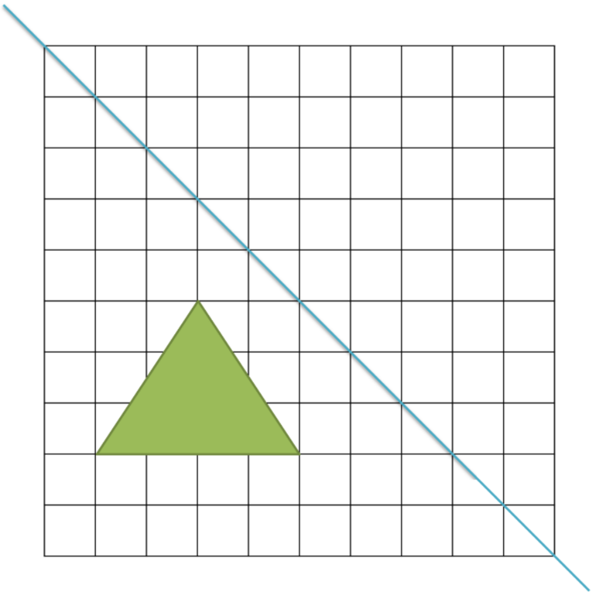




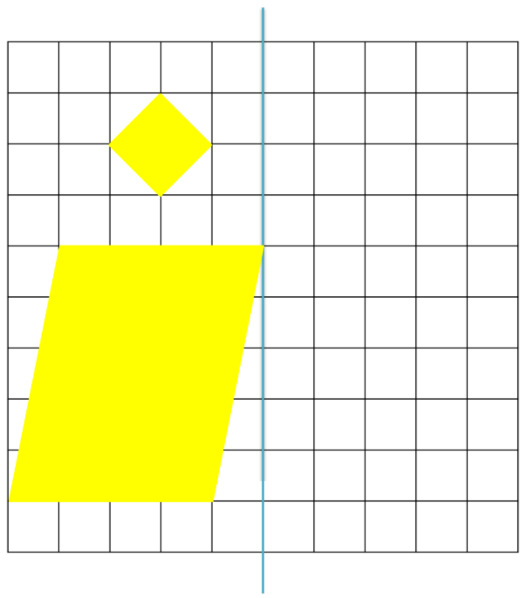
USE YOUR MIRROR TO HAVE A GO

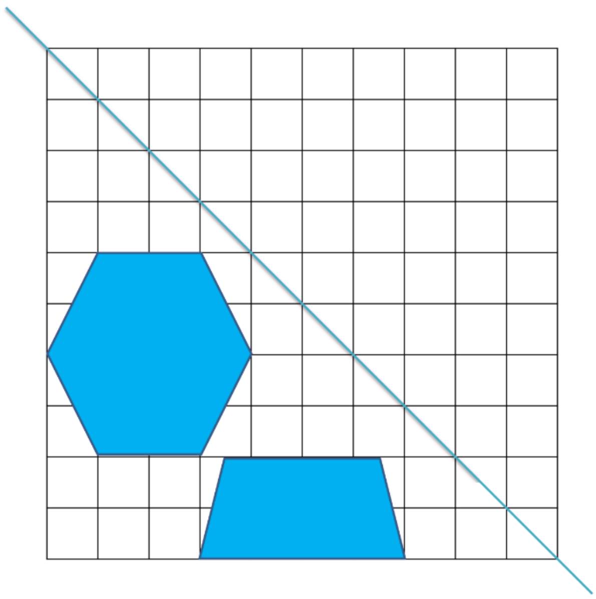






NOW TRY THESE ONES WITHOUT THE MIRROR (YOU CAN CHECK AFTERWARDS





# Appendix F: Information and Consent Forms

## Phase 1 - Parent consent form

INFORMATION AND CONSENT FORM

**AN INVISIBLE SKILL? INVESTIGATING THE IMPACT OF CHILDREN'S SPATIAL SKILLS ON MATHS ATTAINMENT AND SPATIAL SELF-CONCEPT.**

**1. What is this project?**

Spatial skills are a set of abilities which children use for many different tasks, such as when playing video games & sports. Research has shown that high spatial ability is linked to higher attainment in several areas of learning, especially maths and reading. Many people and children do not know what spatial skills are, and that they may have strengths related to them. The role of spatial skills in schools has been under-researched.

Self-Concept is a set of beliefs somebody has about themselves and how other people respond to them. Lots of different types of self-concept have been investigated by research, such as maths self-concept. Maths self-concept is how somebody rates themselves in their maths skills, enjoyment and interest in maths. Research has shown that children who feel that they are good at maths, enjoy it and are interested in it, are more likely to achieve better in maths classes This research will investigate a new kind of self-concept – spatial self-concept.

*Project Aims*

1) This project aims to develop a short 3-minute video to explain to children what spatial skills are, and when they use them.

   After watching this video, they will be asked a short questionnaire about their thoughts and feelings about these spatial skills.

2) This project aims to develop a measure of spatial self-concept.

**2. Who is conducting this research?**

I am a Trainee Educational Psychologist at the University of Exeter and this research form part of my doctoral qualification. My supervisors are Professor Brahm Norwich (B.Norwich@exeter.ac.uk) and Margie Tunbridge (M.Tunbridge@exeter.ac.uk).

I am also on placement as a Trainee Educational Psychologist, but I am conducting this research as a doctoral student and will not be able to offer psychological advice.

**3. What does being part of this study mean for me and my child?**

It will involve your child watching a short 3-min video, explaining what spatial skills are, and some of the times that they use them. They then will be asked to fill out a questionnaire including 20-25 questions. The questionnaire will take 10-15 minutes. They will be able to stop watching the video or not fill in any parts of the questionnaire, should they not want to. The questionnaire will ask them to rate, using a tick box, several statements for how true or false they think they are for them. Their responses will be recorded and may be published, in either journal articles or elsewhere, following this research.

**4. Who can I contact for further information?**

For further information about the research or the questionnaire, please contact:

**Thomas de Sausmarez**

Graduate School of Education

University of Exeter

Heavitree Rd

Exeter EX12LU

Td418@exeter.ac.uk

If you have any concerns/questions about the research you would like to discuss with someone else at the University, please contact:

**Professor Brahm Norwich**

Graduate School of Education

University of Exeter

Heavitree Rd

Exeter EX12LU

01392 724805

b.norwich@exeter.ac.uk

You may also contact the College of Social Sciences and International Studies Research Ethics Committee: ssis-ethics@exeter.ac.uk

**5. What will happen to my child's responses of the questionnaire?**

Data Protection Notice - The information you provide will be used for research purposes and you or your child's personal data will be processed in accordance with current data protection legislation and the University's notification lodged at the Information Commissioner's Office. You or your child's personal data will be treated in the strictest confidence and will not be disclosed to any unauthorised third parties. The results of the research will be published in anonymised form.

**Questionnaire responses**

You and your child's personal and contact details will be stored separately from their Questionnaire responses and may be retained for up to 5 years.

If you request it, you can be supplied with your child's questionnaire responses. You have the right to withdraw your child from the study at any time.

Third parties will not be allowed to access any personal identifiable information.

**CONSENT**

I have been fully informed about the aims and purposes of the project. I understand that:

there is no compulsion for me to participate in this research project and, if I do choose to participate, I may withdraw at any stage.

1. I confirm that I have read the information sheet for the above project. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without my legal rights being affected.

3. I understand that relevant sections of the data collected during the study, may be looked at by members of the research team or individuals from the University of Exeter where it is relevant to My taking part in this research. I give permission for these individuals to have access to my records.

4. I understand that taking part involves anonymised questionnaire responses to be used for the purposes of

   a) inclusion in an archive for a period of up to *5* years

   b) shared with other researchers for use in future research projects

   c) reports published in an academic publication

5. I agree to take part in the above project.

______________________

Name of Participant

______________________ ______________________ ______________________

Name of Parent Date Signature

## <u>**Phase 2 - Parent consent form**</u>

INFORMATION AND CONSENT FORM

**AN INVISIBLE SKILL? INVESTIGATING THE IMPACT OF CHILDREN'S SPATIAL SKILLS ON MATHS ATTAINMENT AND SPATIAL SELF-CONCEPT.**

1. **What is this project?**

Spatial skills are a set of abilities which children use for many different tasks (e.g., video games & sports) and in their learning (e.g., maths and reading). Research has shown that high spatial ability is linked to higher attainment in several areas of learning, especially maths and reading. Many people and children do not know what spatial skills are, and that they may have strengths related to them. The role of spatial skills in schools has been under-researched.

Self-Concept is a set of beliefs somebody has about themselves and how other people respond to them. Lots of different types of self-concept have been investigated by research, such as maths self-concept. Maths self-concept is how somebody rates themselves in their maths skills, enjoyment and interest in maths. Research has shown that children who feel that they are good at maths, enjoy it and are interested in it, are more likely to achieve better in maths classes. This research will investigate a new kind of self-concept – spatial self-concept.

This research aims to investigate whether a short 15-minute spatial skills intervention can lead to improvements in children's maths abilities, and impact on their thoughts and feelings towards different aspects of school, such as maths and reading.

I will be delivering this intervention in your child's classroom on a weekly basis throughout the Autumn Term.

2. **Who is conducting this research?**

I am a Trainee Educational Psychologist at the University of Exeter and this research form part of my doctoral qualification. My supervisors are Professor Brahm Norwich (B.Norwich@exeter.ac.uk) and Margie Tunbridge (M.Tunbridge@exeter.ac.uk).

I am also on placement as a Trainee Educational Psychologist, but I am conducting this research as a doctoral student and will not be able to offer psychological advice.

3. **What does being part of this study mean for me and my child?**

It will involve your child completing maths questions and a questionnaire before, and after the intervention is delivered. There will be 20 maths question test, that have been developed with primary school teachers. They will also be asked to answer some questionnaires about their thoughts and feelings about spatial skills, maths and reading. The questionnaire will ask them to rate, using a tick box, several statements for how true or false they think they are for them. Their responses will be recorded and may be published, in either journal articles or elsewhere, following this research.

4. **Who can I contact for further information?**

For further information about the research or the questionnaire, please contact:

**Thomas de Sausmarez**

Graduate School of Education

University of Exeter

Heavitree Rd

Exeter EX12LU

Td418@exeter.ac.uk

If you have any concerns/questions about the research you would like to discuss with someone else at the University, please contact:

**Professor Brahm Norwich**

Graduate School of Education

University of Exeter

Heavitree Rd

Exeter EX12LU

01392 724805

b.norwich@exeter.ac.uk

You may also contact the College of Social Sciences and International Studies Research Ethics Committee: ssis-ethics@exeter.ac.uk

5. **What will happen to my child's responses of the maths test and questionnaire?**

Data Protection Notice - The information you provide will be used for research purposes and you or your child's personal data will be processed in accordance with current data protection legislation and the University's notification lodged at the Information Commissioner's Office. You or your child's personal data will be treated in the strictest confidence and will not be disclosed to any unauthorised third parties. The results of the research will be published in anonymised form.

**Questionnaire responses**

You and your child's personal and contact details will be stored separately from their Questionnaire responses and may be retained for up to 5 years.

If you request it, you can be supplied with your child's questionnaire responses. You have the right to withdraw your child from the study at any time.

Third parties will be not allowed to access any personal identifiable information.

**CONSENT**

I have been fully informed about the aims and purposes of the project. I understand that:

there is no compulsion for me to participate in this research project and, if I do choose to participate, I may withdraw at any stage.

1) I confirm that I have read the information sheet for the above project. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

2) I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without my legal rights being affected.

3) I understand that relevant sections of the data collected during the study, may be looked at by members of the research team or individuals from the University of Exeter where it is relevant to My taking part in this research. I give permission for these individuals to have access to my records.

4) I understand that taking part involves anonymised questionnaire responses to be used for the

5) purposes of

   d) inclusion in an archive for a period of up to 5 years

   e) shared with other researchers for use in future research projects

   f) reports published in an academic publication

1. I agree to take part in the above project.

______________________

Name of Participant

______________________ ______________________ ______________________

Name of Parent Date Signature

## Appendix G – Ethical Approval Certificate

UNIVERSITY OF EXETER

GRADUATE SCHOOL OF EDUCATION

St Luke's Campus
Heavitree Road
Exeter UK EX1 2LU

http://socialsciences.exeter.ac.uk/education/

### CERTIFICATE OF ETHICAL APPROVAL

Title of Project:
The Impact of a spatial training programme on children's maths attainment and spatial self-concept.

Researcher(s) name: Tom De Sausmarez

Co-Investigators:

Supervisor(s): Brahm Norwich, Margie Tunbridge

This project has been approved for the period

From: 31/07/2021
To: 31/03/2022

Ethics Committee approval reference: D2021-201

Signature: Date: 21/07/2021

(Professor Justin Dillon, Professor of Science and Environmental Education, Ethics Officer)

## Appendix H – Nvivo Coding Hierarchy

Codes

| Name | Files | References |
|---|---|---|
| Implementation | 0 | 0 |
| — Quality of Intervention | 7 | 15 |
| — Enjoyment | 12 | 26 |
| — Understanding of Content | 12 | 30 |
| — Perception of Difficulty | 11 | 38 |
| Percieved Impact | 12 | 72 |
| — New Self Perceptions | 0 | 0 |
| — — New Understanding | 4 | 5 |
| — — Understanding of Indiv | 8 | 13 |
| — — Changes | 11 | 27 |
| — — Percieved Impact | 12 | 78 |
| — Transference | 7 | 12 |
| — — Transference to English | 6 | 7 |
| — — Transference to other s | 10 | 23 |
| — — Transference to Maths | 12 | 33 |
| — The Dynamic Nature of Spa | 12 | 26 |
| — — Variations in Spatial Ski | 8 | 13 |
| — — The Fragmental Nature | 11 | 16 |
| — — Impact of Spatial Skills | 11 | 18 |

# Appendix I – NVivo Coding Example

How?

> They were fun because we used colours and blocks and bedrooms.

What could have been better?

> I am not sure.

How could some of the skills you have learned during the spatial skills lessons help you in school?

> Errm, like maybe in maths there might be a question about perspectives. Maybe when I am playing with my friends. We might play a game that involves spatial skills.

What kind of games?

> Maybe like a mystery game where we are trying to solve a mystery. Like if we pretended there was a criminal, and they've got like a camouflage on the lock, and you have to use your spatial skills to know which box it is in.

Which lessons or subjects especially?

> Erm, im not sure.

What have you got better at since doing the spatial skills session?

> Maybe just like, being more confident, definitely with the perspective ones.

Mathematics lesson-related spatial tasks?

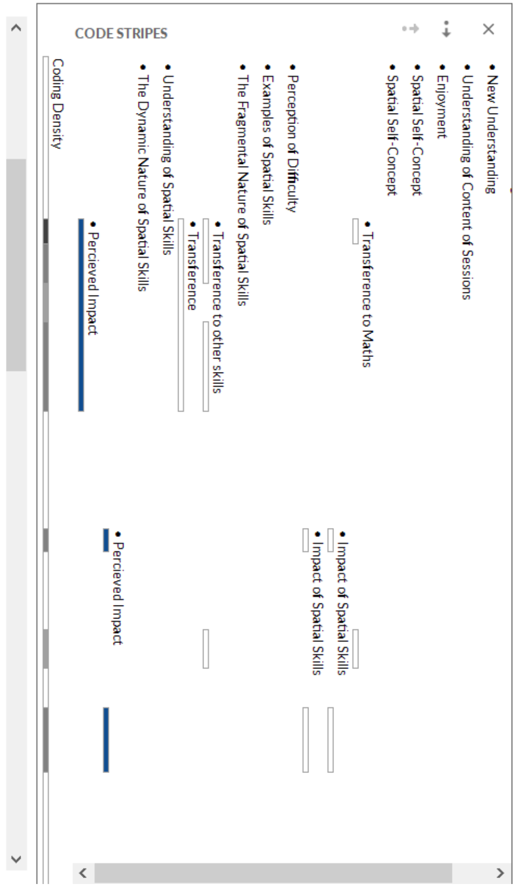
> Like solving problems where you don't have all of the information.

Can you explain that?

> Like the cube one where we had to look at figure out which block it was, and we couldn't see all of the cubes.

What have you learned about yourself and what you can do well and not so well?'

> Erm – I think I am pretty good at perspectives, but not as good at the 3D shapes.



# Bibliography

Ahmed, W., & Bruinsma, M. F. (2006). A structural model of self-concept, vautonomous motivation and academic performance in cross-cultural perspective. *Electronic Journal of Research in Educational Psychology, 4*(3), 551-576.

Aldridge, V. K., Dovey, T. M., & Wade, A. (2017). Assessing Test-Retest Reliability of Psychological Measures: Persistent Methodological Problems. *European Psychologist, 22*(4), 207-218. https://doi.org/10.1027/1016-9040/a000298

Allen, M. S., El-Cheikh, S., & Turner. (2017). A longitudinal investigation of irrational beliefs, hedonic balance and academic achievement. *Learning and Individual Differences, 58*, 41-45. https://doi.org/10.1016/j.lindif.2017.07.003

Allmark, P., & Machaczek, K. (2018). Realism and Pragmatism in a mixed methods study. *Journal of Advanced Nursing, 74*(6), 1301-1309. https://doi.org/10.1111/jan.13523

Amaro, E., Jr., & Barker, G. J. (2006). Study design in fMRI: Basic principles. *Brain and Cognition, 60*(3), 220–232. https://doi.org/10.1016/j.bandc.2005.11.009

Ashcraft, M. H. (2002). Math Anxiety: Personal, Educational, and Cognitive Consequences. *Current Directions in Psychological Science, 11*(5), 181-185. https://doi.org/10.3389/fpsyg.2019.01613

Ashcraft, M. H., & Moore, A. M. (2009). Mathematics anxiety and the affective drop in performance. *Journal of Psychoeducational Assessment, 27*, 197-205. https://doi.org/10.1177/0734282908330580

Bahari, S. F. (2010). Qualitative Versus Quantitative Research Strategies: Contrasting Epistemological and Ontological Assumptions. *Jurnal Teknologi, 52*(1), 17-28. https://doi.org/10.11113/sh.v52n1.256

Battista, M. T. (1990). Spatial visualization and gender differences in high school geometry. *Journal for Research in Mathematics Education, 21(*1), 47-60. https://doi.org/10.2307/749456

Baumeister, R. F., Campbell, J. D., Krueger, J. I., & Vohs, K. D. (2005). Exploding the self-esteem myth. *Scientific American Mind, 16*(4), 50-57. https://www.jstor.org/stable/2499771

Betz, N. (1978). Prevalence, distribution, and correlates of math anxiety in college students. *Journal of Counseling Psychology, 25*(5), 441-448. https://doi.org/10.1037/0022-0167.25.5.441

Bhaskar, R. (2008). *A Realist Theory of Science.* Taylor Francis.

Booth, J. L., & Koedinger, K. R. (2011). Are diagrams always helpful tools? Developmental and individual differences in the effect of presentation format on student problem solving. *British Journal of Educational Psychology, 82*(3), 492-511. https://doi.org/10.1111/j.2044-8279.2011.02041.x

Boyatzis, R. E. (1998). *Transforming qualitative information: Thematic analysis and code development.* Sage.

Branden, N. (1994). *Six pillars of self-esteem.* Bantam.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77-101. https://doi.org/10.1191/1478088706qp063oa

Braun, V., & Clarke, V. (2019). Reflecting on reflexive thematic analysis. *Qualitative Research in Sport, Exercise and Health, 11*(4), 589-597. https://doi.org/10.1080/2159676X.2019.1628806

Braun, V., & Clarke, V. (2021). Can I use TA? Should I use TA? Should I not use TA? Comparing reflexive thematic analysis and other pattern-based qualitative analytic approaches. *Counselling and Psychotherapy Research, 21*(1), 37-47. https://doi.org/10.1002/capr.12360

Briggs, C., & Young, B. (2003). Does reading recovery work in Kansas? A retrospective longitudinal study of sustained effects. *Journal of Reading Recovery, 3,* 59–64.

Brinthaupt, T. M., & Erwin, L. J. (1992). Reporting about the self: Issues and implications. In T. M. Brinthaupt & R. P. Lipka (Eds.), *The self: Definitional and methodological issues* (pp. 137–171). State University of New York Press.

Bruner, J. S. (1964). The course of cognitive growth. *American Psychologist, 19*(1), 1–15. https://doi.org/10.1037/h0044160

Burgoyne, C. (2010). *The Importance of Identifying Particular Strengths: Spatial Ability in Pupils who are at Risk of Not Learning to Read* (Doctoral dissertation, University of Exeter). https://ore.exeter.ac.uk/repository/handle/10036/3150?show=full

Burles, F., Guadagni, V., Hoey, F., Arnold, A. E. G. F., Levy, R. M., O'Neill, T., & Iaria, G. (2014). Neuroticism and self-evaluation measures are related to the ability to form cognitive maps critical for spatial orientation. *Behavioural Brain Research, 271,* 154-159. https://dx.doi.org/10.1016/j.bbr.2014.06.002

Burr, V. (2015). *Social Constructionism* (3rd Ed.). Routledge. https://doi.org/10.4324/9781315715421

Butler, R. J., & Gasson, S. L. (2005). Self-esteem/ self-concept scales for children and adolescents: A review. *Child and Adolescent Mental Health, 10*(4), 190–201. https://doi.org/10.1111/j.1475-3588.2005.00368.x

Byrne, B. M. (1996). Academic self-concept: Its structure, measurement, and relation to academic achievement. In B. A. Bracken (ed.), *Handbook of self-concept: developmental, social, and clinical considerations,* (pp 287–316). Wiley.

Byrne, B. M. (1996). *Measuring self-concept across the life span: Issues and instrumentation.* American Psychological Association. https://doi.org/10.1037/10197-000

Carbonneu, K., Marley, S. C., & Selig, J. P. (2013). A Meta-Analysis of the efficacy of teaching mathematics with concrete manipulatives. *Journal of Educational Psychology, 105*(2), 380-400. https://dx.doi.org/10.1037/a0031084

Chamorro-Premuzic, T., & Furnham, A. (2006). Intellectual Competence and the intelligent personality: A third way in differential psychology. Review of General Psychology, 10, 251-267. https://doi.org/10.1037/1089-2680.10.3.251

Cheng, K. K. F., & Metcalfe, A. (2018). Qualitative Methods and Process Evaluation in Clinical Trials Context: Where to Head to? *International Journal of Qualitative Methods, 17*(1), 1-4. https://doi.org/10.1177/1609406918774212

Clarke, V., & Braun, V. (2013). *Successful Qualitative Research: A Practical Guide for Beginners.* Sage.

Cohen, R. J., & Swerdlik, M. E. (2017). *Psychological testing and assessment* (9th ed.). McGraw-Hill Education.

Cokley, K. O. (2003). What Do We Know about the Motivation of African American Students? Challenging the "Anti-Intellectual" Myth. *Harvard Educational Review, 73*(4), 524–558. https://doi.org/10.17763/haer.73.4.3618644850123376

Cokley, K. O., Bernard, N., Cunningham, D., & Motoike, J. (2001). A psychometric investigation of the Academic Motivation Scale using a United States sample. *Measurement and Evaluation in Counseling and Development, 34*(2), 109–119. https://doi.org/10.1080/07481756.2001.12069027

Cook, D. A., & Beckman, T. J. (2006). Current concepts in validity and reliability for psychometric instruments: Theory and application. *The American Journal of Medicine, 119*, 7-16. https://doi.org/10.1016/j.amjmed.2005.10.036

Cooper, E. E., Ness, M., & Smith, M. (2004). A Case Study of a Child With Dyslexia and Spatial-Temporal Gifts. *Gifted Child Quarterly, 48*(2), 83-94. https://doi.org/10.1177/001698620404800202

Creswell, J. W., & Plano-Clark, V. L. (2007). *Designing and Conducting Mixed Methods Research.* (2nd Edition). SAGE.

Cruickshank, J. (2012). Positioning positivism, critical realism and social constructionism in the health sciences: a philosophical orientation. *Nursing Inquiry, 19*(1), 71-82. https://doi.org/10.1111/j.1440-1800.2011.00558.x

David, L. T. (2012). Training effects of mental rotation, spatial orientation and spatial visualisation depending on the initial level of spatial abilities. *Procedia – Social* *and Behavioural Sciences, 33,* 328-332. https://doi.org/10.1016/j.sbspro.2012.01.137

Deci, E. L., & Ryan, R. M. (1995). Human autonomy: The basis for true self-esteem. In M. H. Kernis (Ed.), *Efficacy, agency, and self-esteem* (pp. 31–49). Plenum Press.

Devers, K. J. (1999) How will we know “good” qualitative research when we see it? Beginning the dialogue in health services research. *Health Services Research, 34,* 1153-1188. https://pubmed.ncbi.nlm.nih.gov/10591278/

Devine, A., Fawcett, K., Szűcs, D., & Dowker, A. (2012). Gender differences in mathematics anxiety and the relation to mathematics performance while controlling for test anxiety. Behavioral and Brain Functions, 8(1), 33. doi:10.1186/1744-9081-8-33. https://doi.org/10.1186/1744-9081-8-33

Dodgson, J. E. (2019). Reflexivity in Qualitative Research. *Journal of Human Lactation, 35*(2), 220-222. https://doi.org/10.1177/0890334419830990

Duff, K., Beglinger, L. J., Schultz, S. K., Moser, D. J., McCaffrey, R. J., Haase, R. F., Westervelt, H. J. K., Langbehn, D. R., & Paulsen, J. S. (2007). Practice effects in the prediction of long-term cognitive outcome in three patient samples: a novel prognostic index. *Archives of Clinical Psychology, 22*(1), 15-24. https://doi.org/10.1016/j.acn.2006.08.013

Dunsmuir, S., Frederickson, N., & Lang, J. (2017). Meeting Current Challenges in School Psychology Training: The Role of Problem-Based Learning. *School Psychology Review, 46*(4), 395-407. https://10.17105/SPR-2016-0017.V46-4

Elliot, C. D., & Smith, P. (2011). *The British Ability Scales 3.* GL Assessment.

Feng, J., Spence, I., & Pratt, J. (2007). Playing and action video game reduces gender differences in spatial cognition. Psychological Science, 18(10), 850–855. https://doi.org/10.1111/j.1467-9280.2007.01990.x

Fereday, J. & Muir-Cochrane, E. (2006). Demonstration Rigor Using Thematic Analysis: A Hybrid Approach of Inductive and Deductive Coding and Theme Development. *International Journal of Qualitative Methods, 5*(1), 80-92. https://doi.org/10.1177/160940690600500107

Ferguson, A. M., Maloney, E. A., Fugelsang, J., & Risko, E. F. (2015). On the relation between math and spatial anxiety: The case of math anxiety. *Learning and Individual Differences, 39,* 1-12. https://doi.org/10.1016/j.lindif.2015.02.007

Ferreira, K. E., & Adleman, N. E. (2020). Memory, emotion regulation, and social inference skills in college students. *Current Psychology, 39*(4), 1269-1276. https://dx.doi.org/10.1007/s12144-018-9833-7

Flahive, M. W., Chuang, Y., & Li, C. (2011). Reliability and validity evidence of the Chinese Piers-Harris children's self-concept scores among Taiwanese children. *Journal of Psychoeducational Assessment, 29*(3), 273-285. https://doi.org/10.1177/0734282910380191

Freeman, L., & Miller, A. (2001). Norm-referenced, Criterion-referenced, and Dynamic Assessment: What exactly is the point? *Educational Psychology in Practice 17*(1), 3-16. https://dx.doi.org/10.1080/02667360120039942

Germain, M. L. (2006). Stages of Psychometric Measure Development: The Example of the Generalized Expertise Measure (GEM). *Online Submission.* https://files.eric.ed.gov/fulltext/ED492775.pdf

Ghazvini, S. D. (2011). Relationships between academic self-concept and academic performance in high school students. *Procedia – Social and Behavioural Sciences, 15,* 1034-1039. https://doi.org/10.1016/j.sbspro.2011.03.235

Giovagnoli, G., Vicari, S., Tomassetti, S., & Menghini, D. (2016). The role of visual-spatial abilities in dyslexia: Age differences in children's reading? *Frontiers in Psychology, 7,* Article 1997. https://doi.org/10.3389/fpsyg.2016.01997

Gore, J., & Cross, S. E. (2011). Defining and Measuring Self-Concept Change. *Psychological Studies, 56*(1), 135-141. https://doi.org/10.1007/s12646-011-0067-0

Gore, J., & Cross, S. E. (2011). Defining and Measuring Self-Concept Change. *Psychological Studies 56*(1), 135-141. https://dx.doi.org/10.1007/s12646-011-0067-0

Groth-Marnat, G. (2009)*. Handbook of psychological assessment (5th ed.). John Wiley & Sons Inc.*

Grove, J. (2017). Researching a marginalised group: Reflections on being an outsider. *Counselling and Psychotherapy Research, 17*(3), 176–180. https://doi.org/10.1002/capr.12120

Guay, F., Marsh, H. W., & Boivin, M. (2003). Academic self-concept and academic achievement: Developmental perspectives on their causal ordering. *Journal of Educational Psychology, 95,* 124–136. https://doi.org/10.1037/0022-0663.95.1.124

Guerin, S. & Tatlow-Golden, M. (2019). How valid are measures of children's self-concept/self-esteem? Factors and content validity in three widely used scales.

*Child Indicators Research, 12,* 1507-1528. https://doi.org/10.1007/S12187-018-9576-X

Guest, G., MacQueen, K. M., Namey, E. E. (2012). *Applied Thematic Analysis.* Sage. https://dx.doi.org/10.4135/9781483384436

Guo, Y. (2018). The Influence of Academic Autonomous Motivation on Learning Engagement and Life Satisfaction in Adolescents: The Mediating Role of Basic Psychological Needs Satisfaction. *Journal of Education and Learning, 7*(4), 254-261. https://doi.org/10.5539/jel.v7n4p254

Haig, B. D. (2009). Inference to the best explanation: A neglected approach to theory appraisal in psychology. *The American Journal of Psychology, 122*(2), 219-234. https://doi.org/10.2307/27784393

Harper, C. E. (2011). Identity, intersectionality, and mixed-methods approaches. *New Directions for Institutional Research, 151,* 103-115. https://doi.org/10.1002/ir.402

Harter, S. (1982). The Perceived Competence Scale for Children. *Child Development*, *53*, 87–97. https://doi.org/10.2307/1129640

Hegarty, M. (2010). *Components of spatial intelligence.* In B. H. Ross (Ed.), *The psychology of learning and motivation: Vol. 52. The psychology of learning and motivation: Advances in research and theory* (pp. 265–297). Elsevier Academic Press.

Hegarty, M., & Kozhevnikov, M. (1999). Types of visual–spatial representations and mathematical problem solving. *Journal of Educational Psychology, 91*(4), 684–689. https://doi.org/10.1037/0022-0663.91.4.684

Hegarty, M., & Waller, D. (2004). A dissociation between mental rotation and perspective-taking spatial abilities. *Intelligence, 32,* 175–191. https://doi.org/10.1016/j.intell.2003.12.001

Heine, S. J., Lehman, D. R., Markus, H. R., & Kitayama, S. (1999). Is there a universal need for positive self-regard? *Psychological Review, 106*(4), 766–794. https://doi.org/10.1037/0033-295X.106.4.766

Heine, S. J., Lehman, D. R., Markus, H. R., & Kitayama, S. (1999). Is there a universal need for positive self-regard? *Psychological Review, 106(*4), 766–794. https://doi.org/10.1037/0033-295X.106.4.766

Helenius, P., Tarkianinen, A., Cornelissen, P. C., Hansen, P. C., & Salmelin, R. (1999). Dissociation of Normal Feature Analysis and Deficient Processing of Letter-strings in Dyslexic Adults. *Cerebral Cortex, 9*(5), 476-483. https://doi.org/10.1093/cercor/9.5.476

Hembree, R. (1990). The nature, effects, and relief of mathematics anxiety. *Journal for Research in Mathematics Education, 21*(1), 33-46. https://doi.org/10.2307/749455

Higgins, E., Fitzgerald, J., Howard, S. (2015). “Literacy Lift-Off”: an experimental evaluation of a reading recovery programme on literacy skills and reading self-concept. *Educational Psychology in Practice, 21*(3), 247-264. https://doi.org/10.1080/02667363.2015.1030592

Hill, C., Waite, P. & Creswell, C. (2016). Anxiety disorders in children and adolescents. *Paediatrics and Child Health, 26* (12), 548-553. https://doi.org/10.1016/j.paed.2016.08.007

Hillerbrand, E. T. (1988). Aristotle and epistemology: Implications for professional psychological training. *Professional Psychology: Research and Practice, 19*(4), 468–473. https://doi.org/10.1037/0735-7028.19.4.468

Hinkin, T. (1995). A review of scale development practices in the study of organizations. *Journal of Management*, *21*(5), 967-988. https://doi.org/10.1016/0149-2063(95)90050-0

Hofstede, G. (2011). Dimensionalizing Cultures: The Hofstede Model in Context. *Online Readings in Psychology and Culture, 2*, 8. http://dx.doi.org/10.9707/2307-0919.1014

Hofstede, G., Hofstede, G. J., & Minkov, M. (2010). *Cultures and Organizations: Software of the Mind. Revised and Expanded*, (3rd Ed.). McGraw-Hill.

Holmes, J., Adams, J. W., & Hamilton, C. J. (2008). The relationship between visuospatial sketchpad capacity and children's mathematical skills. *European Journal of Cognitive Psychology, 20*(2), 272-289. https://doi.org/10.1080/09541440701612702

Howe, K. (1998). The Interpretive Turn and the New Debate in Education. *Educational Researcher, 27*(8), 13-21. https://doi.org/10.3102/0013189X027008013

Howe, K. R. (1988). Against the Quantitative-Qualitative Incompatibility Thesis or Dogmas Die Hard. *Educational Researcher, 17*(8), 10-16. https://doi.org/10.3102/0013189X017008010

Huang, C. (2011). Self-concept and academic achievement: a meta-analysis of longitudinal relations. *Journal of School Psychology, 49*(5), 505-528.

https://doi.org/10.1016/j.jsp.2011.07.001

Hussain, S., & Woods, K. (2019). The use of dynamic assessment by educational psychologists in the early years foundation stage. *Educational Psychology in Practice, 25*, 424-439. https://doi.org/10.1080/02667363.2019.1643293

Jager, J., Putnick, D. L., Bornstein, M. H. (2017). More than Just Convenient: The Scientific Merits of Homogeneous Convenience Samples. *Monographs of the Society for Research in Child Development, 82*(2), 13-30. https://doi.org/10.1111/mono.12296.

James, W. (1890). *The Principles of Psychology.* Dover Publications.

Jameson, M. M., & Fusco, B. R. (2014). Math Anxiety, Math Self-Concept, and Math Self-Efficacy in Adult Learners Compared to Traditional Undergraduate Students. *Adult Education Quarterly, 64*(4), 306-322. https://doi.org/10.1177/0741713614541461

Jebb, A. T., Parrigon, S., & Eun Woo, S. (2017). Exploratory data analysis as a foundation of inductive research. *Human Resource Management Review, 27*(2), 265-276. https://doi.org/10.1016/j.hrmr.2016.08.003

Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed Methods Research: A Research Paradigm Whose Time Has Come. *Educational Researcher, 33*(7), 14-26. http://dx.doi.org/10.3102/0013189X033007014

Jones, K. (2002). Issues in the teaching and learning of geometry. In L. Haggarty (Ed), *Aspects of teaching secondary mathematics: Perspectives on practice* (pp 121-139). Routledge Falmer.

Kell, H. J., Lubinski, D., Benbow, C. P., & Steiger, J. H. (2013). Creativity and technical innovation spatial ability's unique role. *Psychological Science*, *24*(9), 1831–1836. https://doi.org/10.1177/0956797613478615

Kinnear, P. R., & Gray, C. D. (2006). *SPSS 14 Made Simple.* Psychology Press.

Kirby, P. (2020). Dyslexia debated, then and now: a historical perspective on the dyslexia debate. *Oxford Review of Education, 46*(4), 472-486. https://doi.org/10.1080/03054985.2020.1747418

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development (Vol. 1).* Prentice-Hall.

Kozhevnikov, M., & Hegarty, M. (2001). A dissociation between object manipulation spatial ability and spatial orientation ability. *Memory & Cognition, 29*(5), 745–756. https://doi.org/10.3758/BF03200477

Kozhevnikov, M., Hegarty, M., & Mayer, R. (1999*). Students' use of imagery in solving qualitative problems in kinematics.* (Report No. 143). US. (ERIC Document Reproduction Service No. ED 433 239). Retrieved from ERIC Website: https://eric.ed.gov/?id=ED433239

Kozhevnikov, M., Hegarty, M., & Mayer, R. E. (2002). Revising the Visualiser-Verbaliser Dimension: Evidence for Two Types of Visualisers. *Cognition & Instruction, 20*(1), 47-77. https://doi.org/10.1207/S1532690XCI2001_3

Kozhevnikov, M., Kosslyn, S. M., & Shepard, J. (2005). Spatial versus object visualizers: A new characterisation of visual cognitive style. *Memory & Cognition, 33*(4), 710-726. https://doi.org/10.3758/BF03195337

Lauer, J. E., Esposito, A. G. & Bauer, P. J. (2018). Domain-specific anxiety relates to children math and spatial performance. *Developmental Psychology, 54*(11), 2126-2138. https://doi.org/10.1037/dev0000605

Leroyal, C. (2021). Critical realism. *Salem Press Encyclopedia.* Salem Press. https://uoelibrary.idm.oclc.org/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=ers&AN=133860732&site=eds-live&scope=site

Lewin, S., Glenton, C., & Oxman, A. D. (2009). Use of qualitative methods alongside randomised controlled trials of complex healthcare interventions: methodological study. *The British Medical Journal, 339,* 1-7. doi: https://doi.org/10.1136/bmj.b3496

Likhanov, M., Zakharov, I., Kuzmina, Y., Budakova, A., Vasin, G., Malykh, S., & Kovas, Y. (2017). Maths Anxiety Does Not Moderate the Link Between Spatial and Maths Ability. *The European Proceedings of Social & Behavioural Sciences, 33*(21), 212-226. https://dx.doi.org/10.15405/epsbs.2017.12.21

Linn, M. C., & Petersen, A. C. (1985). Emergence and characterization of sex differences in spatial ability: a meta-analysis. *Child Development, 56*, 138–151. http://dx.doi.org/10.2307/1130467

Lowrie, T., Logan, T., & Ramful, A. (2017). Visuospatial training improves elementary students' mathematics performance. *British Journal of Education Psychology, 87*, 170–186. https://doi.org/10.1111/bjep.12142

Lowrie, T., Logan, T., Harris, D., & Hegarty, M. (2018). The impact of an intervention program on students' spatial reasoning: student engagement through mathematics-enhanced learning activities. *Cognitive Research: Principles and Implications, 3*(10), 1-10. https://doi.org/10.1186/s41235-018-0147-y

Lumley, T., Diehr, P., Emerson, S., & Chen, L. (2002). The importance of the normality assumption in large public health data sets. *Annual Review of Public Health, 23,* 151-169. https://doi.org/10.1146/annurev.publhealth.23.100901.140546

Luo, W., Hogan, D., Tan, L. S., Kaur, B., Ng, P. T., & Chan, M. (2014). Self-construal and students' math self-concept, anxiety and achievement: An examination of achievement goals as mediators. *Asian Journal of Social Psychology, 17*, 184-195. https://doi.org/10.1111/ajsp.12058

Maeda, Y., & Yoon, S. Y. (2013). A Meta-Analysis on Gender Differences in Mental Rotation Ability Measured by the Purdue Spatial Visualization Tests: Visualization of Rotations (PSVT:R). *Educational Psychology Review, 25,* 69-94. http://dx.doi.org/10.1007/s10648-012-9215-x

Maloney, E. A., Ansari, D., & Fugelsang, J. (2011). The effect of mathematics anxiety on the processing of numerical magnitude. *The Quarterly Journal of Experimental Psychology, 64*(1), 10-16. https://doi.org/10.1080/17470218.2010.533278

Markus, H. R., & Kitayama, S. (1991). Culture and the Self: Implications for Cognition, Emotion, and Motivation. *Psychological Review, 98*(2), 224-253. https://dx.doi.org/10.1037/0033-295X.98.2.224

Marsh, H. W. (1984). Self-concept: The Application of a Frame of Reference Model of Explain Paradoxical Results. *Australian Journal Education, 28*(2), 165-181.

Marsh, H. W. (1986). Verbal and math self-concept: An internal/external frame of reference model. *American Educational Research Journal, 23,* 129-149. https://doi.org/10.3102/00028312023001129

Marsh, H. W. (1990). The causal ordering of academic self-concept and academic achievement: A multiwave, longitudinal panel analysis. *Journal of Educational Psychology,* 82*,* 646–656. https://doi.org/10.1348/000709910X503501

Marsh, H. W. (1992). Content specificity of relations between academic achievement and academic self-concept. *Journal of Educational Psychology, 84*(1), 35–42. https://doi.org/10.1037//0022-0663.84.1.35

Marsh, H. W. (2007). *Self-concept theory, measurement and research into practice: The role of self-concept in educational psychology*. Leicester, UK: British Psychological Society.

Marsh, H. W. (2008). Reciprocal Effects Between Academic Self-Concept, Self-Esteem, Achievement, and Attainment Over Seven Adolescent Years: Unidimensional and Multidimensional Perspectives of Self-Concept. *Personality and Social Psychology Bulletin, 34*(4), 542-552. https://doi.org/10.1177/0146167207312313

Marsh, H. W., & Craven, R. G. (2006). Reciprocal effects of self-concept and performance from a multidimensional perspective: Beyond seductive pleasure and unidimensional perspectives. *Perspectives on Psychological Science, 1*, 133-163*. https://doi.org/10.1111/j.1745-6916.2006.00010.x*

Marsh, H. W., & Holmes, I. W. M. (1990). Multidimensional Self-Concepts: Construct Validation of Responses by Children. *American Educational Research Journal, 27*(1), 89-117. https://doi.org/10.3102/00028312027001089

Marsh, H. W., & Martin, A. J. (2011). Academic self-concept and academic achievement: Relations and casual ordering. *British Journal of Educational Psychology, 81*(1), 59-77. https://doi.org/10.1348/000709910X503501

Marsh, H. W., (1987). The Hierarchical Structure of Self-Concept and the Application of Hierarchical Confirmatory Factor Analysis. *Journal of Educational Measurement, 24*(1), 17-39. https://doi.org/10.1111/j.1745-3984.1987.tb00259.x

Marsh, H. W., Byrne, B. M., & Yeung, A. S. (1999). Causal ordering of academic self-concept and achievement: Reanalysis of a pioneering study and revised recommendations. *Educational Psychologist, 34,* 155-167. https://doi.org/10.1207/s15326985ep3403_2

Marsh, H. W., Parker, P. D., Guo, J., Pekrun, R., & Basarkod, G. (2020). Psychological comparison processes and self-concept in relation to five distinct frame-of-reference effects: Pan-human cross-cultural generalizability over 68 countries. *European Journal of Personality, 34*(2), 180-202. https://doi.org/10.1002/per.2232

Marsh, H., & O'Mara, A. (2008). Reciprocal Effects Between Academic Self-Concept, Self-Esteem, Achievement, and Attainment Over Seven Adolescent Years: Unidimensional and Multidimensional Perspectives of Self-Concept. *Personality and Social Psychology Bulletin 34*(4), 542-552. https://dx.doi.org/10.1177/0146167207312313

Marsh, H. W., Xu K., & Martin, A. J. (2012). Self-concept: A synergy of theory, method, and application. In K. Harris, S. Graham, & T. Urdan (Eds.) *APA Educational Psychology Handbook.* American Psychological Association.

McWilliams, M. A., Nier, J. A., & Singer, J. A. (2013). The implicit self and the specificity-matching principle: Implicit self-concept predicts domain-specific outcomes. *Personality and Individual Differences, 54*, 474-478. https://doi.org/10.1016/J.PAID.2012.09.014

Milani, L., Grumi, S., & Di Blasio, P. (2019). Positive effects of videogame use on visuospatial competencies: The impact of visualisation style in preadolescents and adolescents. *Frontiers in Psychology*, *10,* 1-9. https://doi.org/10.3389/fpsyg.2019.01226

Moe, A. (2009). Are males always better than females in mental rotation? Exploring a gender belief explanation. *Learning and Individual Differences, 19*(1), 21-27. https://doi.org/10.1016/j.lindif.2017.12.002

Moore, G. M., Audrey, S., Barker, M., Bond, L., Bonell, C., Hardeman, W., Moore, L., O'Cathain, Tinati, T., Wight, D., & Baird, J. (2015). Process evaluation of complex interventions: Medical Research Council guidance. *The British Medical Journal, 350,* 1-7. https://doi.org/10.1136/bmj.h1258

Moran-Ellis, J., Alexander, V. D., Cronin, A, Dickinson, M., Fielding, J., Sleney, J., & Thomas, H. (2006). Triangulation and Integration: processes, claims and implications. *Qualitative Research, 6*(1), 45-49. https://doi.org/10.1177/1468794106058870

Muris, P., Meesters, C., & Fijen, P. (2003) The Self-Perception Profile for Children: further evidence for its factor structure, reliability, and validity. *Personality and Individual Differences, 35,* 1791-1802. https://doi.org/10.1016/S0191-8869(03)00004-7

Nair, M. (2017). Mixed Methods: Is This Appropriate for My Research? *SAGE Research Methods Cases in Health.* SAGE. https://dx.doi.org/10.4135/9781526425867

Nath, S., & Szücs, D. (2014). Construction play and cognitive skills associated with the development of mathematical abilities in 7-year-old children. *Learning and Instruction*, *32*, 73–80. https://doi.org/10.1016/j.learninstruc.2014.01.006

National Research Council (2006). *Learning to think spatially: GIS as a support system in the K–12 curriculum.* National Academy Press. https://doi.org/10.17226/11019

Newcombe, N. S., & Shipley, T. F. (2015). Thinking about spatial thinking: New typology, new assessments. In J. S. Gero (Ed.), *Studying visual and spatial reasoning for design creativity* (pp. 179–192). Springer. https://doi.org/10.1007/978-94-017-9297-4_10

Nola, R. (2007). The hypothetico-deductive method. In R. Nola & H. Sankey (Eds.), *Theories of Scientific Method.* Cambridge University Press. *https://doi.org/10.1017/UPO9781844653881.008*

Norwich, B. (2019). Thinking about the nature of educational research: Going beyond superficial theoretical scripts. *Review of Education, 8*(1), 242-262. https://doi.org/10.1002/rev3.3182

OECD. (2003). *PISA literacy skills for the world of tomorrow - further results from PISA 2000*. OECD and UNESCO. https://www.oecd.org/education/school/literacyskillsfortheworldoftomorrowfurtherresultsfrompisa2000.htm

Osborne, J. W., & Costello, A. B. (2004). Sample Size and Subject to Item Ratio in Principal Components Analysis. *Practical Assessment, Research & Evaluation, 9.* *http*://PAREonline.net/getvn.asp?v=9&n=11

Ozmon, H. A., & Craver, S. M. (2008). *Philosophical Foundations of Education.* Pearson Merrill Prentice Hall.

Parker, P. D., Marsh, H. W., Ciarrochi, J., Marshall, S., & Abduljabbar, A. S. (2013). Juxtaposing math self-efficacy and self-concept as predictors of long-term achievement outcomes. *Educational Psychology, 34,* 29-48. https://doi.org/10.1080/01443410.2013.797339

Piaget, J. (1962). The stages of the intellectual development of the child. *Bulletin of the Menninger Clinic, 26*(3), 120–128. https://pubmed.ncbi.nlm.nih.gov/14486280/

Piers, E. V., & Harris, D. B. (1964). Age and other correlates of self-concept in children. *Journal of Educational Psychology, 55*(2), 91–95. https://doi.org/10.1037/h0044453

Piers, E. V., Harris, D. B., & Herzberg, D. S. (2002). *Piers-Harris 2: Children's self-concept scale*. Western Psychological Services.

Portney, L.G. and Watkins, M.P. (2009). *Foundations of Clinical Research: Applications to Practice.* (3rd Edition). Prentice Hall.

Prior, M. T. (2017). Accomplishing "rapport" in qualitative research interviews: Empathic moments in interaction. *Applied Linguistics Review 9*(4), 1-24. https://doi.org/10.1515/applirev-2017-0029

Quay, L., Steele, D., Johnson, C., & Hortman, W. (2001). Children's achievement and personal and social development in a first-year reading recovery program with teachers in training. Literacy teaching and learning. *International Journal* *of Early Reading and Writing, 5*, 7–25. https://readingrecovery.org/wp-content/uploads/2017/03/LTL_5.2-Quay-Steele-etal.pdf

Rasmussen, C., & Bisanz, J. (2005). Representation and working memory in early arithmetic. *Journal of Experimental Child Psychology, 91*(2), 137-157. https://doi.org/10.1016/j.jecp.2005.01.004

Raven, J., & Raven, J. (2003). Raven Progressive Matrices. In R. S. McCallum (Ed.), *Handbook of nonverbal assessment* (pp. 223–237). Kluwer Academic/Plenum Publishers. https://doi.org/10.1007/978-1-4615-0153-4_11

Reilly, D., & Neumann, D. L. (2013). Gender-Role Differences in Spatial Ability: A Meta-Analytic Review. *Sex Roles, 68*(9), 521-535. https://doi.org/10.1007/s11199-013-0269-0

Riccio, C. A., & Hynd, G. W. (1996). Relationship between ADHD and central auditory processing disorder. *School Psychology International, 17*(3), 235–252. https://doi.org/10.1177/0143034396173001

Schmitt, M. C., & Gregory, A. E. (2005). The Impact of an Early Intervention: Where are the children now? *Literacy Teaching and Learning, 10*(1), 1-20. https://eric.ed.gov/?id=EJ966161

Schwartz, R. M. (2005). Literacy learning of at-risk first-grade students in the reading recovery early intervention*. Journal of Educational Psychology, 97,* 257–267. https://doi.org/10.1037/0022-0663.97.2.257

Scott, D. (2007). Resolving the quantitative-qualitative dilemma: a critical realist approach. *International Journal of Research & Method in Education, 30*(1), 3-17. https://doi.org/10.1080/17437270701207694

Shavelson, R. J., Hubner, J. J., & Stanton, G. C. (1976). Self-concept: Validation of construct interpretations. *Review of Educational Research, 46,* 407-441. https://doi.org/10.3102/00346543046003407

Shaywitz, S. E., Fletcher, J. M., Holahan, J. M., Shneider, A. E., Marchione, K. E., Stuebing, K. K., Francis, D. J., Pugh, K. R., & Shaywitz, B. A. (1999). Persistence of dyslexia: the Connecticut Longitudinal Study at adolescence. *Paediatrics, 104*(6), 1351-1359. https://dx.doi.org/10.1542/peds.104.6.1351

Sims, V. K., & Mayer, R. E. (2002). Domain specificity of spatial expertise: The case of video game players. *Applied Cognitive Psychology, 16*(1), 97-115. https://doi.org/10.1002/ACP.759

Skibbe, L. E., Phillips, B. M., Day, S. L., Brophy-Herb, H. E., & Connor, C. M. (2012). Children's early literacy growth in relation to classmates' self-regulation. Journal of Educational Psychology, 104, 541–553. https://dx.doi.org/10.1037/a002915

Smith, T. (2021). Pragmatism, *Salem Press Encyclopedia.* Salem Press. https://uoelibrary.idm.oclc.org/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=ers&AN=89164374&site=eds-live&scope=site

Sorby, S. A. (1999). Developing 3-D spatial visualization skills. *Engineering Design Graphics Journal, 63*, 21–32. https://diglib.eg.org/xmlui/bitstream/handle/10.2312/egs19991054/sorby_1.pdf

Spreng, R. N. & Mar, R. A. (2012). I remember you: A role for memory in social cognition and the functional neuroanatomy of their interaction. *Brain Research, 1428* , 43-50. https://dx.doi.org/10.1016/j.brainres.2010.12.024

Stallard, P., Sayal, K., Phillips, R., Taylor, J., Gannon, M., Anderson, R., Araya, R., Lewis, G., Millings, A., & Montgomery, A. A. (2012). Classroom based cognitive behavioural therapy in reducing symptoms of depression in high risk adolescents: Pragmatic cluster randomised controlled trial. *BMJ Clinical Research, 345,* e6058. https://doi.org/10.1136/bmj.e6058

Stein, J. (2014). Dyslexia: the role of vision and visual attention. *Current developmental disorders Report, 1,* 267-280. https://doi.org/10.1007/s40474-014-0030-6

Streiner, D. L. and Norman, G. R. (2008). *Health Measurement Scales: A Practical Guide to Their Development and Use.* (4th Edition). Oxford University Press. http://dx.doi.org/10.1093/acprof:oso/9780199231881.001.0001

Streiner, D. L., & Norman, G. R. (2011). Correction for multiple testing: Is there a resolution? *Chest, 140,* 16-18. https://doi.org/10.1378/chest.11-0523

Stoet, G. (2021, September 15). *Mental Rotation Task.* PsyToolKit. https://www.psytoolkit.org/experiment-library/mentalrotation.html

Sullivan, G. M. (2011). A primer on the Validity of Assessment Instruments. *Journal of Graduate Medical Education, 3*(2), 119-120. https://doi.org/10.4300/JGME-D-11-00075.1

Swann, W., Change-Schneider, C., & McClarty, K. (2007). Do people’s self-views matter? Self-concept and self-esteem in everyday life. *American Psychologist, 62*, 84-94. https://doi.org/10.1037/0003-066X.62.2.84

Szczygiel, M. (2021). The relationship between math anxiety and math achievement in young children is mediated through working memory, not by number sense, and it is not direct. *Contemporary Educational Psychology, 65, 1-14.* https://doi.org/10.1016/j.cedpsych.2021.101949

Taber, K. S. (2018). The Use of Cronbach's Alpha When Developing and Reporting Research Instruments in Science Education. *Research in Science Education, 48,* 1273-1296. https://doi.org/10.1007/S11165-016-9602-2

Tavakol, M. and Dennick, R. (2011). Making Sense of Cronbach's Alpha. *International Journal of Medical Education, 2*, 53-55. http://dx.doi.org/10.5116/ijme.4dfb.8dfd

Terlecki, M. S., Newcombe, N. S., & Little, M. (2008). Durable and Generalised Effects of Spatial Experience on Mental Rotation: Gender Differences in Growth Patterns. *Applied Cognitive Psychology, 22,* 996-1013. https://doi.org/10.1002/ACP.1420

Thorton, A., & Lee, P. (2000). Publication bias in meta-analysis: its causes and consequences. *Journal of Clinical Epidemiology, 53,* 207-216. https://doi.org/10.1016/S0895-4356(99)00161-4

Timmerman, H. L., Toll, S. W. M., & Van Luit, J. E. H. (2017). The relation between math self-concept, test and math anxiety, achievement motivation and math achievement in 12 to 14-year-old typically developing adolescents. *Psychology, Society & Education, 9*(1), 89-103. https://doi.org/10.1016/j.tate.2020.103096

Tsang, S., Royse, C. F., & Terkawi, A. S. (2017). Guidelines for developing, translating, and validating a questionnaire in perioperative and pain medicine. *Saudi Journal of Anaesthesia, 11*(5), 80-89. https://doi.org/10.4103/sja.SJA_203_17

Tzuriel, D., & Egozi, G. (2007). Dynamic assessment of spatial abilities of young children: Effects of gender and task characteristics. *Journal of Cognitive Education and Psychology, 6*(2), 219–247. https://doi.org/10.1891/194589507787382160

UK Government. (2022a, April 14). *Find and compare schools in England. https://www.compare-school-performance.service.gov.uk*

UK Government. (2022b, April 14). *National curriculum in England: mathematics programmes of study.* https://www.gov.uk/government/publications/national-curriculum-in-england-mathematics-programmes-of-study/national-curriculum-in-england-mathematics-programmes-of-study

UK Government. (2022c, April 14). *National Curriculum Assessments: Practice Materials. https://www.gov.uk/government/collections/national-curriculum-assessments-practice-materials*

Uttal, D. H., Meadow, N. G., Tipton, E., Hand, L. L., Alden, A. R., Warren, C., & Newcombe, N. S. (2013). The malleability of spatial skills: a meta-analysis of training studies. *Psychological Bulletin, 139*(2), 352–402. https://doi.org/10.1037/a0028446

Uttal, D. H., Miller, D. I., & Newcombe, N. S. (2013). Exploring and Enhancing Spatial Thinking: Links to Achievement in Science, Technology, Engineering, and Mathematics? *Current Directions in Psychological Science, 22*(5), 367-373. https://doi.org/10.1177/0963721413484756

Valentine, J. C., & DuBois, D. L. (2005). Effects of self-beliefs on academic achievement and vice-versa: Separating the chicken from the egg. In H. W. Marsh, R. G. Craven, & D. M. McInerney (Eds.), *International Advances in*

*Self Research*, vol. 2, (pp 53–78). Information Age.

Vera-Toscano, E., Rodrigues, M., & Costa, P. (2017). Beyond educational attainment: The importance of skills and lifelong learning for social outcomes. Evidence for Europe from PIAAC. *European Journal of Education, 52*(2), 217-231. https://doi.org/10.1111/ejed.12211

Vernon, M. D. (1957). Cognitive Inference in Perceptual Activity. *British Journal of Psychology, 48*(1), 35-47. https://doi.org/10.1111/j.2044-8295.1957.tb00597.x

Vidyasagar, T. R., & Pammer, K. (2010). Dyslexia: A deficit in visuo-spatial attention, not in phonological processing. Trends in Cognitive Sciences, 14(2), 57–63. https://doi.org/10.1016/j.tics.2009.12.003

Von Bastian, C. C., Guye, S., & De Simoni, C. (2019). How Strong Is the Evidence for the Effectiveness of Working Memory Training? In J. M. Novick, M. F. Bunting, M. R. Dougherty, & R. W. Engle (Eds.), *Cognitive and Working Memory Training: Perspectives from Psychology, Neuroscience, and Human Development.* Oxford University Press. https://doi.org/10.1093/oso/9780199974467.001.0001

Von Karolyi, C., Winner E., Gray W., Sherman G. F. (2003). Dyslexia linked to talent: global visual–spatial ability. *Brain Language, 85,* 427–431. https://dx.doi.org/10.1016/S0093-934X(03)00052-X

Voyer, D., Voyer, S., & Bryden, M. P. (1995). Magnitude of sex differences in spatial abilities: a meta-analysis and consideration of critical variables. *Psychological Bulletin, 117*(2), 250-270. https://dx.doi.org/10.1037/0033-2909.117.2.250

Wai, J., Lubinski, D., & Benbow, C. P. (2009). Spatial ability for STEM domains: aligning over 50 years of cumulative psychological knowledge solidifies its importance. *Journal of Educational Psychology, 101*(4), 817–835. https://doi.org/10.1037/A0016127

Waite, A. M., & McDonald, K. S.  (2019). Exploring Challenges and Solutions Facing STEM Careers in the 21st Century: A Human Resource Development Perspective. *Advances in Developing Human Resources, 21*(1), 3-15. https://doi.org/10.1177/1523422318814482

Waliaula, A. J. (2022). Positivism. *Salem Press Encyclopedia*. Salem Press. https://uoelibrary.idm.oclc.org/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=ers&AN=89677610&site=eds-live&scope=site

Waugh, R. F. (2001). Measuring ideal and real self-concept on the same scale, based on a multifaceted, hierarchical model of self-concept. *Educational and Psychological Measurement, 61*(1), 85–101. https://doi.org/10.1177/00131640121971086

Wechsler, D. (2014). *Wechsler Intelligence Scale for Children – Fifth Edition.* Psychological Corporation.

Winner, E., von Karolyi, C., Malinsky, D., French, L., Seliger, C., Ross, E., & Weber, C. (2001). Dyslexia and visual spatial talents compensation versus deficit model. *Brain and Language, 76,* 81-110. https://dx.doi.org/10.1006/brln.2000.2392

Witkin, H. A., & Goodenough, D. R. (1981). Cognitive styles: essence and origins. Field dependence and field independence. *Psychological Issues, 51,* 1-141. https://pubmed.ncbi.nlm.nih.gov/7012884/

Yang, W., Liu, H., Chen, N., Xu, P., & Lin, X. (2020). Is Early Spatial Skills Training Effective? A Meta-Analysis. *Frontiers in Psychology, 11*(1938), 1-15. https://doi.org/10.3389/fpsyg.2020.01938