Faculty of Social Sciences
School of Psychology
Doctoral Program in Psychology

DOCTORAL THESIS

SPATIAL REASONING IN THE CLASSROOM: EFFECTS OF AN INTERVENTION ON CHILDREN'S SPATIAL AND MATHEMATICAL SKILLS

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1 Abstract

Long-term longitudinal studies have revealed that good spatial skills in pre-school age predict the choice and successful performance in STEM disciplines during adulthood. Also, different researches have shown a consistent correlation between spatial abilities and early mathematics performance. Even though the association between both kinds of skills, as well as its stability along development, is well documented, an emphasis has been made in need to clarify the nature of the relation between both of them. So far, there are few studies available regarding causal effects between spatial reasoning and mathematical skills, and their findings are inconsistent.

This thesis aimed to contribute to the debate about the causal relationship between spatial and mathematical abilities. A “causal-chain model” was tested, which assigned mediating roles to two components of the visual-spatial memory system, as well as the effect of spatial skills’ improvement over the enhancement of mathematical skills. Moreover, the moderator role of the child’s sex and his/her initial level of spatial skills were examined, as previous research’s findings pointed in that direction. Finally, an additional goal of this thesis was to explore how children used spatial language, hand´s gestures and some specific body movements to carry out the training activities.

Two Chilean urban elementary schools, receiving students from middle and low SES, participated in this research. In total, 185-second graders took part. They received spatial training, implemented in the classroom setting. It consisted of 9 hours of hands-on activities, executed in small groups of children. The training was designed following the guided-play approach and embodied cognition theories.

The data analyses were carried out comparing groups performance, through univariate (mixed ANCOVA) and multivariate (Latent Change Score Model) statistical techniques.

The results showed a significant effect of training over children spatial skills (mental rotation and perspective-taking) and on visual-spatial short-term memory. However, it was not found a transfer effect over students' mathematical performance.

Regarding differential intervention effects, children with a low initial level of spatial skills obtained bigger gains, but against the hypothesis, children' sex had not a moderator effect.

2 Introduction

During last decades, a growing body of knowledge has renewed and increased the interest in the development of spatial reasoning. Long-term longitudinal studies have revealed that good spatial skills in pre-school predict the choice and successful performance in STEM disciplines during adulthood (Wai, Lubinski, Benbow, & Steiger, 2010). From an educational perspective, different studies have shown a consistent correlation between spatial skills and early mathematics performance. Based on that evidence, some researchers have suggested the need for “spatializing the mathematical curriculum” (Davis, Okamoto, & Whiteley, 2015; Newcombe, 2017).

Even though the association between both kinds of skill, as well as its stability along development is well documented, emphasis has been made in the need to clarify the nature of the relation between both skills. Is there any causal relation between them? If this is the case, in what direction does it work? So far, there are few studies available regarding causal effects between spatial reasoning and mathematical skills, and their findings are inconsistent.

This thesis aimed to contribute to the debate about the causal relationship between spatial and mathematical abilities. Through a quasi-experimental and mixed research design, spatial training to second-grade students was carried out. The intervention was implemented in the classroom setting, and it consisted in 9 hours of hands-on activities, executed in small groups of children. The activities were designed according to the guided-play learning approach and embodied cognition theories.

This study also aimed to contribute in the theoretical arena, modelling the causal relation among various variables that have been previously identified by research on these topics. Thus, a “causal-chain model” was tested, which assigned mediating roles to two components of a visual-spatial memory system (i.e., working memory and short-term memory), as well as the role of spatial skills’ improvement in the enhancement of mathematical skills. Moreover, the moderator role of child’s sex and his/her initial level of spatial skills were examined, as previous research’s findings pointed in that direction. Finally, an additional goal of this thesis was to explore how children use spatial language, hand´s gestures and some specific body movements in order to carry out the intervention activities

Two Chilean urban schools, which attend students from low-middle SES, participated in this research. In total, 185 students grouped in six classrooms took part. The children age varied between seven and eight years old, and 47% of participants were girls.

The data analyses were carried out comparing groups performance, through univariate (mixed ANCOVA) and multivariate (Latent Change Score Model - LCSM) statistical techniques.

The results show a significant effect of training over children spatial skills (mental rotation and perspective-taking), and on visual-spatial short-term memory. However, it was not found a transfer effect over students' mathematical performance.

Regarding differential intervention effects, children with a low initial level of spatial skills obtained bigger gains, but against the hypothesis, children’ sex had not a moderator effect.

The "causal-chain model" tested through LCSM, had a moderated support. Nonetheless, the analysis contributed to identifying the mediator role that VS memory system and Perspective-taking have, between the spatial and mathematical skills. Additionally, the resulting model suggests that a "common cause model" might be tested in the future and that VS memory system could be the common cause of spatial and mathematical skills.

Concerning the use of hand gestures and spatial language along the training sessions, children showed the conjoint use of both kind of language while they were trying to communicate their spatial reasoning. Interestingly, when they were trying to understand the spatial task and explain it to themselves, they tended to use gesture alone. No difference was found in the amount or variety of spatial language and gestures used, according to children' sex.

The whole research process is detailed in the next pages. The document begins with the review of relevant backgrounds, followed by a description of research questions and hypotheses. Then, the research methodology used is reported and the results obtained are described. The thesis finalises with a discussion section that relates these research findings with prior knowledge. Furthermore, the study’s limitations are pointed out, and future research questions are proposed.

3 Theoretical and Empirical Background

3.1 Defining spatial reasoning

Spatial reasoning has been defined through various concepts; these are related to each other and not clearly delimited in the specialised literature. Various authors mention terms such as, "spatial skills", "visual-spatial skills", "spatial cognition", "spatial intelligence", "spatial ability", and "spatial reasoning", frequently using them as synonymous.

Lohman (1994a, p. 1000), for instance, defines spatial ability as a cognitive attribute: the competence "to generate, retain, retrieve, and transform well-structured visual images in the mind" (in Wai, Lubinski, & Benbow, 2009). On the other hand, Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, (2014) pose that "the ability to mentally manipulate information about objects in the environment and the spaces we inhabit, is essential for everyday functioning" (p.8).

Whiteley, Sinclair, & Davis, (2015) claim that spatial reasoning is not just spatial awareness but rather a form of non-verbal reasoning. Therefore, the conceptualizations of spatial reasoning presuppose an explanation for why, when, or how spatial metaphors are employed. Also, since it can be exercised without using the sense of vision, spatial reasoning is not exclusively a visual experience. People also learn about space through their daily kinaesthetic experiences using their hands, through body movements, and gestures.

Spatial skills were initially defined from a psychometric approach, carrying-out an exploratory factor analysis to identify the latent structure of spatial abilities. This approach, however, lacks a theoretical background (Uttal et al., 2013)

Authors agree that 'spatial skills' is a multidimensional construct. Linn & Petersen (1985) suggested that spatial skills have three dimensions: spatial perception, mental rotation, and spatial visualization. Spatial perception refers to the ability to determine spatial relationships with reference to the observer's orientation, despite any distracting information. Mental rotation refers to the skill of mentally turning certain stimulus to compare it with another in order to establish if they are identical. Finally, spatial visualization is the ability to imagine and mentally transform spatial information in a multistep manipulation of the available data. Linn and Petersen explain that this dimension allows the transformation of an object from 2D to 3D, or vice versa. This last sub-skill is the most criticised because of its lack of specificity (in Uttal et al., 2013).

Uttal et al. (2013) proposed a new typology of spatial skills that is widely used today. They developed a nomenclatural system using two fundamental criteria: the distinction between intrinsic and extrinsic information, and between static and dynamic tasks. Regarding the first criteria, Uttal et al. (2013) define extrinsic information as the one that addresses the relation between objects, while intrinsic information relates to characteristics of a specific object. Therefore, analysis of extrinsic information requires the estimation of the relative position of one object in relation to another or to a reference point. The other criterion used in this classificatory system is the distinction between static and dynamic tasks. A static task operates on a fixed object, while in a dynamic task, the performance involves objects in movement.

These criteria generate a double entrance table (2x2) as shown in Figure 1. The spatial skills related to **Intrinsic-Static** information refer to the ability to distinguish objects or spatial configurations despite distracting background information. Two typical ways to assess this ability are embedded figures tasks and mazes. This category is considered to be equivalent to the spatial visualisation skill in Linn & Petersen's taxonomy (1985).

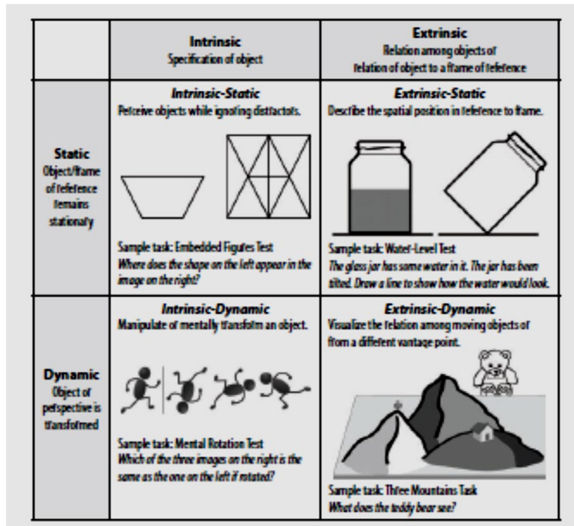
The spatial skills that involve an **Intrinsic-Dynamic** process include putting together various objects in more complex configurations and being able to visualise and transform them in one's mind (e.g., from 2 to 3 dimensions or conversely). This kind of abilities partially correspond to spatial visualisation and mental rotation as defined in Linn & Petersen's taxonomy.

The ability to analyse **Extrinsic-Static** visual information demonstrates an understanding of abstract spatial principles such as horizontal invariance or verticality. A standard measurement of this skill is the water-level task. This skill is almost equivalent to spatial perception in Linn & Petersen's classification.

Lastly, the spatial skill related to the analysis of **Extrinsic-Dynamic** visual information involves visualising an entire environment from a different point of view. Piaget's Three Mountains Task is a typical measure for this spatial skill. Linn & Petersen's classificatory system does not include this category.

Some researchers have found that individuals who outperform others as "object visualizers"—that is, those who have strong intrinsic-static spatial skills—do not exceed when the task requires analysis of intrinsic-dynamic spatial information. The latter would be "spatial visualizers" and are frequently found among scientists. The former, on the contrary, are often recognised among visual artists (Kozhevnikov, Kosslyn, & Shephard, 2005 in Uttal et al., 2013).

Figure 1. Classification of spatial skills and examples of each spatial process (Whiteley, Sinclair & Davies, 2015, adapted from Uttal et al., 2013).



In order to foster the discussion about the importance of spatial reasoning in learning environments, (Davis, Okamoto, & Whiteley, 2015) have developed a different model. They propose a nested model that captures the complexity of the phenomena. In other words, their system does not intend to isolate each component in mutually exclusive cells. On the contrary, the model focuses specifically on the combination of cognitive processes that take place when a person is reasoning about space. Usually, when a person is solving a typical spatial task, he/she may shift to skills of other categories by virtue of his/her interpretation or performance.

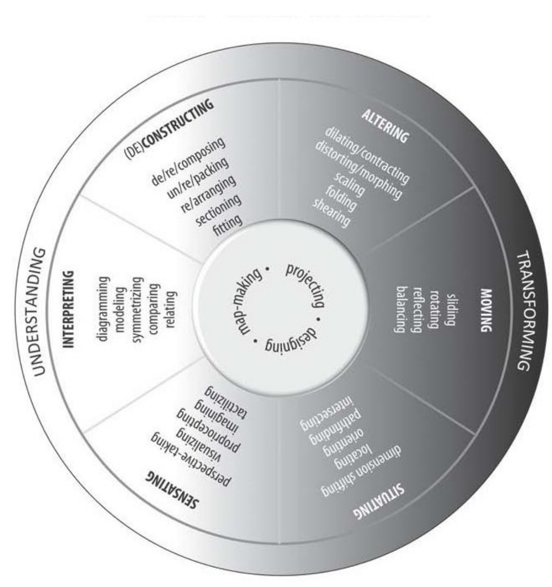
Figure 2 illustrates a representation proposed by Davis et al. (2015). The aim of this model is to underscore that spatial reasoning involves intertwined processes of "mental understanding" and "physical transformation". In order to avoid the notion of conceptual scaling that is typically associated with a linear diagram, they represent this idea through a circular layout. Aspects commonly related to understanding are situated in the lighter zone, whereas those aspects that are related to physical transformation are located in the darker hues.

The “Understanding Area” involves deploying cognitive processes such as “sensating” (perceiving through the senses: proprioception, visualizing, imagining, “tactilizing”, perspective-taking); “interpreting” (diagramming, modelling, symmetrizing, comparing, relating), and “(de)constructing” ([de/re]composing, [un/re]packing, [re]arranging, sectioning, fitting).

The “Transforming Area” involves actions or thoughts such as “altering” (dilating-contracting, distorting-morphing, scaling, folding, shearing), “moving” (sliding, rotating, reflecting, balancing), and “situating” (dimension shifting, locating, orienting, pathfinding, intersecting).

Competencies that emerge from the combination of different spatial skills (namely, map-making, projecting and designing, among others) are situated at the centre of the image.

Figure 2: Spatial reasoning characterisation model (Davies, Okamoto, & Whiteley, 2015).



In spite of the richness of the proposals aforementioned, the debate concerning the definition of spatial skills continues to be an unresolved and interesting one. The nomenclature proposed by Davies et al. (2015) intends to elicit discussion among educators and move beyond the disconnected description of spatial reasoning. However, in order to promote the development of spatial skills in the classroom, the debate should go beyond the boundaries of psychological laboratories as well.

To summarise this section, spatial skills are defined as a non-verbal reasoning that consists in being capable of generating, hold in mind, and manipulate information about objects in space. There is some consensus about the multidimensional nature of spatial skills. However, although several classifying schemes of spatial skills have been proposed, tension persists between psychological and educational approaches. The former emphasises how to distinguish and delimitate particular skills, while the educational approach intends to embrace the complexity of these phenomena the way they appear in the classroom. In other words, the educational approach offers a representation that attempts to integrate the cognitive understandings and physical transformations that take place when spatial skills are at work.

The next section reviews the current understanding of the development of spatial skills throughout a person's life.

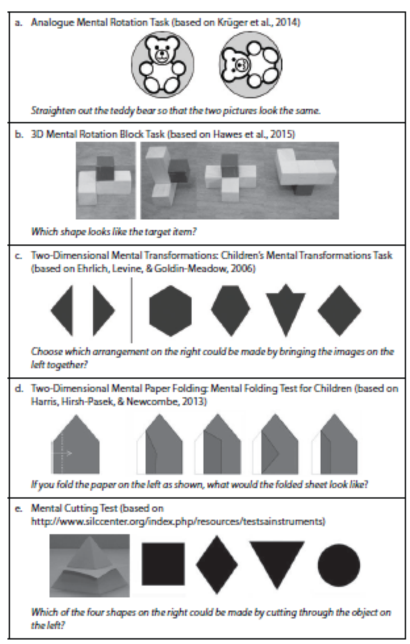
3.1.1 How does spatial reasoning develop and how is it assessed?

Infants are born in a 3D world. They capture the spatial cosmos with touch, movement and vision at a very early stage in their development.

Children begin school with many spatial capabilities already at their disposal. For instance, pre-schoolers are perfectly able of building a 3D LEGO figure following the instructions in a two-dimensional drawing. They can also play video games such as Tetris for extended periods of time. Both of these activities require the use of specific spatial skills (Okamoto, Kotsopoulos, McGarvey, & Hallowell, 2015).

Regarding ***intrinsic-dynamic*** mental transformations, Frick & Wang (2014, in Okamoto, Kotsopoulos, McGarvey, & Hallowell, 2015) suggest that this type of spatial skill shows a U-shaped pattern of evolution: as young as 3-month-old infants show emergent abilities of mental rotation, which disappear around the age of 3, and are displayed again after the age of 5. Figure 3 shows conventional tests that assess intrinsic-dynamic spatial skills during early infancy.

Figure 3. Test of intrinsic-dynamic spatial skills in young children (Okamoto, Kotsopoulos, Mcgarvey, & Hallowell, 2015).



As mentioned previously, ***extrinsic-dynamic*** spatial skills involve the recognition of changing spatial relations between two or more objects, or between one's body and the landmarks in its surroundings. For example, when children play looking for hidden treasures using a map, they are using navigational capacities that include motor skills and mental perspective-taking.

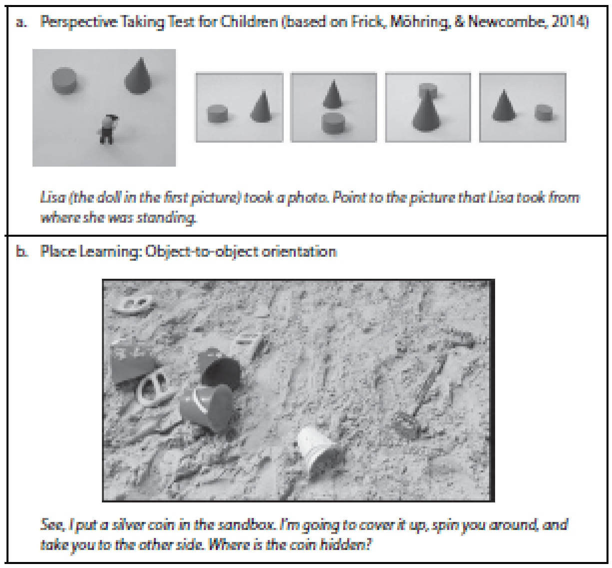
When a child learns to grasp, crawl, and walk, he/she is developing this kind of skills. These movements contribute to the child's cognitive development allowing him/her to acquire notions of distance, direction, body's position in space, and rotation. Concerning perspective-taking—that is, the ability to imagine a movement or view from another spatial location—research findings are consistent. Flavell (1999) argues that 18-month-old children are able to understand that another person might see something different than what he/she is viewing, regardless the other person´s location. This would be an evolutionary precursor of perspective-taking (in Okamoto, Kotsopoulos, Mcgarvey, & Hallowell, 2015).

Frick, Möhring, & Newcombe (2014) studied this ability in children between four and eight years old. The results reveal the classic developmental pattern for this capacity: 4-year-old children respond by chance, six-year-olds are beginning to inhibit egocentric perspective, while most eight-year-olds show a well-developed perspective-taking.

Moreover, there is evidence that spatial language plays an essential role in the development of navigational skills. The caregiver's use of adjectives, prepositions, and verbs—such as "big", "near", "curved", "above", "below to", "through", "around", "across", "over", "toward", among others—has been shown to help children become more attentive to spatial information. It also helps them to hold and retrieve from memory relevant spatial information (Ferrara, Hirsh-Pasek, Newcombe, Golinkoff, & Lam, 2011).

Figure 4 shows a test that measures perspective-taking in young children.

Figure 4. Test of extrinsic-dynamic spatial skills for young children (Okamoto, Kotsopoulos, Mcgarvey, & Hallowell, 2015).



Intrinsic-static spatial skills are essential for the recognition, description, and classification of spatial attributes of objects, and also for the ability to understand relations between the whole and its parts (Okamoto, Kotsopoulos, Mcgarvey, & Hallowell, 2015).

Regarding those skills, Clements, Swaminathan, Anne, & Hannibal (1999) found that 2.5-year-old toddlers can identify and label simple geometrical shapes. This kind of learning is quite early, probably because it is instructed since infancy. Tasks that involve determining the properties of shapes and patterns, and classifying them correctly, are often included in the early mathematics curriculum. Despite the initial instruction, some researchers claim that it fails to produce deep learning because pre-schoolers fail to recognise the central properties of each geometric configuration. Children tend to distinguish salient visual aspects but are not able to understand the features that explain why a particular figure is a triangle and not a square (they can't answer 'it is due to the number of angles').

Also, most of the instruction and materials that children receive have canonical geometrical forms (e.g., equilateral triangle), hence children fail to identify other types of triangles (i.e., isosceles or scalene) (Verdine et al., 2014a).

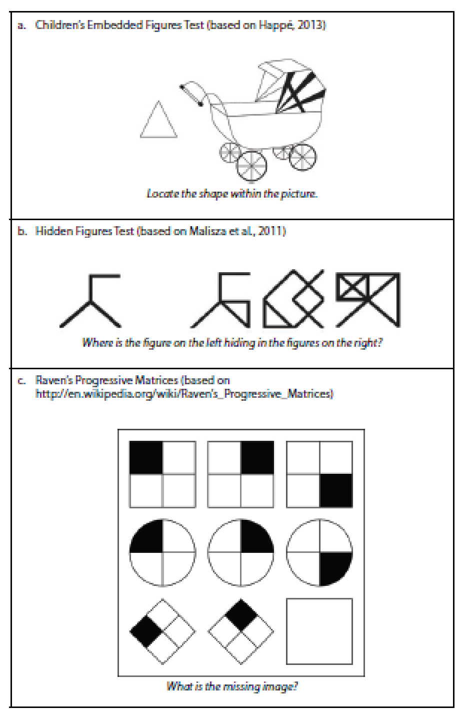


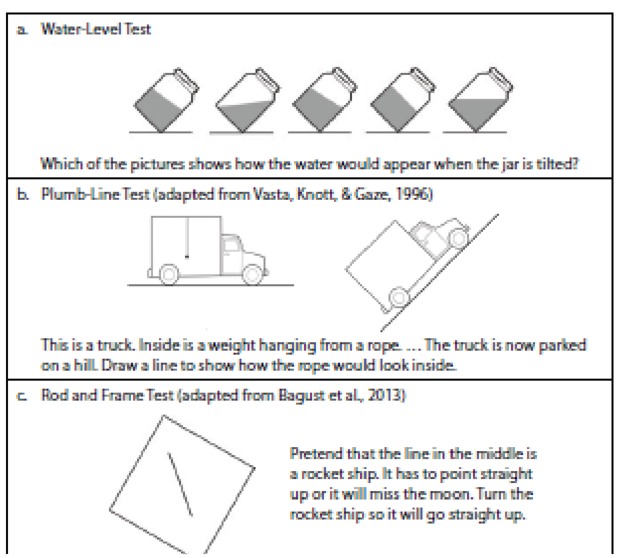
Figure 5: test of intrinsic-static spatial skills in young children (Okamoto, Kotsopoulos, Mcgarvey, & Hallowell, 2015).

A person uses ***extrinsic-static*** spatial skills when he/she analyses a map and tries to determine which among several options would be the best route to get from one place to another.

In this kind of task, individuals must analyse the position of one object, considering gravity or a reference point (e.g., landmarks in a map). Piaget and Inhelder (1967) designed the classical task to assess horizontal and vertical invariance (in Okamoto, Kotsopoulos, Mcgarvey, & Hallowell, 2015) (see Figure 6). Young children typically fail in these tasks and make alignment errors. Their answers tend to draw on internal cues instead of external ones. However, Baldy, Devichi, & Chatillon (2004) have criticised the use of this 2D test with young children by showing that they perform better in similar tasks when they are tested using 3D models or stimulus from the real world. With this method, children as young as three years old can resolve the task.

Figure 6. Test of extrinsic-static spatial skills in young children.

(Okamoto, Kotsopoulos, Mcgarvey, & Hallowell, 2015).



Perhaps the most critical issue that needs to be emphasised regarding the methods used by previous research to measure spatial skills of interest is related to the developmental considerations of the instruments. Researchers have frequently used paper and pencil tasks, which presuppose that children understand the conventions regarding the representation of 3D objects as 2D drawings. This assumption is questionable because these conventions are not taught explicitly to children. As suggested by Baldy et al. (2004), this may result in a moderate performance, poorer than their true spatial competence would allow them.

Future instruments selected to operationalise spatial skills should use 3D objects young children can manipulate. Verdine et al., (2014) have developed a promising test using interlocking blocks construction to evaluate 3-year-olds' spatial assembly skills (3D-TOSA). This instrument includes a rubric to assess three spatial dimensions: vertical location, rotation, and translation. Hawes, Lefevre, Xu, & Bruce (2015) have also developed a test of three-dimensional mental rotation for 4 to 8-year-old children with tangible 3D objects. A preliminary study revealed that the measure was both valid and reliable.

The experimental task designed by Frick et al., (2014) to measure extrinsic-dynamic skills is auspicious. They elaborated a similar methodology that proposes conflicting frames of reference to assess perspective-taking in children between 4 and 8 years old. For that purpose, they created scenes of toy photographers taking pictures of objects layouts of from different angles. Children were asked to choose one of four images to identify the photographer's point of view.

To summarise, the literature review regarding how these abilities emerge in the course of human development reveals that even 3-month-old babies show precursors of spatial cognition. The early spatial reasoning development seems to be intertwined with body movements and how infants explore their environment. Some explanations of individual variability in those abilities connect the frequency and quality of spatial language used by primary caregivers with children's level of spatial skills.

Cognitive science has generated extensive data regarding the assessment of children's spatial skills. However, the most recent approaches point out the importance of using developmentally sensitive measures and privileging the utilisation of 3D and manipulative tasks.

Next section explores whether spatial skills are malleable, and which are the best ways to improve them.

3.1.2 Training spatial skills: empirical evidence

3.1.2.1 Are spatial skills malleable?

So far, the literature reviewed suggests that spatial skills emerge quite early in human development, and while they improve with age, they also depend strongly on an individual´s experience. There is considerable variability in spatial skills among individuals—in extension as well as depth—which can probably be attributed to environmental opportunities.

Importantly, for a long-time the spatial skills were considered to be fixed traits and innate abilities. Historically speaking, spatial reasoning was understood as a central part of intelligence (Hawes, Tepylo, & Moss, 2015).

However, recent research has shown that spatial skills are trainable. The meta-analysis conducted by Uttal et al. (2013) on the topic of the malleability of spatial skills demonstrated that these skills are trainable, and the effects of instruction remain in time. The authors reviewed 206 studies published or presented at conferences from

1984 to 2009, in which people were trained at different ages (although, mostly adults), and established a sophisticated method for eligibility in the meta-analysis. The researchers report that, excluding outliers, the average effect size was .47 for trained groups. Generally speaking, these results suggest that spatial skills are moderately ductile and training improved performance, on average, by almost one half of a standard deviation. According to the researchers, the extrinsic-static skills have the highest potential to be acquired through education when compared with the other three categories they have formulated. The authors also found that training effects are stable and appeared undiluted in follow-up studies' assessments. Nevertheless, what type of training is more likely to produce long-term effects is not yet clear.

Uttal et al. (2013) explored in their study several moderators that might explain the differential effects of training in spatial skills. For instance, they identified that initial levels of spatial skills affected the degree of malleability, since individuals who started at lower levels showed greater gains than those who started at higher levels. In other words, the participants with high initial scores are constrained by ceiling effects.

The study also found sex differences in the response to training. While both men and women improved as a consequence of practice, the sex gap in spatial skills—which is frequently reported and favours men—did not disappear completely, regardless of the kind of intervention. Moreover, the results suggest that when training periods are brief women benefit from the intervention less, i.e. they show smaller training-related gains than men.

In their attempt to grasp the mechanisms of learning and improvement, Uttal et al. (2013) found evidence on the importance of training for key cognitive processes required for spatial reasoning, such as attention and visual-spatial working memory. Previous research about mental rotation training through video-games found that post-intervention the players could hold a higher number of elements in working memory (Green & Bevalier, 2007 in Uttal et al., 2013; Tzuriel & Egozi, 2010). Additionally, the acquisition of new strategies or rules and their correct application may account for part of the learning acquired through training. For instance, Just & Carpenter (1985) identified participants who could not rotate the whole stimulus in their mind but were still able to compare specific aspects of the stimulus with the target figure. This strategy improved their performance's efficiency (in Uttal et al., 2013).

Although the evidence indicating that spatial skills are modifiable is robust, several researchers have identified early gaps attributable to socioeconomic status and gender.

Indeed, children from lower socioeconomic levels exhibited a weaker performance on spatial tasks compared to their peers from higher levels (Levine, Vasilyeva, Lourenco, Newcombe & Huttenlocher, 2005). Additionally, boys perform better than girls in various spatial tasks. Several investigators report higher achievement of male pre-schoolers in mental rotation tasks (Ehrlich, Levine, & Goldin-Meadow, 2006; Frick, Möhring, & Newcombe, 2014a; Sarama & Clements, 2009; Tzuriel & Egozi, 2010). These differences are apparent so early that they can be identified in 3- and 4-month-old infants (Quinn & Liben, 2014).

Also, Vasilyeva & Bowers (2006) identified significant differences favouring male pre-schoolers in mapping tasks. Although some authors have proposed biological causations underlying sex differences in spatial skills, Newcombe (2007) has shown that there is no substantial evidence to sustain this hypothesis. She emphasises that earlier does not always nor necessarily mean biological causation, much like later does not always imply only environmental causes.

Evidence provided by (Levine et al., 2005) shows that socioeconomic status modifies the sex difference in spatial skills. They followed 547 students in 2nd and 3rd grade from Chicago for two years and observed that boys and girls of lower SES did not differ in spatial skills performance, yet both sexes differed in middle and high SES. So, this difference would be attributable to a lack of availability of toys and other materials that enhance spatial skills (such as blocks, puzzles, video games) in children of low SES, both girls and boys. When available, it is likely that boys engage in this kind of play more than girls. An alternative explanation posits that better spatial skills are related to a greater freedom to explore the environment. Usually, boys enjoy greater freedom to inspect their neighbourhood than girls. However, caregivers in disadvantaged environments tend to perceive walking around their communities to be dangerous, therefore both boys and girls experience considerable restrictions.

Casey, Dearing, Dulaney, Heyman, & Springer's research (2014) intended to study in depth the effect of environmental opportunities on the development of spatial skills, and to identify specific relationships between maternal support and spatial skills in 6- and 7-year-old girls. They videotaped mother-daughter interactions in home visits where the pair was to jointly solve origami tasks (paper folding). To analyse the information, the researchers identified patterns in data through structural equation modelling (SEM) and their findings support the hypothesis that mothers with high spatial skills offer specific environmental opportunities and scaffolding to their daughters during joint spatial activities.

In previous studies, they had found that the exposure to spatial activities and materials does make a difference for girls (Dearing et al., 2012 in Casey et al., 2014). The findings of this study suggest that the effect of mothers' spatial skills on girls' spatial performance was mediated by maternal support and child's verbal skills.

During recent decades research has produced increasing evidence concerning the malleability of spatial skills in children. Furthermore, promising findings support the possibility of reducing the sex gap in spatial skills. The work of Tzuriel & Egozi, (2010) for instance, showed that mental rotation (intrinsic–dynamic spatial skill) could be trained through a carefully designed intervention delivered along eight weeks (completing a total of 6 hours). A sample of 116 children of 1st grade (6- and 7-year-olds) was randomly assigned to an experimental group (n=60) and a control group (n=56). Children in the experimental condition participated in a program based on Wheatley's (1996) "Quickdraws" aimed to improve skills by representation and transformation of spatial information.

The intervention's focus was to expand children's visual-spatial working memory, and not the direct training of mental rotation, and researchers gathered essential findings. First, the intervention improved mental rotation abilities in experimental children, but most importantly, it downsized the initial gender gap in mental rotation detected in the pre-test. Indeed, scores from girls and boys in the experimental group did not show significant differences in the post-test. Also, as a consequence of training, girls in the experimental group had higher gains in mental rotation tasks than experimental boys. This conclusion is interesting because it demonstrates that girls benefited more than boys from an intentional extended intervention.

Moreover, this research confirms findings reported by Uttal et al. (2013) and Casey, Dearing, Dulaney, Heyman, & Springer (2014) regarding the differential effect of training in women and girls. As these researchers have pointed out, the mere availability of resources and opportunities to practice freely does not guarantee the girls' improvement in spatial skills. Instead, they require specific scaffolding.

To recapitulate the findings of studies about the effects of spatial training on spatial abilities, the evidence has shown that even brief interventions improve mental rotation abilities (intrinsic-dynamic spatial skill) in children participating in the experimental condition. However, to close the gap in spatial abilities attributed to sex and socioeconomic status, guided practice and more prolonged training are required.

3.1.2.2 How do spatial skills relate to mathematics achievement?

So far, there is substantial evidence of the existence of correlations between spatial skills and mathematical achievement (Clements & Sarama, 2011; Davis & Spatial Reasoning Study Group, 2015).

Other researchers have explored the extent to which both variables are related. In a recent longitudinal study, Verdine, Golinkoff, Hirsh-Pasek, & Newcombe (2017) found that spatial skills at the age of 3 predict mathematics skills at age 5 (almost at the beginning of primary education), even after statistically controlling by measures of vocabulary, executive functions, and earlier mathematical skills.

On the other hand, Wai et al., (2010) followed a cohort from pre-school age to adulthood, and they showed that early spatial reasoning predicted success in the fields of science, technology, engineering and mathematics (STEM).

It has been suggested that spatial reasoning seems to assist mathematical understanding and problem-solving (Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2014; Verdine, Irwin, Golinkoff, & Hirsh-Pasek, 2014). But the nature of the relationship between spatial and mathematical skills remains unclear.

Some researchers have pointed out that spatial and mathematical skills would share some resources (Hawes, Tepylo, et al., 2015). At brain level; Hubbard, Piazza, Pinel, & Dehaene (2009) have shown that there is a representational overlap among these skills: they activate the same neural mechanisms in the parietal cortex.

At a cognitive level, the research has identified the visual-spatial memory system like one of these shared cognitive resources between both abilities. Indeed, the spatial tasks require the recognition of location, position and configuration of objects while processing them simultaneously or sequentially (Mammarella et al., 2006). To solve them, a person needs an intensive use of his/her visual-spatial working memory. The same is true for calculation tasks. Even the simpler arithmetic, involve sustaining in working memory simultaneous and sequential algorithms.

Nath & Szücs (2014) showed that visual-spatial memory has a mediating role between spatial ability (measured through the constructional play with LEGO) and mathematical performance. They tested their hypothesis with children of 6 to 8 years old and found "that Lego construction play is strongly related to mathematical performance in primary school children and this relationship is mediated by visuospatial memory" (p.80). In their inquiry, the researchers also ruled out that a domain-general memory system or verbal memory performed a mediator role between spatial and mathematical skills.

Notwithstanding these advances, several researchers have insisted on the necessity of overcome correlational studies, and carry-out experimental designs to study the cause-effect relationship between spatial and mathematical skills (Bailey, 2017; Nath & Szücs, 2014; Verdine et al., 2017; Hawes, Tepylo, & Moss, 2015).

3.1.2.3 Does the training on spatial skill transfer to mathematical skills?

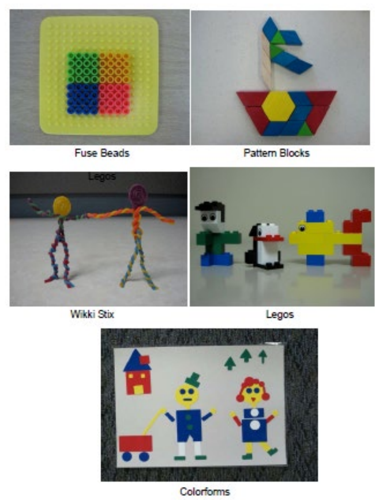
In the last five years, some researchers have taken on the challenge. Using experimental designs, they have tried to test whether spatial training could also enhance children's mathematics performance.

Grissmer et al. (2013), for instance, presented an experimental training study with kindergarteners and 1st graders from an at-risk population in South Carolina, USA. Children in the experimental condition were subjects of an intensive and prolonged after-school intervention (Minds in Motion Program) to develop their executive functions, spatial, and fine-motors skills. For seven months children in the experimental condition (n=45) participated four times a week in a guided-play program with a set of selected materials or toys (e.g. LEGO, Wikki Stix, and pattern blocks).

Children were invited to create and copy increasingly difficult geometric designs for 45 minutes during each session (see Figure 7). On the other hand, children in the control group (n=42) participated in non-spatial activities after school (such as cooking, theatre, and football). Researchers reported that compared to the control group, children in the experimental condition demonstrated better scores in spatial reasoning, executive function, and in their performance in a mathematics standardised test. In particular, without explicit mathematics instruction, they showed gains in numeracy (number awareness, place value, and magnitude) and mathematical problem solving (simple computation).

Several aspects of the program were considered by the researchers to be the reasons for these positive results: low initial skills level of participants; a "high dosage" intervention; playful activities that contributed to increase children's engagement; time spent on the task; use of diverse activities or novel material and use of consistent practice to strength target spatial skills. Furthermore, the results suggest that introducing certain types of play in pre-school math curricula or after-school programs, can enhance foundational math skills in children with a disadvantaged background, and contribute to close the achievement gap in mathematics (Grissmer et al., 2013).

Figure 7: Design copy templates from Mind in Motion (Cottone, Chen, & Brock, 2013)



A second study that reported on the direct effect of spatial training on math performance in elementary students was conducted by Cheng & Mix (2014). They recruited 58 children, between 6- to 8- year-olds, residing in Michigan. The researchers carried out an experimental study to prove the effects of a brief intervention consisting in one 40-minute session to improve children’s mental rotation ability.

Children in the control condition completed crossword puzzles in an intervention of similar duration. In the pre- and post-test assessments, the children were evaluated using the spatial relations subtest of Thurstone, a 2D mental rotation test and a math test with calculation problems with one, two and three digits. The math test also included missing term problems (e.g., 4+___=11).

Findings show that students in the experimental condition outperformed the control group in mental rotation and in the mathematical test. Most notably, children trained in mental rotation showed a statistically significant improvement in items that measure missing-term problems and multi-digit calculations.

The authors suggest two possible explanations for these findings. According to the first hypothesis, the mental rotation training possibly offered children another strategy for resolving missing-term problems. In this manner, children could mentally rotate the missing term equation into a more intuitive form, operating not in the typical “left to right order", but in a way more familiar to them. Thus, they could resolve the problem faster.

The other hypothetical explanation suggests that math performance improvement could be an indirect training effect. That is, by increasing the capacity of the visual-spatial working memory through this training, children's math achievements improve.

However, a later study carried out by Hawes, Moss, Caswell, & Poliszczuk (2015) could not replicate this causal relationship between mental rotation training and children’s calculation skills. In this inquiry, researchers were interested in examining the effects of a training program with computerised 2D mental rotation tasks on spatial thinking in children between 6 and 8 years old. Also, they wanted to determine whether spatial skills training would have any effects on children’s mathematical skills.

One distinctive feature of this training study was that activities were embedded in mathematical lessons. Participants were 61 middle-class children from Ontario, Canada. They were randomly assigned to the experimental condition (spatial training with Ipad device) or the control condition (literacy training with Ipad device). All students participated in the in-class intervention, for six weeks, three times a week. Each play session lasted 15-20 minutes, completing a total of 4.5 hours of training.

Children were assessed pre- and post-intervention using tests that measure near, intermediate and far transfer cognitive abilities. A 2D mental rotation test on paper and pencil format was applied to evaluate the near transfer skills. The intermediate transfer abilities were assessed using a 3D mental rotation test, various spatial transformation tasks, and a puzzle task (see Figure 8). Finally, remote transfer abilities were assessed using exact arithmetic and missing term problems tests.

Figure 8. Examples of items used to measure intermediate transfer effects.

(Hawes et al, 2015).

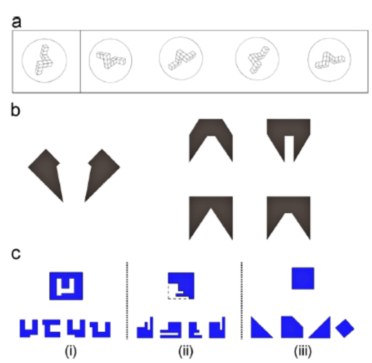


Fig. 3. Examples of items used to assess intermediate transfer effects. Fig. 3a is an example of the 3D Mental Rotation Task [31], Fig. 3b is an example of the Children's Mental Transformation Task [26], and Fig. 3c is an example of the Visual–Spatial Puzzle Task. The types of questions depicted in (i) and (ii) required participants to identify the 'missing piece,' whereas (iii) required participants to indicate the two shapes that could be put together to make the image centered above.

The results show that mental rotation training improved 2D mental rotation skill in the experimental group. That is, on abilities closely related to the trained skill, children in the experimental condition achieved better scores than children in the control group. Regarding intermediate transfer skills, analyses of performance on the Mental Transformation Task showed a marginally significant interaction between condition and time (p .056), and the spatial group outperformed the literacy group. Notwithstanding, there were no differences between both groups on the other intermediate transfer abilities (3D Mental Rotation Task and Visual-Spatial Task), neither in the remote transfer task assessed (mathematical performance).

Analysing the discrepancy between their findings and those of Cheng & Mix (2014), Hawes et al. (2015) suggest that they could be attributed to the different timing in the post-test. In Cheng & Mix's study, the post-test was administered immediately after training, while in Howes et al.'s research the post-test was delayed 3–6 day. Thereby, Howes et al. (2015) posit that "it is possible that the evidence of transfer [in Cheng & Mix's study] resulted from a priming effect and was not necessarily driven by changes in spatial thinking per se" (p.67).

Finally, Moss, Hawes, Naqvi, & Caswell (2015) conducted another study intending to demonstrate the effects of spatial training on children's mathematical skills. This research was part of an ongoing professional development program executed in Ontario, Canada (Math for Young Children – M4YC). In this case, researchers worked with teachers from kinder to 2nd grade. The educators implemented adult-initiated activities embedded in the mathematics curriculum, called "rug activities". Children in the experimental condition (n=67) participated in activities to develop their intrinsic-dynamic spatial skills three times a week for seven months (a total of 40 hours approx.).

The intervention was delivered mainly through brief "in-class" tasks like visualising, drawing, building, and copying. Figure 9 shows some examples of these "rug activities".

Figure 9. Examples of rug activities from Math for Young Children Program (Hawes, Tepylo, & Moss, 2015).

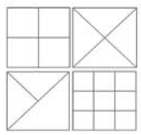
Name of "rug activity"	Description of activity	Geometry and spatial skills targeted
1. Can you draw this? 	• Children were provided with pieces of paper with an outline of a square on it • Children were then shown a geometric design composed within the square boundaries • After viewing the design for 10 seconds, children attempted to re-create (using a pencil) the exact design within the boundaries of their own square • Teachers facilitated discussions around strategies and different ways of remembering the designs • Note: this activity was based on Wheatley (1996); also see Tzuriel & Egozi (2010) for a study on the effectiveness of this activity.	• Visual-spatial memory/ visualization • Composing/decomposing/ partitioning space • Proportional reasoning
2. Can you build this? 	• Similar procedures to "Can you draw this?" • Children were shown a geometric structure composed of multilink cubes • After viewing the structure for 10 seconds, children attempted to re-create the structure from memory using their own multilink cubes • In another version of this activity, children were presented with a structure and asked to re-create it with no memory component	• Visual-spatial memory/visualization • Composing/decomposing 3D shapes
3. Building with the Mind's Eye 	• Children were given oral instructions in how to build a 2D or 3D shape (e.g., "Take two blue cubes and attach them together, one on top of the other. Stand up the two attached cubes and make them look like a tower. Now take a red cube and attach it to ...") • Children built images of the shape in mind, based on instructions given • After giving instructions, teacher showed children multiple shapes and had children discuss/reason which one perfectly matched the description	• Visualization • Composition of 2D shapes, 3D shapes • Mental transformations • Spatial language comprehension • Visual-spatial working memory
4. Shape Transformer 	• Modeled after the "Function Machine," an "input/output" activity typically done with numbers (e.g., input = 2, output = 4; input = 5, output = 10, ... etc. Rule, $y = 2x$) • In this version, input and output functions deal with spatial relationships (e.g., transformations) • Children were presented with a "machine" made out of a poster board, with "input" and "output" slots cut out • Teacher (and eventually students) prepared input and output cards to enter and exit into/out of the "machine" • Children watched and paid attention to relationship between input and output cards and tried to predict the transformation (e.g., each shape that goes into the machine gets rotated 45°)	• Mental transformations/visualization • Visual-spatial reasoning/ deductive reasoning • Composition/decomposition of 2D shapes
5. Barrier Game 	• Children worked in pairs with a barrier (folder) in between them and each with their own building materials (e.g., pattern blocks or multilink cubes) • One partner built a shape and described how to build the shape to his/her partner, who built according to the instructions provided • Children then compared their structures before reversing roles	• Spatial language • Visualization • Composing/decomposing 2D shapes/3D shapes

Table 3.1: Examples of "rug activities" carried out in the experimental classrooms.

As a result, children in the experimental group outperformed children in the control group in spatial language, 2D mental rotation, and visual-spatial geometric reasoning. They also showed gains in the Arabic-digits magnitude comparison test, which is probably related to children's arithmetic performance (in Hawes, Tepylo & Moss, 2015).

In summary, the spatial training effects on far transfer abilities (i.e., improvement in children's mathematical skills) have not been soundly demonstrated yet. The observed effects depend on how mathematical skills are operationalised. In this manner, when math skills are measured as numeracy knowledge (i.e., positional value, magnitude comparison), the effects of spatial training are positive and significant. But when math skills are tested as computational abilities (simple arithmetic and algebra), results are inconsistent. Some researchers have found a causal link among spatial skills training and improvement in calculation performance (Cheng & Mix, 2014; Grissmer et al., 2013), while others could not replicate these findings (Hawes, Moss, et al., 2015).

Future research should contribute to clarify proximal and distal effects of spatial cognition training and promote a deeper discussion regarding how spatial skills should be operationally defined. Future studies should also contribute to identify the underlying mechanisms that explain the improvement on mathematics performance associated to spatial skills training. This would inform with greater accuracy how to apply the findings in educational settings.

Next section presents the literature reviewed concerning how to improve children's spatial skills. The focus will be on evidence supported by embodied cognition theory and playful learning.

3.2 How to improve spatial reasoning?

3.2.1 Embodied cognition, playful learning and spatial reasoning.

In the past fifty years, embodied cognition theories have illuminated the relationship between play and learning, introducing new considerations to this debate. The embodied cognition theories include several approaches, but at the core, they share a rejection of the Cartesian separation between mind and body. They discard dualist epistemology, which established the supremacy of cognition (or mind) as via regia to true knowledge (Thom, D'Amour, Preciado, & Davies, 2015).

From the perspective of embodied cognition, people learn and capture their surroundings through actions of the body that inform the mind's new understandings. Knowing and doing are inseparable processes (Thom et al., 2015).

Moreover, embodiment approaches emphasize the power of movement as a means to explore and learn. Intelligence, they say, arises as a result of the sensory-motor activity of an agent interacting with its environment (Smith & Gasser, 2005). Therefore, learning is conceived as a multimodal experience and memory would strength through the use of multiple senses during the processing and recording of information. In other words, the more sensory channels participate simultaneously (i.e., vision, hearing, smell, taste, proprioception, and vestibular sense), the more likely deep learning will take place.

For the specific purpose of developing spatial skills, recent embodied cognition research underscores the importance of gestures in children's spatial reasoning (Ehrlich et al., 2006; Goldin-Meadow, 2015). Studies seeking to understand how people communicate about space have shown that—at all ages—people use spontaneous gestures while talking about space. Even more, spontaneous gestures can help when there are no words that can precisely describe an intended movement, navigation through space, or when a person does not find or know the word to explain the motion through speech. As Goldin-Meadow (2015) put it: “gesture is, in fact, a special kind of action in that it represents the world rather than directly manipulating the world (gesture does not move objects around)” (p.1).

It is probably easier for children to use their hands rather than words to express how things roll, slide, twist, or stack (Thom et al., 2015). Hence, teaching could be more effective if teachers tried to interpret and capture the meaning of their pupil's gestures. The reason is gestures do not only reflect ideas, but they also modify them. By acting as a bridge that connects action and representation, gestures allow us to learn abstract concepts, such as space and time (Goldin-Meadow, 2015). In their study with pre-schoolers, Ehrlich, Levine, & Goldin-Meadow (2006) found that children who spontaneously gesticulated more while explaining how they solved a mental transformation task performed better on the assignment. Also, they found that boys tended to gesture more and achieved better performance in mental rotation tasks than girls.

From a didactic perspective, it is important to underline that spatial skills cannot be “taught” like other subjects at school—that is, exclusively through verbal and symbolic languages. For children to develop spatial skills, they should make things, move through space, and reproduce real world's objects (Whiteley, Sinclair, & Davis, 2015). When children are reproducing an observed model, they are not merely copying patterns—they are visualising, interpreting, constructing, and modifying images/objects.

For children to understand their mental images, they usually require manipulating them through constructional play. Also, while they are involved in such activities, they are probably speaking to themselves. This behaviour is called ‘private speech’ and has an important function in cognitive development. When a child comments on his/her activity, this helps him/her to maintain his/her attention, hold the goal in mind, track the achievement, and self-regulate his/her actions. This way, children can develop perseverance (Whitebread, Basilio, Kuvalja, & Verma, 2012).

The embodied cognition foundations are utterly consistent with playful learning approaches, as presented in the next pages.

3.2.2 Play-based learning approaches

In Chile, the dominant pedagogical practice in elementary education is direct instruction. In this educational approach, the teacher is the protagonist. He/she has the responsibility to transmit the contents to students, who adopt a complementary role and are transformed in passive vessels of knowledge (Weisberg, Hirsh-Pasek, & Golinkoff, 2013; Weisberg, Kittredge, Hirsh-Pasek, Golinkoff, & Klahr, 2015).

This instructional practice is entirely coherent with the Cartesian paradigm because of its emphasis on the mind´s role in learning. The empirical evidence shows that young children exposed to this methodology achieve the proposed learning objectives but pay an emotional toll. Indeed, some studies show that pre-schoolers subjected to direct instruction faced disadvantages in other areas of development, compared to children exposed to more playful and comprehensive pedagogies. The former tend to be more distractible, display more behaviours indicative of stress, enjoy challenging tasks less, and reveal less progress in social, language, and motor skills at the end of the school year; than children educated with playful pedagogies (Alfieri, Brooks, Aldrich, & Tenenbaum, 2011; Weisberg et al., 2013).

Also, such didactic experiences do not accelerate the development of skills required to successfully face the transition to first grade. In other words, direct instruction does not accelerate school readiness (Singer, Golinkoff, & Hirsh-Pasek, 2006).

In their longitudinal study Hart, Charlesworth, Burts, & Yang (2003) compared a cohort of children educated with playful methodologies to another that received direct instruction from kinder to third grade. Their study confirms that the disadvantages observed in the last group persist through primary education (in Weisberg et al., 2013).

Direct instruction has been questioned as an appropriate pedagogical method for young children due to its lack of developmental sensitivity. By contrast, “free play” is considered the most developmentally sensitive learning approach. The feature aspect in this modality is that the child retains the ability to choose his/her activities without active guidance from the teacher. Often, learning opportunities are joyful, voluntary, flexible, and ludic in this approach, and suppose active engagement and intrinsic motivation. It usually incorporates elements of sociodramatic play (Weisberg et al., 2013, 2015).

Free play is associated with better socio-emotional adjustment (Brown, 2009; Singer et al., 2006), more self-regulated learning, and metacognitive skills (Whitebread et al., 2012; Whitebread, 2011)). It is also related to positive developments in early mathematics learning (Lewis Presser, Clements, Ginsburg, & Ertle, 2015; Ramani & Eason, 2015).

Despite its benefits, some empirical evidence shows that this didactic strategy is not adequate for every curricular learning objectives. Both because with free play, children could become confused about what they should learn, and because it does not limit children's exploratory behaviour in an effective manner (Weisberg et al., 2013, 2015).

Overall, the evidence suggests that playful and child-centred approaches that incorporate some degree of scaffolding by adults are more effective teaching strategies for achieving academic results with young children than those involving direct instruction or free play alone (Lillard, 2013).

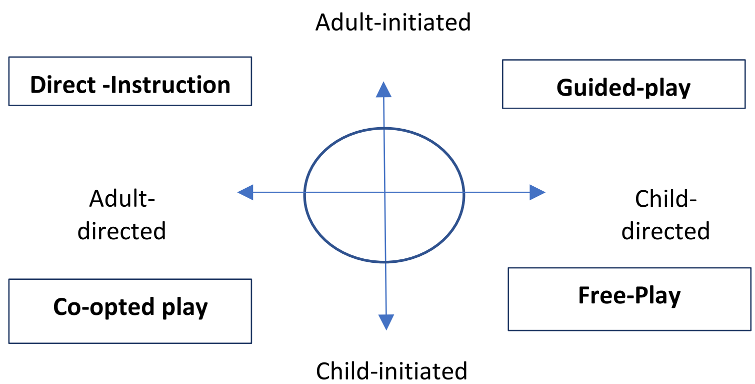
In this scenario, Weisberg, Hirsh-Pasek, & Golinkoff (2013) proposed the notion of “guided-play” as a methodology that allows the articulation of the curricular demands of educational systems, while being respectful towards children's abilities and interests. This approach is also called "hands-on learning" in specialized literature. It involves learning by discovering and practicing. As embodied cognition theories suggest: "it consists of thinking through fingers" (Frick, Tardini, & Lorenzo, 2013, in Peabody, 2015).

A mayor characteristic of guided-play is that adults begin the play and, therefore, limit learning goals. Although adults are responsible for maintaining the focus on the goals, it is the child who guides his/her discovery process and chooses different paths within a play context. Thus, play does not begin spontaneously, but it retains the dimension of child agency. Accordingly, the child is honoured as the protagonist of his/her learning process (Weisberg et al., 2015).

Aligning with socio-constructivist tradition inaugurated by Vygotsky (1896-1934), in guided-play the adult encourages the child's exploration and learning during the interaction. This way the adult initially structures and facilitates the play, but it is the child who directs its course, makes decisions and mistakes, and engages in the process at his/her own pace. In an atmosphere of social support and genuine respect for the autonomy of the child, adults help children to develop cognitive tools that enable them to think by themselves (Weisberg et al., 2013, 2015).

The next figure is adapted from Weisberg, Kittredge, Hirsh-Pasek, Golinkoff, & Klahr (2015), to summarise and compare playful learning methods. Two criteria were employed to establish the typology: who initiates the interaction and who directs it.

Figure 10: Types of early childhood pedagogical approaches (adapted from Weisberg, Kittredge, Hirsh-Pasek, Golinkoff, & Klahr, 2015)



In the co-opted play the child starts the play, but soon the adult takes control. In consequence, the adult sets the agenda and designs the scenario without giving space to the child's agency. It becomes a task disguised as play, although young children promptly recognise its lack of authenticity. Paraphrasing Bruckman's famous words (1999), co-opted play is a hijacked activity, a kind of "chocolate-covered broccoli" (in Pyle & Danniels, 2017)

To Weisberg et al., (2015), guided-play has comparative advantages over other teaching models. This approach draws on the findings of recent research indicating that narrowing the parameters in which the apprentice must focus his/her attention facilitates learning. Indeed, this is one of the underlying mechanisms that explain its effectiveness: the distraction that hinders learning is reduced. In turn, this helps a child to focus on the relevant dimensions for his/her own current learning goal without limiting his/her curiosity.

One of the studies cited to demonstrate the comparative advantages of guided-play v/s direct instruction in a young child's education, is the experiment carried out by

Bonawitz et al. (2011). This study makes it clear that direct instruction can be a "double-edged sword": the children learn the contents that they are taught explicitly but tend to be more restrictive in the exploration and generation of creative and innovative responses.

Another study implemented by Kittredge, Klahr, & Fisher (2014, 2015) yields similar findings, that is, that focusing a child's attention to achieve some learning objective could not be done without paying a cost in terms of his/her free exploration. This study also included two experimental groups. In both, the task supposed to discover hidden miniature animals in a forest. In a group, children were shown only one way to find animals in the forest ("this is how you can find the animals"). In the other group, children received the same demonstration but were also told this phrase: "This is how you can find the animals ... but there may be many other ways to find animals". As result, it was clear that children in the first group were focused on the proven strategy and found only a few hidden animals.

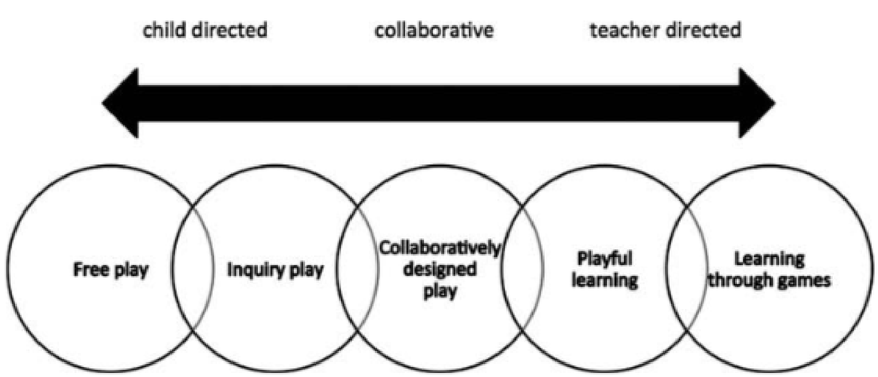
On the contrary, children in the second group not only used the strategy they had been taught but went further, exploring and discovering more hidden animals (in Weisberg et al., 2015). Therefore, using only direct instruction inhibits children's natural curiosity and constrains their creativity.

The body of research that proves the positive effects of guided-play interventions on curricular learning achievements is continuously growing. Most of these studies have been conducted with pre-schoolers, and indicate that guided-play is a better and more beneficial tool to promote young children's acquisition of geometric knowledge (Fisher, Hirsh-Pasek, Newcombe, & Golinkoff, 2013) and increased use of spatial language (Ferrara et al., 2011).

Studies concerning the positive effects of guided-play for older children are scarce. Whitebread, Basilio, Kim, & Torres (2015) presented the preliminary results from a study that tested a guided-play intervention, using LEGO to enhance metacognitive abilities, creativity, and narrative skills in primary English students. Although study design was not experimental, the preliminary results showed an improvement in the quality of writing products in the post-test. Children also showed higher post-intervention metacognitive control, as well as a better performance on creativity measures (Whitebread & Basilio, 2017; Whitebread, Basilio, Kim, & Torres, 2015).

Along with the identification of the beneficial effects of guided-play on children's learning and development, some researchers have concentrated their efforts on developing a more nuanced typology of guided-play. Pyle & Danniels (2017), in particular, have proposed a continuum of play-based learning (Figure 11), which has been formulated using empirical data and is intended to be a useful tool for practitioners dealing with the daily challenge of creating learning opportunities for children. The gradient is determined by who leads the process.

Figure 11: Continuum of play-based learning (Pyle & Danniels, 2017)



In inquiry play, the child sustains the control of the play, and the teacher extends such play by responding to the child's interest or curiosity. It is similar to the "learning by discovery" approach.

In the collaboratively designed play, child and teacher share control—both of them design play's environment and themes.

According to Pyle & Danniels (2017), playful learning is a more structured approach that intends to support the learning of some academic standards that will not be naturally acquired through play. Playfulness becomes a strategy to increase students' engagement and children retain some control over the play process.

Lastly, learning through games would be the most structured type of play-based learning identified by these authors. In this kind of play the teacher prescribes the process and directs the outcomes, and the children follow the rules of the game (Pyle & Danniels, 2017).

3.2.3 How can adults support play-based learning of spatial reasoning?

At least two strategies adults use when trying to focus children's attention during play-based learning have been identified. These are contextual and socio-cognitive scaffolding.

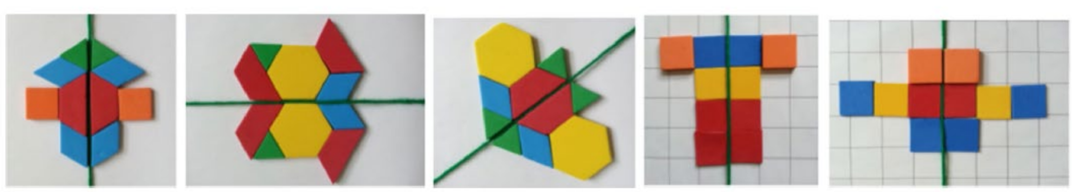
3.2.3.1 Contextual scaffolding.

This strategy involves the enrichment of the environment with objects/toys, or games that provide learning opportunities linked to a specific curricular content. Weisberg, Hirsh-Pasek, Golinkoff, & McCandliss (2014) have called this strategy "mise en place". They borrow the expression from gastronomy, where it refers to the organisation and ingredients the chef uses when preparing a recipe. In the context of play-based learning, the "mise en place" describes the structuring of the learning environment before initiating learning activities. It entails the selection of materials or toys that allow children to explore at their own pace.

In terms of selected materials to enhance spatial reasoning, there is sound evidence that supports the use of building blocks and geometric figures. When used to reproduce or create designs, children learn to understand part/whole relationships (larger objects can be segmented into smaller units), as well as count or measure units to develop symmetric designs around an axis (see Figure 12) (Casey et al., 2008; Ferrara et al., 2011; Jirout & Newcombe, 2015; Moss, Hawes, Naqvi, & Caswell, 2015; Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2014a).

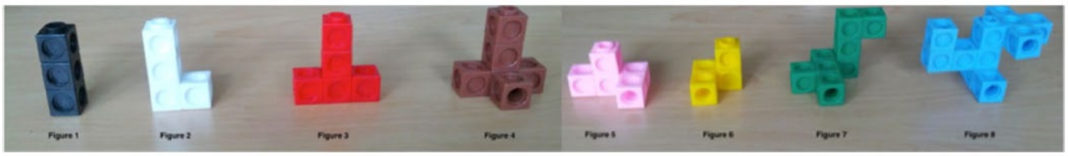
Figure 12. Symmetrical constructions with pattern blocks built by young children

(Moss, Hawes, Naqvi, & Caswell, 2015)



Meanwhile, by using multilink cubes children can learn to compose and decompose 3D shapes and understand mirror images (facilitating the developing of mental rotation) (see Figure 13).

Figure 13. 3D figure compositions with multilink cubes (Moss et al., 2015).



LEGO blocks are a particularly promising material because of their special characteristics. Unlike traditional building blocks, LEGO blocks are not smooth but have anchor points (pips) that allow children to explore different types of assemblies. To reproduce the "right" montage and replicate a model, children need to count the necessary pips, understand the notion of part and whole, and invoke measurement concepts (Verdine et al., 2014a).

The use of shapes with varied forms in each category—that is, not only using canonical forms—could also help children to learn the defining features of each geometrical shape (Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2014)

The drawings have shown to be useful to teach the conventions of 2D representations of 3D forms (see Wheatley's "Quickdraws" in Tzuriel & Egozi, 2010). Finally, puzzles, tangrams, as well as origami and other kinds of paper-folding tasks have proved to stimulate the development of children's spatial skills (Cakmak, Isiksal, & Koc, 2014).

In brief, adults can scaffold play-based learning providing carefully selected materials to enrich play environments. Regarding the development of children's spatial reasoning, previous research has shown positive results with geometric figures, building blocks (specially, interlocking blocks), 2D drawings of 3D forms, tangrams, and paper-folding tasks.

3.2.3.2 Socio-cognitive scaffolding

The other type of scaffolding that boosts play-based learning is the socio-cognitive adult's mediation. This kind of strategies may include the adult's participation as co-player, discussing children's findings, and formulating open questions about hypothesised situations ('What do you think would happen if ...?').

Also, adults may suggest new ways to explore and play with the materials in manners children had not previously visualised. However, the adult's intervention should be minimally intrusive as well as respectful of the child's choices to avoid "hijacking" the play (Weisberg, Kittredge, Hirsh-Pasek, Golinkoff, & Klahr, 2015).

The socio-cognitive scaffolding can imply, for example, the use of a storytelling context for the learning activity. The study conducted by Casey et al., (2008) offered empirical evidence about the benefits of storytelling during constructional play to enhance children's memory and their development of spatial skills. The children immersed in constructive play along with a narrative showed better results than children from the guided-play condition without the fiction narrative element. Besides, children's engagement and motivation were higher in the group with the narrative device.

Another study carried out by Casey et al. (2014) pointed out that the amount of spatial language that adults use is essential for children's development of spatial skills. Using a rich spatial lexicon would be another form of socio-cognitive scaffolding provided by adults. This kind of support has proved critical to girls' development of spatial skills. The use of contextual scaffolding (i.e., the availability of spatial toys and games) seems to be not enough support to enhance girls' spatial reasoning.

Connecting the ideas previously reviewed, and in order to design a comprehensive intervention that fosters children's spatial skills, the following criteria should be met:

- Provide long, frequent, and cohesive intervention (from 6 to 60 hours) to target different spatial skills. Ideally, the training should be aligned with the mathematical curriculum.
- Design diverse, hands-on, and playful activities to boost and sustain children's intrinsic motivation. Spatial skills development requires that children move and providing them, for instance, with opportunities for constructional play.
- Use a wide variety of materials to set up the appropriate "mise en place": drawings, different types of blocks (cubes, LEGO, pattern blocks), paper folding activities such as origami, puzzles, dominoes, tangrams, and art materials (clay, Wikki Stix, pipe cleaners, geometric form stickers).
- Promote an adult's socio-cognitive scaffolding that favours discovery learning for children. Adults should deliberately use a rich and frequent spatial language during interactions with children.
- Adult facilitators should encourage and pay attention to a child´s gestures when they are asked to explain his/her movements or actions during constructional play.

3.3 What are the knowledge gaps in spatial reasoning research?

Previous research has shown that a high level of development in spatial skills associates to high mathematics achievement and increases the probability of choosing a career in STEM fields (Wai, Lubinski, Benbow, & Steiger, 2010).

Although different studies have shown a consistent correlation among spatial skills and early mathematics performance, little is known about the direction of causal effects or underlying mechanisms that explain this relationship.

Regarding causal effects, previous findings are inconsistent. Cheng and Mix (2014) found that a brief mental rotation training with 6 to 8-year-old children, improved their performance in the calculation tasks and missing-term problems. However, Hawes et al. (2015) carried out a training study with children of the same age and in-class setting and could not replicate these findings.

There are several differences in the research design of both studies that could explain the inconsistency of results. In first place, both training studies differed in the "dose" of the intervention: training provided in Hawes et al.'s (2015) study was more comprehensive, intensive and prolonged. Second, they differed in the control degree of experimental conditions: Cheng & Mix' study was conducted in a laboratory, and hence, the trial setting was more standardised. Nonetheless, the study of Hawes et al. (2015) fulfilled the criteria for ecological validity better. Third, both studies differed in the time schedule for the post-test measurement. Hawes et al. (2015) scheduled the post-test later (one week after the end of the intervention) than Cheng & Mix' study (they applied the post-test immediately after the training ended). Based on this last difference between both studies, Hawes et al. (2015) have suggested that the findings of Cheng & Mix might be the result of a priming effect rather than real learning or improvement of spatial skills.

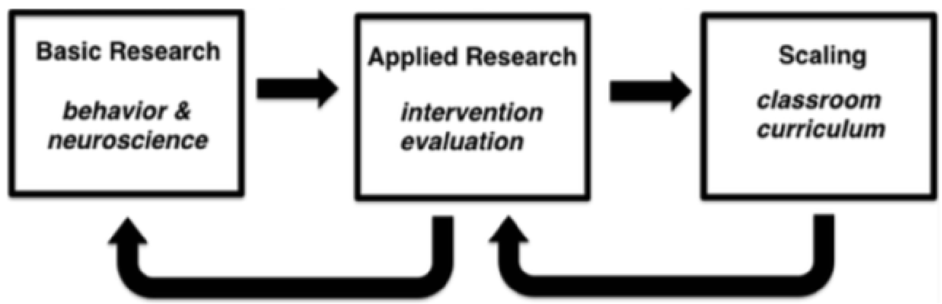
These alternative explanations about prior findings require further inquiry to clarify the nature of the relationship between spatial and mathematical skills. The present doctoral research intends to contribute in this direction. With that aim, this research design adopts some ideas developed by Hawes et al. (2015). Indeed, this study proposes to test the hypothesis regarding the causal relationship between spatial and mathematical skills in a natural environment, that is, it intends to avoid artificial effects attributable to lab settings. Besides, it borrows the notion of near, intermediate and transfer skills used by Hawes et al. (2015), although this thesis operationalises some of them differently. In this research, near transfer skills were understood as those directly trained along the intervention (i.e. mental rotation and perspective-taking). Intermediate transfers skills were those indirectly and partially trained by the intervention (i.e. visual-spatial working memory and short-term memory). Finally, the far transfer skills refer to those that were not trained along the intervention, but it was expected improvement as a transfer of learning (algebra and arithmetic calculation skills).

This thesis also intends to contribute to the discussion about which are the best training strategies to improve spatial skills on children in classroom settings, that is, an environment that group children with an initial level of spatial skills quite diverse. For that, the intervention designed is based on the evidence available about what works for particular groups of children (i.e. girls and children with a lower level of spatial abilities). At the same time, it explores less investigated variables in training studies, such as the children use of hand gesture and spatial language, in order to provide useful insights for the instructional design of spatial and mathematical activities.

To locate this research on a broader framework of educational research, the model proposed by Gabrieli (2016) offers useful concepts [see Figure 14]. Even though this model was introduced initially to understand how educational neuroscience research is organised, it could be extended to others educational research arena. In Gabrieli's words:

> "the educational neuroscience combines with behavioural science to motivate experimental interventions, which, if effective, can be scaled to widespread classroom practice (top row of arrows). Considering educational needs inspires basic research directions, and priorities development of interventions (bottom row of arrows)" (p.617).

Figure 14: "A pipeline organisation of educational neuroscience" (Gabrieli, 2016)



According to Gabrieli's model, the research proposed in this thesis would be in the circuit between basic and applied research. Indeed, it is in the stage of applied research because it connects the evidence provided by previous empirical studies to design a small-scale intervention that improves children spatial skills. Simultaneously, it intends to provide feedback to a basic research question when it seeks to study the intervention's effects on a set of interconnected skills and to test a chain-causal model.

In the next pages, it is presented the research objectives and questions. Then, the methodology used is profusely described.

4 Research Objectives

1. To investigate the effects of comprehensive and evidence-based training in a sample of Chilean 2nd-grade students on:
    1.1. Near transfer skills: mental rotation (intrinsic-dynamic) and perspective-taking (extrinsic-dynamic).
    1.2. Intermediate transfer skills: visual-spatial memory system (working memory and short-term memory).
    1.3. Far transfer skills: and mathematical calculation skills (arithmetic and algebra).
2. To investigate differential effects of training associated with children' sex and their initial level of spatial skills.
3. To model the relationships between near (mental rotation and perspective-taking), intermediate (visual-spatial working memory and short-term memory) and far transfer (arithmetic and algebra) effects.
4. To explore changes in the use of spatial language and hand gestures or body movements in a subsample of experimental group' students.

5 Research Questions

1. Does the training based on guided-play and embodied cognition improve students':
    1.1. Near transfer skills: mental rotation (intrinsic-dynamic) and perspective-taking (extrinsic-dynamic)?
    1.2. Intermediate transfer skills: visual-spatial memory system (working memory and short-term memory)?

1.3. Far transfer skills: mathematical achievement (arithmetic and algebra)?

2. Are there any differential training effects between subgroups?
   2.1. Are training effects greater in girls than boys?
   2.2. Are training effects greater in children with low initial skills?

3. How are the relationships among the near, intermediate and far transfer skills?

4. How do the students use spatial language, hand gestures, and body movements along the intervention?

6 Methodology

6.1 Research Design

The research design of this study was quasi-experimental. It consisted of a training study with a mixed design that enables between and within subjects' comparisons.

The independent variable (IV) was the in-class intervention based on guided-play and embodied cognition principles.

The dependent variables (DV) included: spatial skills (perspective-taking and mental rotation), visual-spatial memory, and mathematical calculation skills (two-digit arithmetic and algebra). Nevertheless, these variables were located in different levels of causal proximity in the hypothesised effects model. Spatial skills were considered near transfer abilities, visual-spatial memory was treated as an intermediate transfer ability (the hypothesised mediator), and calculation skills were treated as far transfer abilities.

The study design also included an exploratory inquiry of children's use of gestures, body movements, and spatial language along the intervention. It intended to describe preliminary modes regarding how children employed these resources to make sense of objects' transformations, either in position or in shape.

In using intact groups (in this case, classes), the scientific literature on quasi-experimental studies suggests one should determine the subjects' initial levels in variables that could play a role in the training results. This allows to carry out a statistical control of their effects as covariates. Hence, in this research, the non-verbal IQ and oral understanding of verbal language were measured before the intervention began.

All children were individually assessed at three different moments to measure their spatial skills and visual-spatial memory:

- Pre-test (T1): one week before training (week number 1)

- Post-test (T2): one week after the training's completion (week number 6)
- Follow-up (T3): three weeks after the training's completion (week number 9)

Regarding their calculation skills, children were collectively assessed in two separate moments: pre-test (week 1) and post-test (week 6). Compared to the other variables evaluated in the study, a different format was used here as an intent to minimise the interruption of children's school routine and also because the intervention's completion coincided with the end of the school year.

An a priori analysis with G-Power software was carried out to establish the sample size, using ANCOVA as the statistical test. The meta-analysis of Uttal et al. (2013) posited an average effect size of 0.47 (SE= 0.04) (Hedges's g) between training and control groups. Considering this data as the actuarial criterion proposed by Lypsey and given a statistical power of 0.95 (α=0.05; 1-β=0.95) with two comparison groups and two covariates, the minimal total sample size required was 147 subjects, divided in two groups of 74 students each.

6.2 Participants

Two urban schools participated in the study, with two parallel 2nd grade classes in each of them. At each school, one class was randomly assigned to the experimental condition and the other to the control condition. One of the schools participated in the study for two years, so the 2nd-grade classes from 2016 and 2017 received training.

Both schools receive students from the low-middle socioeconomic background. The classes grouped 185 students with ages ranging between 7 and 8-years-old. 47% of participants were female (n=87), and 47% of students were part of the experimental condition (n=87). Table 1 sums up the participants' distribution.

Table 1: Participants' distribution.

	School 1 (P)		**School 2 (Y)**				
Cohort	2016		2016		2017		
Condition	Experimental	Control	Experimental	Control	Experimental	Control	**Total**
Boys	12	19	15	14	17	21	98
Girls	13	15	15	14	15	15	87
Total n per condition	25	34	30	28	32	36	185
Total n per school	59		126				

The sample was selected using an intentional criterion, searching for a homogeneous sample in terms of SES and school grade. On the one hand, the type of school administration and district were used as a proxy of SES to select middle-class students. Also, time and budget restrictions were strong reasons to include only middle SES students to achieve the required sample size.

On the other hand, the sample was configured by students of the same school grade and age range. Second graders (7 and 8-year-olds) were selected to facilitate the comparison with results of previous research (Cheng & Mix, 2014; Hawes et al., 2015). Although early interventions tend to have a better impact in the long-term, first-grade students were excluded because they are struggling with transitional issues that could have hindered the training's implementation.

6.3 Procedures

The schools' headmasters and second-grade teachers were contacted to explain them the research objectives and obtain their authorisation. Then, the researcher attended the parent's meetings at school to talk to them about the research's aims, invite their children to participate, clarify any questions they might have, and hand them over the consent letter.

Once the parents' consents were obtained, the researcher visited the children's classrooms. They received a booklet that explained the research activities and were invited to participate. All these documents are attached in the Appendix 1, and ethical procedures will be further described in section 5.6

As was previously mentioned, each student's performance was evaluated on three different occasions: one week before the intervention began, one week after the intervention's ending, and at a three-weeks follow-up. All assessments were carried out individually, except for mathematical calculation skills tests, which were applied to each class as a whole.

Regarding the intervention, the lessons in the experimental condition were designed to enhance children spatial skills through construction play. Specifically, the activities were selected following the principles of guided-play (Weisberg, Hirsh-Pasek, & Golinkoff, 2013; Weisberg, Hirsh-Pasek, Golinkoff, & McCandliss, 2014; Weisberg, Kittredge, Hirsh-Pasek, Golinkoff, & Klahr, 2015) and embodied cognition theories (Ehrlich, Levine, & Goldin-Meadow, 2006; Goldin-Meadow, 2015).

Adhering to the Guided-play approach implied that adult initiated the play sequence, but the children were who directed it and made their choices along the play. By doing so, the adult provided the contextual scaffolding, offering the proper play material to foster children spatial reasoning, and aligning the activity proposed with the math standards for second graders. Also, the adult offered socio-cognitive scaffolding to children, that is, she included herself as a co-player, formulated open questions to children or prompts to explore materials in new ways. In any case, her interventions during the play activity were minimally intrusive, preserving the children's choices.

According to the embodied cognition's principles, the play activities boosted the children's use of body movements in order to understand and resolve the spatial reasoning tasks. Besides, the offered spatial activities implied the manipulation of different materials (used mostly in constructional play) and offered multimodal sensorial experiences (visual, tactile, and kinesthetic).

Finally, the play activities had to be resolved in small groups of four children. So, they had to take turns, and sometimes, dialogue and negotiate among them to address the task.

The twelve activities that composed the intervention were selected from various programs and studies. In all cases there was some evidence of their effectivity. In spite of that, a pilot application of the activities was carried out in a different sample of children. The activities included in the intervention are described with more detail in the Appendix 2.

The experimental training was implemented over four weeks (three sessions per week). The aim was to provide a "high dosage of treatment", that is, extended and intensive training. Each lesson was 45 minutes long and was conducted by two implementers during in-class hours at the children classroom. To warrant the intervention's fidelity, the lessons were always imparted by the researcher, while a research assistant provided support with materials and filming devices. Importantly, the activities were conducted in groups of four students each, to maximise children's participation and engagement.

For fifteen groups in the experimental condition, each lesson was videotaped to perform a post-hoc analysis of the variations in children's use of spatial language, gestures, and movements. The groups to be filmed were selected randomly among those where children's parents had given their consent.

Children of the control condition received a standard, although delayed, intervention.

6.4 Measures

6.4.1 Co-variates

In the pre-test, the **"understanding of oral instructions"** was individually assessed with the subtest "Comprensión de indicaciones" (Comprehension-Knowledge) from Batería III-Woodcock-Muñoz (Muñoz-Sandoval, Woodcock, McGrew, & Mather, 2005). It measures the ability to listen to and follow a sequence of instructions.

The children are presented with five pictures, and then they should follow increasingly difficult instructions, signalling some objects that appear in the drawings, in an ordered sequence. The items scored 0 (non-achieved) or 1 (achieved), and the maximum total score was 46 points.

Based on Spanish calibration data, the internal consistency reliability coefficients reported by the authors is r = .92 for children 9 years-old (Schrank et al., 2005).

The **non-verbal IQ** (according to Spearman' g factor of intelligence) was measured with Raven´s Coloured Progressive Matrices (CPM). CPM first appeared in 1947 and was created specifically for children aged between 5 and 11 years of age. It was revised in 1956, and this version continues to be used today in both clinical and research settings. The CPM comprises 36 items divided into three sets of 12 items of an increasing level of difficulty (Cotton et al., 2005). According to Uttal's current taxonomy, the CPM would assess the intrinsic-static spatial skills.

The items were 0 (non-achieved) or 1 (achieved), and the maximum total score was 36 points.

The internal consistency estimates in an Australian sample ranged from a low .76 (11 year-olds) to a high .88 (for 8 and 9 year-olds) (Cotton et al., 2005).

6.4.2 Near transfer skills

Two types of spatial skills were assessed: mental rotation (intrinsic-dynamic spatial skill) and perspective taking (extrinsic-dynamic spatial skill).

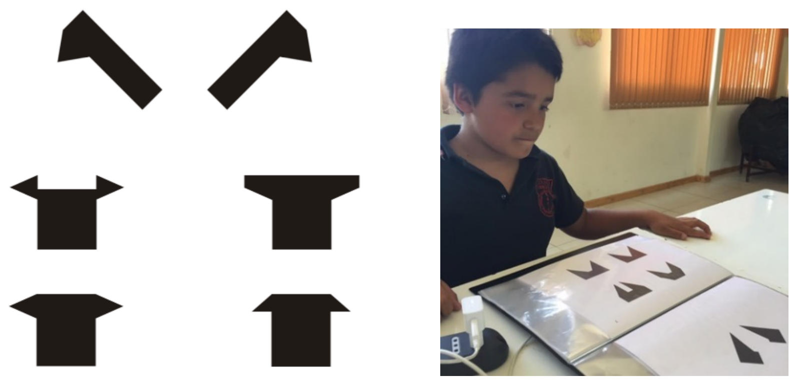
Mental rotation **(MR)** was measured with "Children's Mental Transformation Task" (CMTT-Form D) developed by Levine, Huttenlocher, Taylor, & Langrock (1999). The authors were contacted and consented to its use.

The test included 16 items (see figure 15), and children were required to choose, among 4 options, what shape would result from moving two separate pieces together. The instrument included four types of 2D mental transformations: 1) horizontal translation, 2) diagonal translation, 3) horizontal rotation, and 4) diagonal rotation.

The items scored 0 (non-achieved) or 1 (achieved), and the maximum total score was 16 points.

The reliability obtained in this study was α=.82.

Figure 15. Example of Items from CMTT (MR)



The test developed by Frick, Möhring, & Newcombe (2014) to evaluate the ***perspective-taking skill*** **(PT)** was used, and their authorisation was also previously obtained.

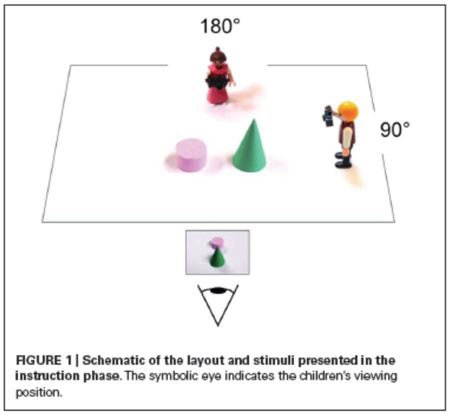
The test included 18 scenes of toy photographers taking pictures of layouts of objects from different angles. Children were asked to choose which one out of four pictures could have been taken from a specific viewpoint (see figure 16).

The items scored 0 (non-achieved) or 1 (achieved), and the maximum total score was 18 points.

The reliability reported by the authors was an internal consistency of α=.91.

The reliability registered in the present study was α=.98.

Figure 16. Perspective-taking test (PT)



6.4.3 Intermediate transfer skills

The visual-spatial Memory (both working and short-term memory) was assessed with the "Neuropsychological Child Assessment Test" (TENI) designed by Chilean CEDETi-UC (Tenorio, Arango, Aparicio, Benavente, Thibaut, & Rosas, 2012). The instrument is administered on a tablet (touch-screen) device.

The two subtests of this instrument that specifically measure the visual-spatial memory system were applied. The subtest "Torpo, el topo torpe" (Torpo, the clumsy mole) evaluates the visual-spatial working memory (VSWM), whilst "The Mexican house" evaluates the visual-spatial short-term memory (VSST).

The **VSWM test** begins with a screen that shows a 3x3 grill (Figure 17). The instruction the child receives is that the clumsy mole is trapped, and he/she has to help it to get out. To do so, the child must observe the holes in which the mole appears, and then repeat the sequence, touching the holes in the exact same order. The items' difficulty increases progressively, and the system records the child's touch sequence. The scale ranges from 0 to 16 points (Tenorio et al., 2012).

In **VSST test**, the child reproduces in the tablet an image previously displayed and not available anymore (Figure 18). The scale ranges from 0 to 32 points (Tenorio et al., 2012).

Figure 17: VS Working-memory (VSWM).

Figure 18: VS Short-term memory (VSST).

The data of each child's performance is digitally sent and analysed at CEDETI-UC, which then reports the final child's score in each test (the description per item is not included).

The reliability data reported by the authors for VSWM test was α=.9; interrater reliability for VSST test was .8 (Tenorio, et al., 2012).

6.4.4 Far transfer skills

Two tests were used to assess calculation skills. One of them was developed ad-hoc to evaluate two-digit arithmetic problems (addition and subtraction) **[ARI]** and was aligned with Chilean curriculum standards for second graders. The second calculation test was elaborated and provided by Hawes, Moss, Caswell, & Poliszczuk (2015). It was applied to measure abilities to resolve simple algebra tasks, specifically, missing-term problems **(ALG).**

The items scored 0 (not-achieved) or 1 (achieved), and the maximum total score for each test was 18 points (with a total of 36 points for both tests).

Table 2: Summary of Measurement Instruments

Variable's Role in this research design	Instrument	Authors	α reported by authors	Range of raw scores
Covariates	**"understanding of oral instructions"** (Comprehension-Knowledge) from Batería III-Woodcock-Muñoz	Muñoz-Sandoval, Woodcock, McGrew, & Mather, (2005).	α =.92	0-46
	non-verbal IQ was measured with Raven´s Coloured Progressive Matrices (CPM).	Raven, (1947).	Ranged from a low .76 (11 year olds) to a high of .88 (for 8 and 9 years) (Cotton et al., 2005)	0-36
Near Transfer skills (DV)	***mental rotation*** **(MR)** was measured with "Children's Mental	Levine, Huttenlocher, Taylor, & Langrock (1999).	Not reported. The reliability obtained in this study was α=.82	0-16

	Transformation Task" (CMTT-Form D)			
	***perspective-taking skill* (PT)**	Frick, Möhring, & Newcombe (2014),	α=.91	0-18
Intermediate transfer skills (DV)	**VSWM test** from "Neuropsychological Child Assessment Test" (TENI)	CEDETi-UC, Chile (Tenorio, Arango, Aparicio, Benavente, Thibaut & Rosas, 2012).	α=0.9	0-16
	VSST memory test from "Neuropsychological Child Assessment Test" (TENI)	CEDETi-UC, Chile (Tenorio, Arango, Aparicio, Benavente, Thibaut, & Rosas, 2012).	interrater reliability= .8	0-32
Far transfer skills (DV)	***Arithmetic calculation test***	Developed ad-hoc	See Results (CFA)	0-18
	missing-term problems **(algebra calculation test)**	Hawes, Moss, Caswell, & Poliszczuk (2015).	Not reported	0-18

6.5 Data Analysis

Differences between experimental and control group were examined as part of several of the analyses performed. Thus, in order to answer the first research question, it was carried-out several univariate two-way mixed ANCOVAS, with time and condition as independent variables. Only Raven' scores were used as a covariate because initials scores of understanding oral instructions showed no significant differences between children from experimental and control condition [F(1,183)= .424, p.516]. Near, intermediate, and far transfer skills were sequentially treated as dependent variables. The analyses with univariate statistical techniques were implemented to facilitate comparisons with the research carried out by Chang & Mix (2014) and Hawes et al. (2015). Both research's teams used this kind of analytical procedures.

However, as this research design supposed the identification of several DV, a multivariate statistical technique should be the appropriate choice. In consequence, the treatment effect was also analysed through a Latent Change Score Model (LCSM). This technique is a multivariate statistical technique that belongs to Structural Equation Models (SEM). It allows analysing the simultaneous contribution of different independent variables over several dependent variables. In the LCSM model three methods were used to compare condition groups:

a. estimating the differences as defined parameters within the model;
b. using a *Lagrange Multiplier Test* (Bentler & Chou, 1992) and
c. including the treatment as a regressor of the change scores.

To answer the second research question, the same sequence was done. Firstly, univariates ANCOVAS were carried-out, comparing treatment groups by sex and spatial skill initial level. Then, a multilevel regression to model mediation along the time was implemented, specifically, a Cross-Lagged Panel Model (MacKinnon, 2008). In this analysis, treatment was included as regressor, evaluating as well its interactions with children sex and their initial levels of spatial skills as moderator variables.

To solve the third research question, a Latent Change Score Model (LCSM) was used to test the hypothesised causal model (causality in chains). These analyses will be further described in the following pages.

Finally, the fourth question required the use of a combined methodology. In the first place, a qualitative phase of coding was carried out. Then, the codes were converted into numbers (nominal variables). This allowed to obtain descriptive statistics to characterise how the children used spatial language, gestures and body movements. Details will be given at the final of this chapter.

Table 3 presents a summary of the types of analyses performed:

Table 3: Summary of data analysis

Research Questions	Type of analysis
1. Does the training based on guided-play and embodied cognition improve students': 1.1. Near transfer skills: mental rotation and perspective taking? 1.2. Intermediate transfer skills: visual-spatial memory system (working memory and short-term memory)? 1.3. Far transfer skills: calculation skills (arithmetic and algebra)?	Univariates Two-way mixed ANCOVA, adjusted by a covariate (non-verbal IQ) And Latent Change Score Model (LCSM)
2. Are there any differential training effects between subgroups? 2.1. Are training effects greater in girls than boys? 2.2. Are training effects greater in children with low initial spatial skills?	Univariates Three-way mixed ANCOVA, adjusted by a covariate (non-verbal IQ) Moderator variables: sex, initial level of spatial skills And Cross-Lagged Panel Model
3. How are the relationships among the near, intermediate and far transfer skills?	Latent Change Score Model (LCSM)
4. How do the students use the spatial language, hand gestures, and body movements along the intervention?	Descriptive statistics to characterise and identify patterns of use. Groups' comparison by sex with a non-parametric statistic.

Regarding the used software, the statistical analyses conducted to answer research questions number one, two and four were executed with Excel (version 16.17) and SPSS (version 24). In order to solve research question number three, the statistical analyses were performed using the R language programming environment version 3.5.1 (R Core Team, 1997/2018), with specific packages. Multiple Imputation by Chained

Equations was performed using the mice package 3.3.0 (Stef van Buuren & Groothuis-Oudshoorn, 2011). Confirmatory Factor Analysis and Structural Equation Modelling were conducted with the lavaan package 0.6-3 (Rosseel, 2014), complemented with the package semTools 0.5 (Jorgensen, Pornprasertmanit, Schoemann, & Rosseel, 2018) for computing reliability measures and measurement invariance. Bayesian structural equation modelling was performed using the lavaan package (Merkle & Rosseel, 2018), while multilevel regressions were estimated with the brms package (Bürkner, 2017).

6.5.1 Missing data handling

When possible, likelihood-based methods were used to deal with missing data, such as Full Information Maximum Likelihood (FIML) (Enders & Bandalos, 2001), Pairwise Maximum Likelihood (Katsikatsou, Moustaki, Yang-Wallentin, & Jöreskog, 2012), and data augmentation within the Bayesian Markov Chain Monte-Carlo (Merkle, 2011).

Otherwise, computations pooling estimates from multiply imputed data were performed. Only when there was no available procedure to perform either, a single imputed dataset was used, averaging the mean or modes from the multiply imputed data (Burns et al., 2011)

Multiple imputations were performed through Multivariate Imputation by Chained Equations (van Buuren, 2018), using a non-theoretical model with all identificatory variables (school, sex, treatment condition, etc.), the linear composite scores of the measurements, and other particular variables that were significantly correlated with the one under imputation ($r > .25$).

For binary outcomes, imputations were performed using bootstrapped logistic regression. Polytomous regression was used for categorical non-ordered variables with more than two values. For ordinal variables, proportional odds logistic regression (POLR) was used, and the MIDAStouch version of predictive mean matching was used for continuous outcomes (Gaffert, Meinfelder, & Bosch, 2016).

6.5.2 Psychometric properties of measurement' scores.

Previous to perform all the analyses mentioned before to answer questions 1 to 3, the reliability and validity of used measures were studied. With that aim, the latent structure and reliability index of all measurement' scores were examined through a Confirmatory Factor Analysis (CFA), except those of VSWM and VSST because they were not available.

Latent Variables of PT, MR, ARI, ALG, as well as a second order factor of Mathematics—measured by ARI and ALG—were modeled. The models' goodness-of-fit was evaluated, and a multi-group CFA was performed to study measurement invariance across time-points.

The following two estimators were used: (i) unweighted least squares with robust standard errors and mean and variance adjusted test statistic (ULSMV), and (ii) Pairwise Maximum Likelihood (PML). While ULSMV is a standard estimator for ordinal and dichotomous outcomes—alongside WLSMV (Forero, Maydeu-Olivares, & Gallardo-Pujol, 2009)—the PML has been studied over the last decade and has shown to perform as good as (U/W)LSMV. Still, PML has some advantages, such as the possibility to deal with missing data from a likelihood-based approach, as Full Information Maximum Likelihood does (Katsikatsou, Moustaki, Yang-Wallentin, & Jöreskog, 2012).

Besides the χ^2 test and the Pairwise Likelihood Ratio Test (PLRT), four goodness-of-fit indices were calculated when appropriate: Comparative Fit Index (CFI) and Tucker-

Lewis Index (TLI), as incremental fit indices; Root-Mean-Square Error of Approximation as parsimony correction index; and Standardized Root Mean Residual (SRMR), as absolute fit index.

For ULSMV estimations,[1] the following cutoff values were used (P. Bentler, 1990; Yu, 2002):

- Good fit cutoff values: CFI ≥ .96, TLI ≥ .95, RMSEA ≤ .05, SRMR ≤ .06;
- Acceptable fit cutoff values: CFI and TLI ≥ .90, RMSEA ≤ .08, SRMR ≤ .08;
- Mediocre fit cutoff values: When .08 < RMSEA ≤ .10, .08 < SRMR ≤ .10, with CFI and TLI ≥ .90. Meeting, at least, two of these three criteria in one level of satisfaction, and the remaining in an adjacent level (upper or lower), the model fit was assumed as conforming to the former (Brown, 2006; Hu & Bentler, 1999).
- Finally, when CFI or TLI < .90, or RMSEA > .10, the model was rejected.

As to reliability indices of composite scores, α (Cronbach, 1951), ω, and ωt (McDonald, 1999) were calculated.

The measurement invariance across time-points was studied performing PLRT with the (Satorra, 2000) adjusted test statistic. The aim was to use the approach proposed by (Wu & Estabrook, 2016), according to which thresholds are fixed at configural invariance before proceeding with the usual progression of loadings (weak), intercepts (strong), and residuals (strict, not used here).

While PML was used over the original data for all final computations (e.g., estimates, model comparison, measurement invariance), the modification indices were explored with ULSMV, due to current technical restrictions with the implementation of PML in *lavaan*.

[1] Proper simulation studies concerning how these several fit indices behave under PML estimation have not yet been reported. Therefore, they were used only for comparison purposes.

6.5.3 Details of some data analyses procedures.

6.5.3.1 Latent Change Score Model (LCSM)

In order to analyse five aspects of the data a Latent Change Score Model was estimated (Ghisletta & Mcardle, 2012; Henk & Castro-Schilo, 2015; Kievit et al., 2017)

1 covariances of the variables at time 1 or pre-test (T1);
2 correlated changes between repeated measures;
3 leading variables of changes in the others, (i.e., those which starting values were related to change scores of other variables);
4 self-feedback parameters (i.e. the regression coefficient of a change score over the score of the respective variable at a previous time-point); and
5 the change scores themselves.

To examine basic parameters (e.g., change score, self-feedback coefficient), a univariate LCSM was estimated for each variable. Then, two Multivariate LCSM with the five factors of interest were estimated. The first one was calculated with a simple correlation between change scores, and the second with a multivariate regression model based on the mediation hypotheses. According to the mediation hypotheses, the improvements in spatial abilities (PT and MR), would produce improvements in mathematical skills (ALG and ARI), mediated by their effect on visual-spatial working memory (VSWM) and visual-spatial short-term memory (VSST).

This second LCSM allowed to estimate and test direct and mediated effects of some change scores over others. Standardized effect sizes and statistical significance were calculated.

Factor scores of latent variables, modelled in CFA, were used for these analyses. To account as precisely as possible for measurement error, the LCSM was estimated with single-indicator latent variables with residuals, according to an expected error of measurement of .05.

A multiple-indicator SEM model, which would have been the ideal choice, was not feasible given the sample size.

6.5.3.2 Multilevel regression for modelling moderation (Cross-Lagged Panel Model)

To evaluate the hypothesis about the moderating role of sex and initial spatial skill level on treatment effect, a Cross-Lagged Panel Model based on multivariate multilevel regressions was examined. All analyses were performed with Bayesian computations with non-informative priors, which render results equivalent to frequentist approaches. The choice of Bayesian statistics for these computations was mainly due to their relative stability in the estimation of more complex models with relatively small sample sizes.

The Bayesian sampling of the posterior distributions in the multilevel regression model was done with two chains of 5,000 iterations over each of the 20 multiplies imputed datasets. This resulted in a total of 40 chains and 200,000 iterations (excluding adaptive/warmup iterations). Convergence of the MCMC was considered dubious when the Potential Scale Reduction Factor ($\hat{R}$) was >1.0 and rejected when $\hat{R}$>1.1 or the effective sample were below 200 (1/1000th of total sampling iterations).

6.5.3.3 *Exploratory analysis of how children use the spatial language, hand gestures, and body movements along the intervention*

Due to time and budget constraints, a subsample of the videos was chosen to be coded, following a hierarchical set of criteria. The first criteria to select the videos was to choose the "best exemplar". Therefore, the experimental group with the best conditions of training implementation (better school environment, a teacher more involved and children more engaged) was selected. Within the experimental group with the best conditions of training implementation, three of the five groups filmed were selected for they had higher attendance during the training sessions. The third criterion was to pick some of the lessons filmed for each group at each stage: two of the training's initial sessions, two from the intermediate phase, and two from the last part of training.

Thus, from a pool of 156 videos, 17 were coded to identify how did the children use spatial language, gestures, and body movements along the training sessions. The 17 videos amounted for a total of 620 minutes (10 hours and 20 minutes) of footage observed and coded.

All the videos were double-coded by the researcher and a specially trained research assistant.

The selected videos were coded using the software ELAN version 5.2. This software allowed to divide each recording in 30 seconds time-lapses. For each time-lapse the spatial language, gestures and body movements displayed by every child of the group were coded.

6.5.3.3.1 Spatial language (SP) code scheme

The spatial language used by the children along the sessions was described through the code scheme developed by Cannon, Levine, & Huttenlocher (2007).

This code scheme includes words used to describe the space in eight broad categories (for a detailed version, see Appendix 3):

A. *Spatial Dimensions:* Words that describe the size of objects, people, and spaces.
B. *Shapes*: Words that describe the standard or universally recognized form of enclosed two- and three-dimensional objects and spaces.
C. *Locations and Directions*: Words that describe the relative position of objects, people, and points in space.
D. *Orientations and Transformations*: Words that describe the relative orientation or transformation of objects and people in space.
E. *Continuous Amount*: Words that describe amount (including relative amount) of continuous quantities (including extent of an object, space, liquid, etc.).
F. *Deictic*: Words that are place deictic/pro-forms (i.e., these words rely on context to understand their referent).
G. *Spatial Features and Properties*: Words that describe the features and properties of 2D and 3D objects, spaces, people, and the properties of their features.
H. *Pattern*: Words that indicate a person may be talking about a spatial pattern (e.g., big, little, big, little, etc. or small circle, bigger circle, even bigger circle, etc.).

Firstly, the code scheme was translated into Spanish. Then, other words used by the children that are specific to the Spanish speaking context were added to the original code-scheme.

The inter-rater agreement obtained with this code-scheme was 0.8

6.5.3.3.2 Hand Gestures and body movements (HG&BM) code scheme

A simple code-scheme was developed to code the hand gestures and body movements displayed by children over the training sessions, as shown in table 4:

Table 4: Hand gestures and body movements Code-scheme

Code number	Behaviour
1	To point or signal something with the finger or hand
2	To show something with the hands
3	To turn or move training material (for instance, to compare own product with a classmate's or with an image projected on-screen)
4	To draw a figure with the fingers (for instance, to slide)
5	Other hands gestures (for instance, ok, to spill, to break, to stop, to kick)
6	To turn or rotate (gesture taught along the training)
7	To flip over (gesture taught along the training)
8	To turn or slightly move the head (to compare with an image projected on-screen, or to look at a figure from various angles)

Furthermore, since the children frequently used gestures accompanied by spatial language, a specific code was created to identify this kind of situation (Table 5):

Table 5: Hand gestures alone or combined with SL.

Code number	Behaviour
1	Gesture alone
2	Gesture in combination with spatial language

The inter-rater agreement obtained with this code-scheme was 0.74

The numerical data obtained with both code-schemes were analysed with descriptive statistics in order to identify children's patterns of use along the training sessions. Some comparison between groups by sex was made, using a non-parametric statistic (Mann-Whitney U-test).

6.6 Ethical Considerations and Procedures

This study firmly adhered to the international codes of ethics (Belmont Report and Common Rule from US Federal agencies) and institutional regulations of Chilean Catholic University's Review Board.

About the ethics principle "Respect for persons", this study was classified as "Research involving no greater than minimal risk". Thereby, it required the permission of one parent and the child's assent. To ensure the proper respect for the child's agency, the information provided should be understandable for him/her. Thus, children were provided with a specially designed explanatory booklet that clarified the purpose of the research and offered a description of their required participation (see Appendix).

Moreover, it asked for their voluntary participation and underlined their right to withdraw their consent to participate.

To guarantee the principle of “Beneficence”, avoid any potential harm, and maximise possible benefits, a systematic assessment of risks and benefits was conducted. Its conclusion was that the intervention did not imply evident risks, distress or harm for children. Also, the participants’ identity was protected: their anonymity has been assured in publications and presentations.

The data chain of custody was preserved since access to videos and database were restricted, and research assistants signed a confidentiality agreement.

Finally, to ensure the principle of “Justice” and confirm that all participants shared the potential intervention benefits and not just its burdens, children of the control group received a standard, although delayed, intervention.

7 Results

The results reported in this section are organised as follows. Firstly, there is a description of the analyses performed to evaluate the psychometric properties of the measurement instruments used. Particularly, the CFA allowed assessing the latent structure of the instruments and their invariance over time. Likewise, two internal consistency values (α y ω[2]) are reported.

A preliminary exploration of changes over time of the measured variables for the complete sample (i.e. regardless of the experimental condition,) is also reported in this section. The descriptions obtained with univariate LCSM offers a general overview of variables performance.

Thereon, results are organised according to the research questions of this study, to establish whether the available empirical evidence confirms or rejects the study's hypotheses.

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[2] In recent decades researchers specialising in latent variables have progressively reached a consensus in terms that α shows higher rates of type I and II errors, as compared to ω. Nonetheless, reporting both parameters has been recommended in order to facilitate this transition in the scientific community (Revelle & Zinbarg, 2009; Yang & Green, 2011).

7.1 Psychometric analyses of measurement instruments (CFA)

7.1.1 Factorial structure and Goodness-of-fit

The four tests for which full information[3] was available, were analysed to assess their factor structure and reliability index (see Table 6).

Regarding the scores of ***Perspective Taking (PT)***, the single-factor theoretical structure was found to be untenable. PT scores were further explored, examining the Kayser-Meyer-Olkin measure of sampling adequacy. This analysis indicated the variance of the items 8, 10, 12, 19, and 21 were not reliable to perform a common factor analysis with the other items.

In consequence, and since they did not present a reliable separate structure either, these items were excluded from the analyses. The residual variance of items 11 and 18 was allowed to correlate. With these adjustments, the scores of the reduced set of items were appropriately explained by a single-factor structure (*PLRT* = 28.2, *df* =19.1, *p* = .08, CFI[4] = .979, TLI = .996, SRMR = .024). The general score for PT presented high reliability (α = .98, ω = .93).

The scores for ***2D Mental Rotation (MR)*** were adequately explained by a single-factor structure (*PLRT* = 71.5, *df* = 66.2, *p* = .30, CFI = .984, TLI = .987, SRMR = .066). Residual variances of some pairs of items were allowed to correlate: 12~~6, 12~~1, 6~~4, 13~~8, 6~~4, 3~~14. Reliability of the MR score was acceptable-to-good (α = .82, ω = .69).

[3] For VS working memory and VS short-term memory, only the individual total score was available, and not the scores per item.

[4] As noted before, CFI, TLI, SRMR, and RMSEA indices under PML estimation should not be evaluated under the common cutoff values, since they have not been appropriately studied. They are reported for comparison purposes.

Due to initial inconsistencies, the ***measurements for arithmetic and algebra*** were examined through exploratory IRT analyses, to assess possible sources of the misfit. Items between the 1 to 7, except item 2, were omitted from the final arithmetic score. The item 7 from the algebra measurement was excluded as well.

In addition, in view of the high correlation of the latent variables for algebra and arithmetic (.76, p < .001), a second-order factor was modelled, and this structure was compared to a bifactor alternative. The model presented good fit to the data (*PLRT* = 104.5, *df* = 51.7, *p* < .001, CFI = .911, TLI = .976, SRMR = .079). The ***second-order mathematics factor*** (α = .97, ω = .84) explained the data appropriately, and it was preferred over a bifactor structure. The decision was adopted because the reliability of algebra domain-specific factor decreased below acceptable levels (ω = .13), although the overall fit of the bifactor structure was better.

Table 6: Summary of measurements' psychometric attributes

Instrument	Factorial Structure	Items omitted	Maximum theoretical score	Reliability Index	
Perspective Taking	Single-factor structure	8, 10, 12, 19 and 21	13	α = .98	ω = .93
Mental Rotation	Single-factor structure	None	16	α = .82	ω = .69
Mathematic	Second-order factor structure	Arithmetic: 1,3,4,5,6,7 Algebra: 7	29	α = .97	ω = .84

7.1.2 Measurement Invariance

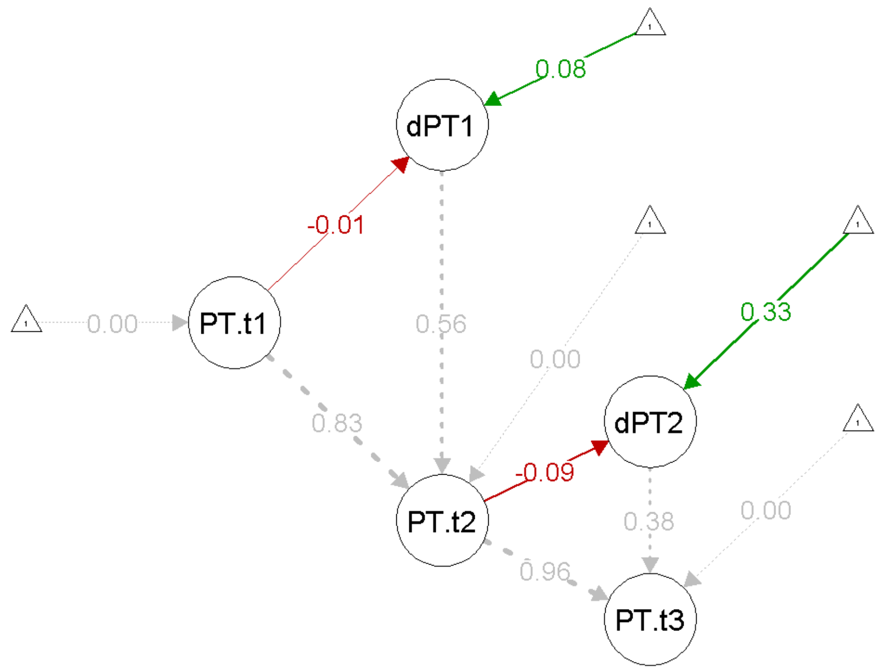
To compare scores across time-points, the instruments' measurement invariance was evaluated. All of them showed strong (configural, thresholds, loadings, and intercepts) measurement invariance, rendering them valid for across-measures comparisons.

7.1.3 Change Scores in Univariate Models LCSM

In order to explore how the measured variables changed over time, the variations were estimated modelling univariate LCSM for the whole sample. In each diagram, the change scores are represented with a delta (Δ/d). These coefficients represent raw changes.

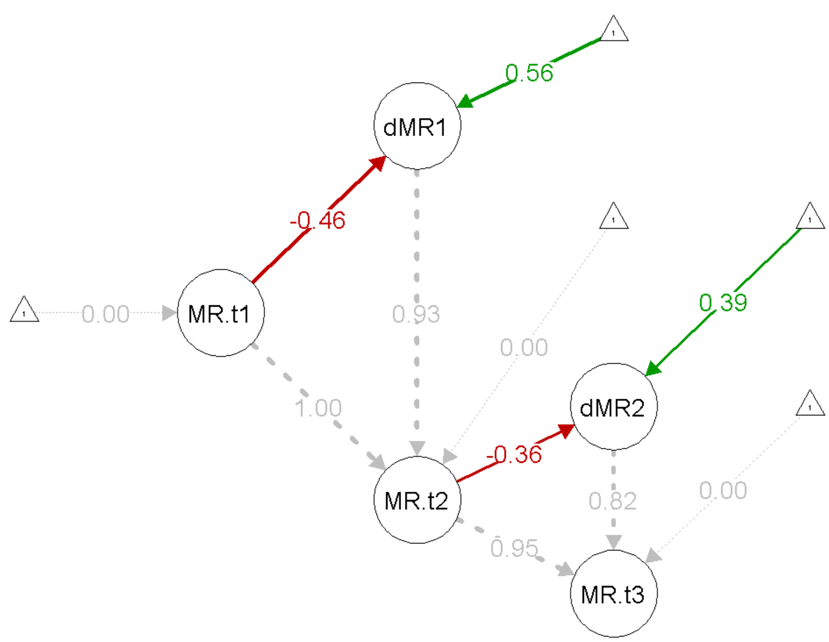
Perspective Taking univariate LCSM ($\chi 2$ = 1.7, df = 2, p = .43) showed no significant mean change between T1 and T2 (.081, p = .33) but it did when comparing T2 and T3 (.327, p = .001), with non-significant self-feedback parameters in both occasions (p = .91 and p = .29). The starting levels for each transition explained almost nothing of the change (R2 = .000 and .009) [See figure 19].

Figure 19: Change score of Perspective Taking (PT)



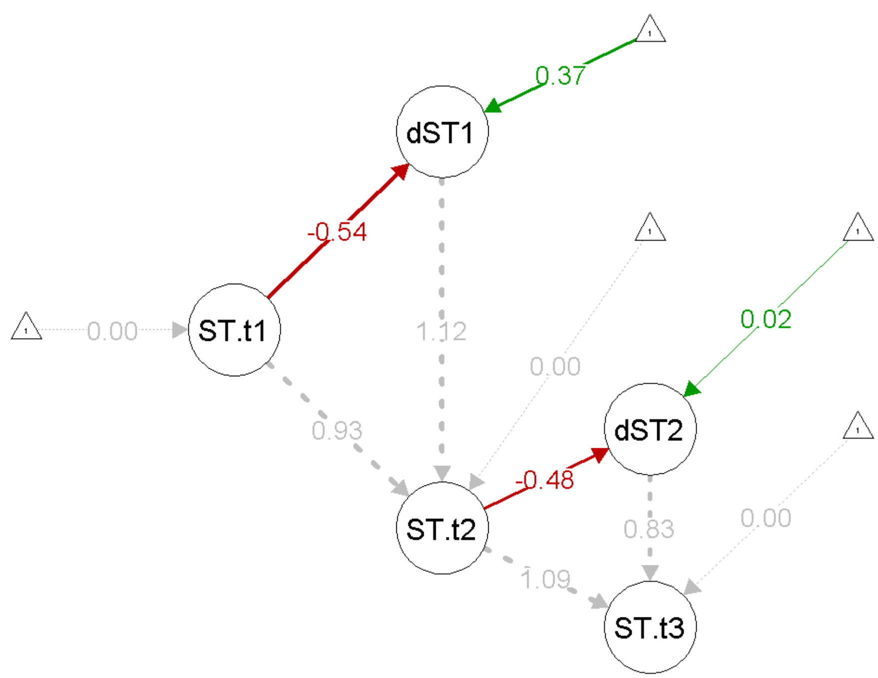
Mental Rotation (χ^2 = 13.5, *df* = 2, *p* = .001) presented the most noticeable change between T1 and T2 (.559, p < .001), and significant improvement could also be seen between T2 and T3 (.389, p < .001). The self-feedback parameter from T1 to the respective change score was significant and with a big effect size (-.463, p < .001), as well as the second self-feedback parameter (-.364, *p* < .001). This explained some variance of both change scores (R2 = .215 and R2 = .133, respectively) [See figure 20].

Figure 20: Change score of 2D Mental Rotation (MR)



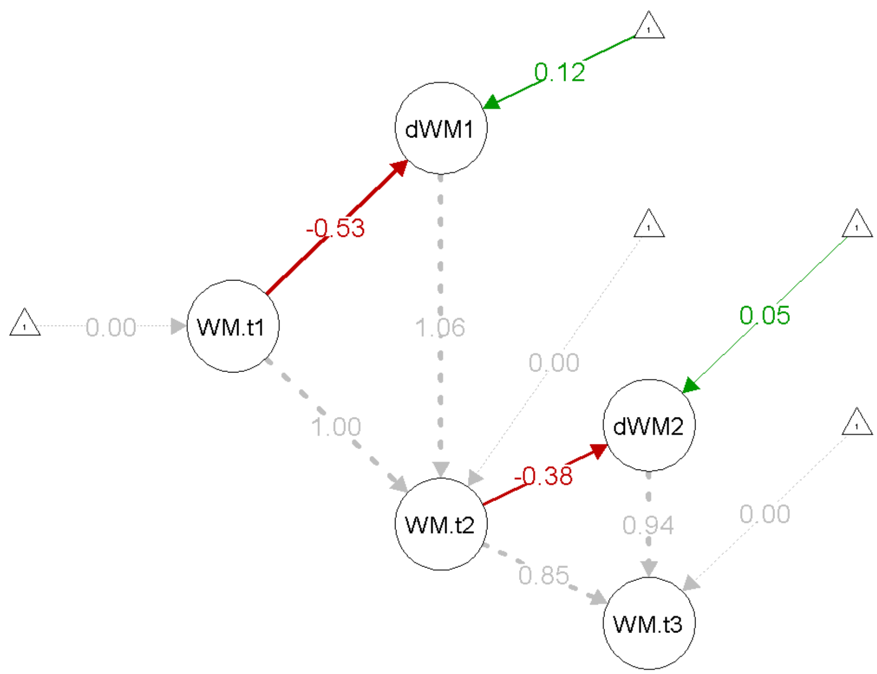
Visual-Spatial Short-Term Memory (χ^2 = 0.036, *df* = 2, *p* = .982) also presented significant mean changes between T1 and T2 (.374, *p* < .001) but not significant mean changes between T2 and T3 (*p* = .85). Self-feedback parameters were high and significant for first (-.536, p <.001) and second (-.481, p < .001) transitions, explaining a relevant portion of individual differences (R2 = .287 and R2 = .231) [See figure 21].

Figure 21: Change score of Visual-Spatial Short-Term Memory (VSST)



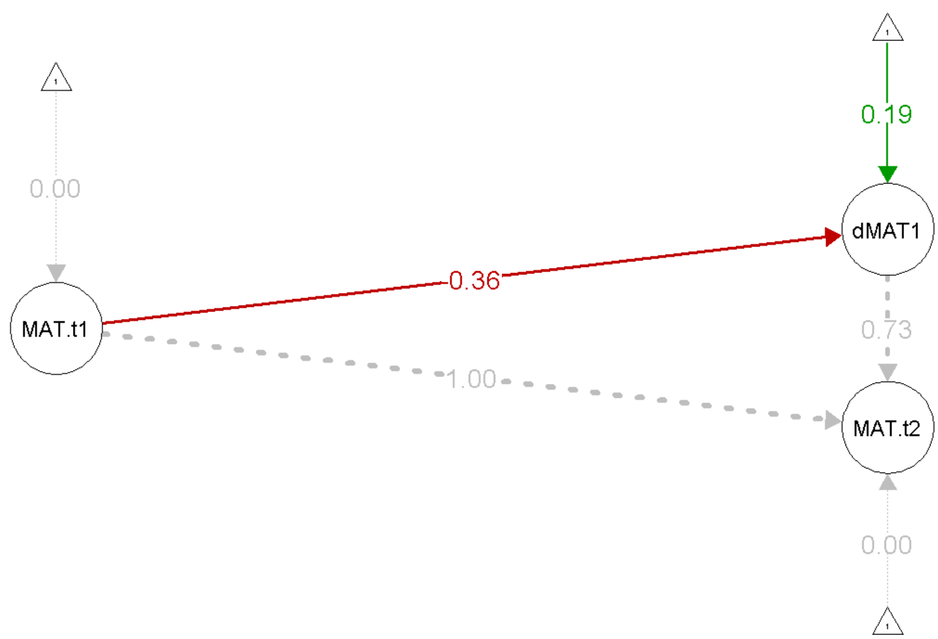
Visual-Spatial Working Memory LCSM (χ^2 = 19.9, *df* = 2, *p* < .001) showed less significant mean changes during first transition (.124, p = .073) and no significant mean changes during the second one (p = .56). Self-feedback parameters were expectedly large and negative both from T1 (-.529, p <.001; R2 = .280) and from T2 (-.379, *p* < .001, R2 = .144) [See figure 22].

Figure 22: Change score of Visual-Spatial Working Memory (VSWM)



The LCSM model for ***Mathematics*** (χ^2 = 0.00, *df* = 1, *p* = .999)[5] was also a moderate mean change between T1 and T2 in *Mathematics* (.190, p = .012) with a negative and moderate self-feedback parameter (-.362, p < .001, R2 = .131) [See figure 23].

Figure 23: Change score of Mathematics skills



[5] The global model fit is not relevant for this model since only two time-points were identified/measured and therefore, goodness-of-fit could not be evaluated.

In summary, the analysis of changes scores shows that there was change in all the studied variables over time (for the complete sample). Those with the larger changes in the first transition (i.e. comparing pre- and post-test measures) were MR, followed by VS Short-term memory. Changes in Mathematics and VS Working memory were very small in the first transition. There was virtually no change in Perspective Taking.

In the second transition (post-test and follow-up), the only statistically significant changes were the scores for Perspective Taking and Mental Rotation. As explained before, it was not possible to carry out a third measurement for Mathematics, given that follow-up coincided with the end of the school year.

With regard to the improvement in PT and MR observed in the second transition, it can be argued that these skills continued to improve after the end of the intervention. To verify if there was any difference in the magnitude of these changes among children in the experimental and control conditions, the comparisons carried out between the groups are reported below.

7.2 Research question 1: Does the training improve students' near, intermediate, and far transfer skills?

7.2.1 Near transfer skills

The ***Mental Rotation*** scores were analysed using a (3) × 2 mixed-ANOVA with Time as the within-subjects factor (pre, post and follow-up), condition as the between-subjects factor (experimental v/s control), and non-verbal IQ as covariate. Mauchly's test indicated that the assumption of sphericity had not been violated, so the 'Sphericity assumed index' was employed.

There was a statistically significant interaction effect between Time and Condition on Mental Rotation; F(2,364) = 8.05, p < .000, η_p^2= .042.

Considering the interaction effect, three separate repeated measures ANOVAs were conducted to determine the difference between time-points for each condition group (simple main effects).

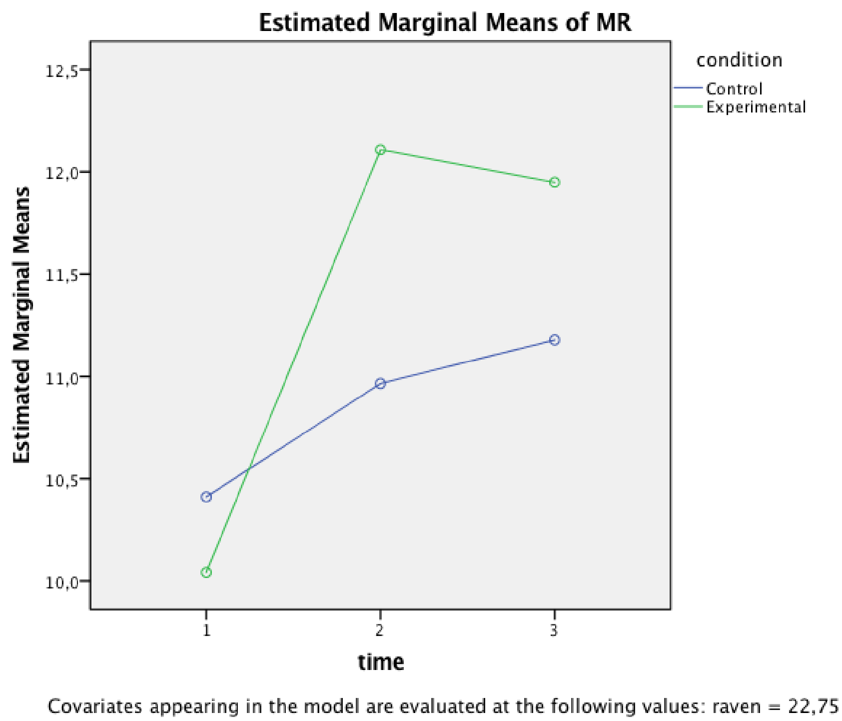
The analyses showed that only the experimental group had improvements in Mental Rotation' scores between pre-test and post-test (Table 6). Also, their scores did not change between post-test an follow-up testing, suggesting the improvement remained stable; F(2,170) = 5.365, p<.006, η_p^2= .059. The changes between the three time points for the control group were not statistically significant.

Table 6: Descriptive statistics for MR

condition	Time	Estimated marginal means	Std. Deviations	n
Control	1	10,411[a]	2,601	98
	2	10,966[a]	2,356	
	3	11,178[a]	2,767	
Experimental	1	10,042[a]	2,745	87
	2	12,108[a]	2,695	
	3	11,949[a]	2,767	

a. Covariates appearing in the model are evaluated at the following values: raven = 22,75

Plot Mental Rotation (Time * Condition)



The ***Perspective Taking*** scores were analysed in the same way [(3)x2 Mixed ANOVA]. Mauchly's test of sphericity indicated that the assumption of sphericity had been violated, $\chi^2(2) = 18.993$, $p = .000$. In consequence, the Greenhouse-Geisser correction was applied ($\varepsilon = 0.909$).

The analysis showed a marginally significant interaction effect between Time and Condition, with a small effect size [F(1.819,364) = 3,207, p < .046, η_p^2= .017].

Considering the interaction effect, three separate repeated measures ANOVAs were conducted to determine the difference between time points for each condition group (simple main effects).

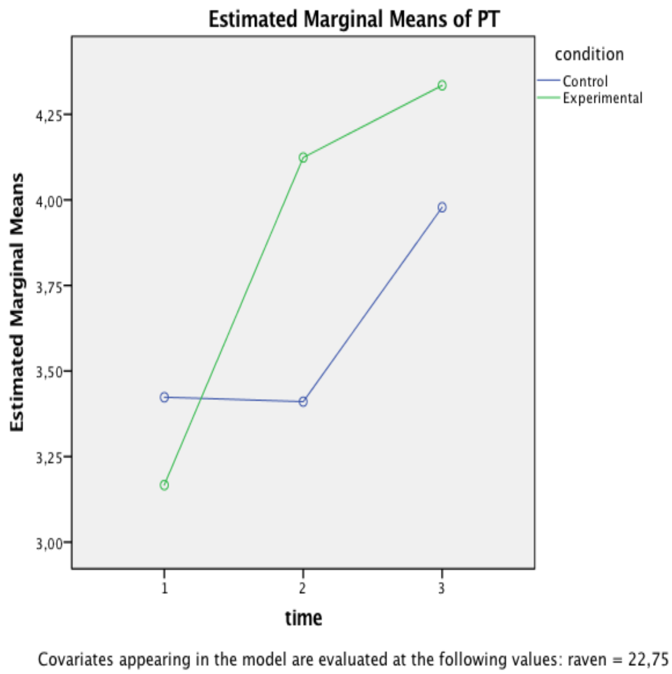
Only the experimental group had improvements in Perspective Taking' scores between pre-test and post-test (Table 7). Also, their scores did not change between post-test an follow-up testing, suggesting the improvement remained stable; F(2,172) = 9.166, p<.000, η_p^2= .096. The changes between the three time points for the control group were not statistically significative.

Table 7: descriptive statistics for Perspective Taking

condition	Time	Estimated marginal means	Std. Deviation	n
Control	1	3,423[a]	3,35295	98
	2	3,411[a]	3,78760	
	3	3,979[a]	3,90031	
Experimental	1	3,167[a]	3,02016	87
	2	4,124[a]	3,74230	
	3	4,335[a]	3,93230	

a. Covariates appearing in the model are evaluated at the following values: raven = 22,75

Plot Perspective Taking (Time * Condition)



7.2.2 Intermediate transfer skills

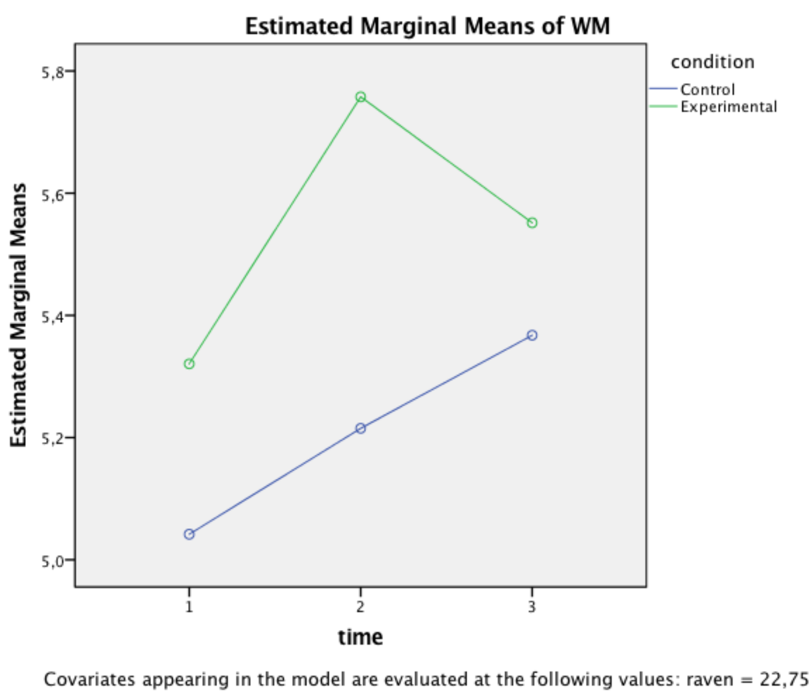
VS Working memory did not improve on time x condition [F(2,364)=.667, p.514, η_p^2=.004]. Also, there were no main effects of time or condition. For details, see Table 8 and the respective plot.

Table 8: descriptive statistics for VS Working memory

condition	time	Estimated marginal means	Std. Deviation	n
Control	1	5,042[a]	1,972	98
	2	5,215[a]	1,922	
	3	5,368[a]	2,121	
Experimental	1	5,321[a]	1,749	87
	2	5,758[a]	1,673	
	3	5,552[a]	2,108	

a. Covariates appearing in the model are evaluated at the following values: raven = 22,75

Plot VS Working Memory (Time * Condition)



Otherwise, the training had a significant effect on ***VS Short-term memory***. In this analysis, the Mauchly's test of sphericity indicated that the assumption of sphericity had been violated, $\chi^2(2) = 14.195$, $p = .001$. Therefore, the Greenhouse-Geisser correction was applied ($\varepsilon = 0.930$).

The Mixed ANOVAs revealed a main effect of time [F(1.86, 364)= 9.79, p.000, η_p^2=.051] and condition [F(1,182)=5,545, p.02, η_p^2=.03] in VS Short-term memory.

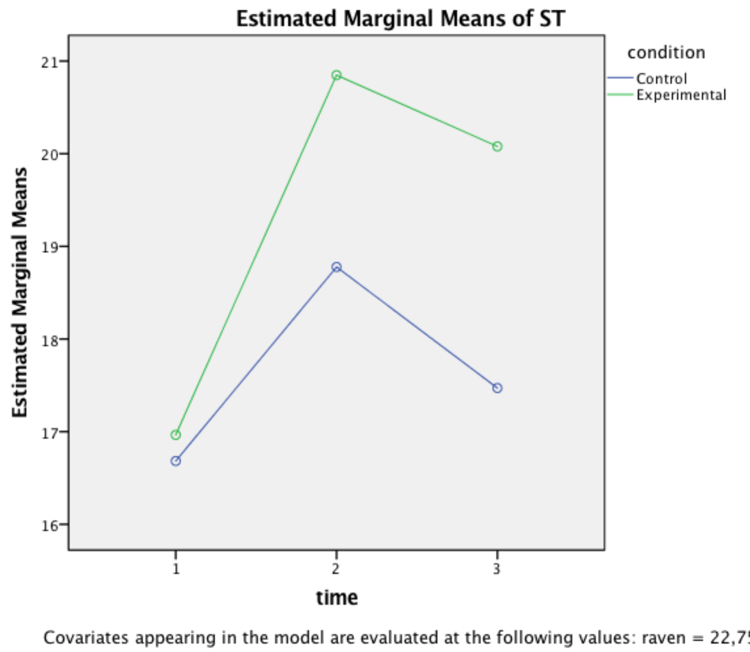
The post-hoc comparisons showed a significant difference between T1 and T2 measures. That is, both experimental and control groups improved between pre-test and post-test, while the change remained stable at follow-up measurement. However, the improvement on Short-term memory was greater for the experimental group. (See Table 9 and plot).

Table 9: descriptive statistics for VS ST Memory

condition	time	Estimated marginal means	Std. Deviation	n
Control	1	16,684[a]	6,183	98
	2	18,777[a]	7,505	
	3	17,471[a]	5,985	
Experimental	1	16,965[a]	7,224	87
	2	20,848[a]	6,466	
	3	20,079[a]	6,587	

a. Covariates appearing in the model are evaluated at the following values: raven = 22,75

Plot VS Short-Term Memory (Time * Condition)



7.2.3 Far transfer skills

The univariate analyses showed that training on spatial skills had no significant transfer effect on Mathematical skills. In other words, there was not interaction effect between Time and Condition, F(1,182)= .594, p.442, η_p^2=.003. Also, there were no main effects of time or condition (See Table 10 and the respective plot)

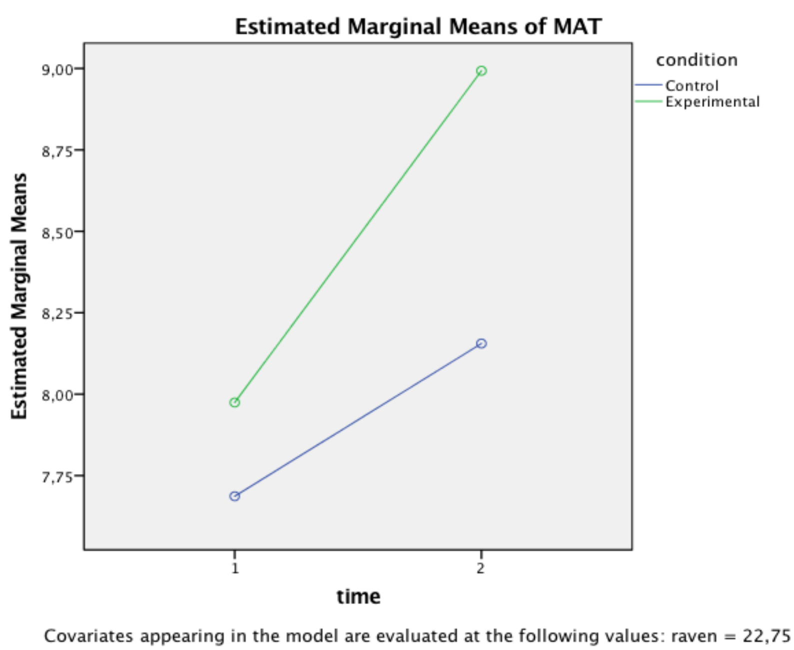
For this analysis, the Mauchly's test of sphericity indicated that the assumption of sphericity had been violated, $\chi^2(2) = 14.195$, $p = .001$. Therefore, the Greenhouse-Geisser correction was applied.

Table 10: Descriptive statistics for Mathematics

condition	time	Estimated marginal means	Std. Deviation	n
Control	1	7,687[a]	6,55368	98
	2	8,155[a]	6,05769	
Experimental	1	7,974[a]	5,33340	87
	2	8,993[a]	5,94898	

a. Covariates appearing in the model are evaluated at the following values: raven = 22,75

Plot Mathematics skills (Time * Condition)



In summary, when comparisons are done with univariate statistical techniques, the results show that the treatment had a positive significant effect on near transfer skills (MR & PT) for children in the experimental group. In turn, regarding intermediate transfer skills, the intervention shows a positive significant effect only in the skills of VS Short-term Memory in the experimental group. On the other hand, the treatment had no effect over the skills of mathematical calculation in children from the experimental group. These skills were not trained as part of the intervention, but a transference effect was expected.

As it will be showed later, under the headline 6.4 (Latent Change Score Model), when the treatment effect is simultaneously analysed over the complete set of dependent variables, the results is pretty similar. The multivariate analysis reveals the effect of treatment over Mathematics was the smallest one (.083, $p = .034$), and that this effect is fully mediated by the change on near and intermediate transfer skills.

7.3 Research Question 2: Are there any differential training effects between subgroups?

7.3.1 Are training effects greater in girls than boys?

The evidence provided by univariate analyses do not support differential training effects by sex on any skills. A three-way mixed ANOVA was run to understand the effects of sex, condition and time on each Dependent Variable. There were no three-way or two-way interaction effects (sex * condition, or sex* time) in the analyses executed ($p <.05$). Table 11 & 12 summarises the obtained information.

Table 11: Summary of effects' statistical significance (children's sex as a moderator variable)

Dependent Variable	Three-way interaction between sex, condition and time	Two-way interaction between sex * condition, or sex* time
MR	not statistically significant, $F(1.942,360)$ = .287, p = .794. η_p^2=.002.	not statistically significant (p > .05).
PT	not statistically significant, $F(1.823,360)$ = .492, p = .595, η_p^2=.003.	not statistically significant (p > .05).
VSST	not statistically significant, $F(1.862,360)$ = .492, p = .595, η_p^2=.004.	not statistically significant (p > .05).
VSWM	not statistically significant, $F(2,360)$ = .215, p = .806, η_p^2=.001.	not statistically significant (p > .05).
MAT	not statistically significant, $F(2,360)$ = .215, p = .806, η_p^2=.001.	not statistically significant (p > .05).

Table 12: Descriptive statistics (children's sex as a moderator variable)

Variable/time	sex	Condition	Mean	Std. Deviation	N
PT.t1	girl	Control	3,93	3,51	54
		Experimental	3,16	3,22	44
	boy	Control	3,30	3,16	44
		Experimental	2,67	2,82	43
PT.t2	girl	Control	4,17	4,00	54
		Experimental	4,25	4,10	44
	boy	Control	3,07	3,46	44
		Experimental	3,40	3,32	43
PT.t3	girl	Control	4,93	4,12	54
		Experimental	4,39	4,05	44
	boy	Control	3,39	3,47	44
		Experimental	3,70	3,82	43
mr.t1	girl	Control	10,70	2,68	54
		Experimental	9,66	2,63	44
	boy	Control	10,73	2,53	44
		Experimental	9,74	2,89	43
mr.t2	girl	Control	11,59	2,37	54
		Experimental	11,95	2,63	44

	boy	Control	10,75	2,28	44
		Experimental	11,70	2,78	43
mr.t3	girl	Control	11,43	2,65	54
		Experimental	11,70	2,71	44
	boy	Control	11,27	2,93	44
		Experimental	11,79	2,86	43
st.t1	girl	Control	16,33	6,54	54
		Experimental	14,05	6,96	44
	boy	Control	18,16	5,63	44
		Experimental	18,88	6,72	43
st.t2	girl	Control	17,81	7,57	54
		Experimental	19,32	6,56	44
	boy	Control	20,48	7,24	44
		Experimental	21,88	6,17	43
st.t3	girl	Control	16,54	6,36	54
		Experimental	18,43	6,19	44
	boy	Control	18,59	5,35	44
		Experimental	21,79	6,62	43
wm.t1	girl	Control	5,43	1,95	54
		Experimental	5,14	1,91	44
	boy	Control	4,84	1,98	44
		Experimental	5,23	1,59	43
wm.t2	girl	Control	5,70	1,80	54
		Experimental	5,73	1,48	44
	boy	Control	4,91	2,00	44
		Experimental	5,49	1,86	43
wm.t3	girl	Control	5,65	2,08	54
		Experimental	5,34	2,30	44
	boy	Control	5,39	2,19	44
		Experimental	5,40	1,92	43
MAT1	girl	Control	8,83	6,92	54
		Experimental	6,90	5,41	44
	boy	Control	7,53	6,07	44
		Experimental	7,80	5,28	43
MAT2	girl	Control	9,08	6,63	54
		Experimental	7,58	5,51	44

	boy	Control	8,11	5,30	44
		Experimental	9,33	6,31	43

The multivariate analysis (Cross-lagged panel model), neither support a moderation of treatment effect by children' sex (see Table 13).

Table 13: Moderation of treatment effect by sex and initial performance

Mod	Ind	Estimate	Est.Error	CI.Lower	CI.Upper	Evidence Ratio	Probability
sex	mat	0,142	0,117	-0,050	Inf	7,789	0,886
sex	st	-0,058	0,186	-0,362	Inf	0,594	0,373
sex	wm	0,101	0,146	-0,138	Inf	3,017	0,751
sex	mr	0,047	0,125	-0,155	Inf	1,800	0,643
sex	pt	0,109	0,106	-0,068	Inf	5,592	0,848

7.3.2 Are training effects greater in children with low initial spatial skills?

A three-way mixed ANOVA was run to understand the effects of spatial skill initial level (SSIL), treatment and time on VD scores.

In order to run these analyses, the SSIL was created. It was calculated using the modes of MR and PT at pre-test. The scores were categorised as Low Level if they were ≤ to the mode of their respective distribution.

It is important to note that the sample's PT scores were quite low. 41% of the children at pre-test, got 1 point (the mode in this distribution) of 13 points (max. theoretical score).

The resultant variable was calculated as the mean between the initial level of PT and MR. Therefore, three categories were established:

- Low SSIL (n=46)
- Middle-Low SSIL (n=84)
- Middle-High SSIL (n=55)

The evidence partially supports the hypothesis regarding the moderator effect of spatial skills initial level. The training had a differential effect just for one of the Near transfer skills, i.e. Mental Rotation.

Although the three-way interaction between time, treatment (condition), and spatial skills initial level was not statistically significant for MR [$F(4, 356) = 1.169$, $p = .324$]; there was a statistically significant two-way interaction between spatial skills initial level and treatment [$F(4, 356) = 3.368$, $p = .010$].

Statistical significance of a simple main effect was accepted at a Bonferroni-adjusted alpha level of .05. All pairwise comparisons were performed for statistically significant simple main effects. Bonferroni corrections were made with comparisons within each simple main effect considered a family of comparisons. There was a statistically significant simple main effect of treatment on MR at each category of spatial skill initial level. This means that in the experimental group, children of the three categories of SS initial level improved their MR scores between pre and post-test, and the change remained stable when they were measured at follow-up time. Besides, the effect size of change was greater for children of Low SSIL compared to Middle-low and Middle-high SSIL.

For the control condition, only the Low SSIL group improved their MR scores on post-test. Although they didn't receive formal training on MR, the improvement could be attributed to the learning effect produced by the measurement. For details, see Table 14 & 15.

Table 14: Summary of effects' statistical significance (SS initial level as a moderator variable)

Categories of SS Initial Level	Experimental	Control
Low SSIL (n=46)	Improve from T1 to T2 and remain stable to T3 F(2,50)=20.782 p = .000, η_p^2=.454	Improve from T1 to T2 and remain stable to T3 F(2,38)=14.120, p = .000, η_p^2=.426
Middle-Low SSIL (n=84)	Improve from T1 to T2 and remain stable to T3 F(2,80)=17.486, p = .000, η_p^2=.304	No significant change (p <.05)
Middle-High SSIL (n=55)	Improve from T1 to T2 and remain stable to T3 F(2,38)=5.389, p = .009, η_p^2=.221	No significant change (p <.05)

Table 15: Mean change along the time in experimental group (SS initial level as a moderator variable)

Spatial Skills Initial Level (experimental group)	∆ mean between T1-T2	∆ mean between T2-T3
Low SSIL	+2.8 *	-0.3
Middle SSIL	+2 *	+0.2
High SSIL	+1.7 *	-0.6

7.4 Research Question 3: How are the relationships among the near, intermediate and far transfer skills?

Statistical techniques belonging to Structural Equation Modelling, specifically Multivariate Latent Change Score Model, were applied in order to answer this question and test the causal model hypothesised.

Taking into consideration the empirical and theoretical information gathered in the literature review, variables categorised as Near Transfer skills (MR & PT) and Intermediate Transfer skills (VSWM & VSST) were assigned mediator roles. Mathematical calculation skills (Far Transfer skills) were treated as output or DV, while special skills' training was considered a predictor or IV.

Three different multivariate LCSM were modelled:

1. Model 1: with latent change scores merely correlated (without regressions).
2. Model 2: with the hypothesized multivariate mediation model between them.
3. Model 3: including several relevant covariates such as sex, non-verbal intelligence (Raven), understanding of oral instructions, and school. All presented good fit, and the two nested models (without covariates) presented almost identical fit to the data. The more complex model still presents good fit, although the estimations include a little more 'noise'.

Table 16 shows the adjustment index for each model tested.

Table 16: Global fit of LCSM alternative models

Model	X^2	*Df*	p value	AIC	BIC	BIC2	CFI	TLI	SRMR	RMSEA
Correlated changes	60.4	36	.007	2815	3133	2820	.977	.933	.046	.059
Mediated Effects	60.4	37	.009	2813	3129	2818	.978	.937	.046	.057
With Covariates	124.8	77	.000	3678	4103	3685	.962	.917	.074	.057

For parsimony, only the results of the third model are described. First, the model with the mediated effects is presented. Then, the covariates effects are included in the same model, increasing its level of complexity.

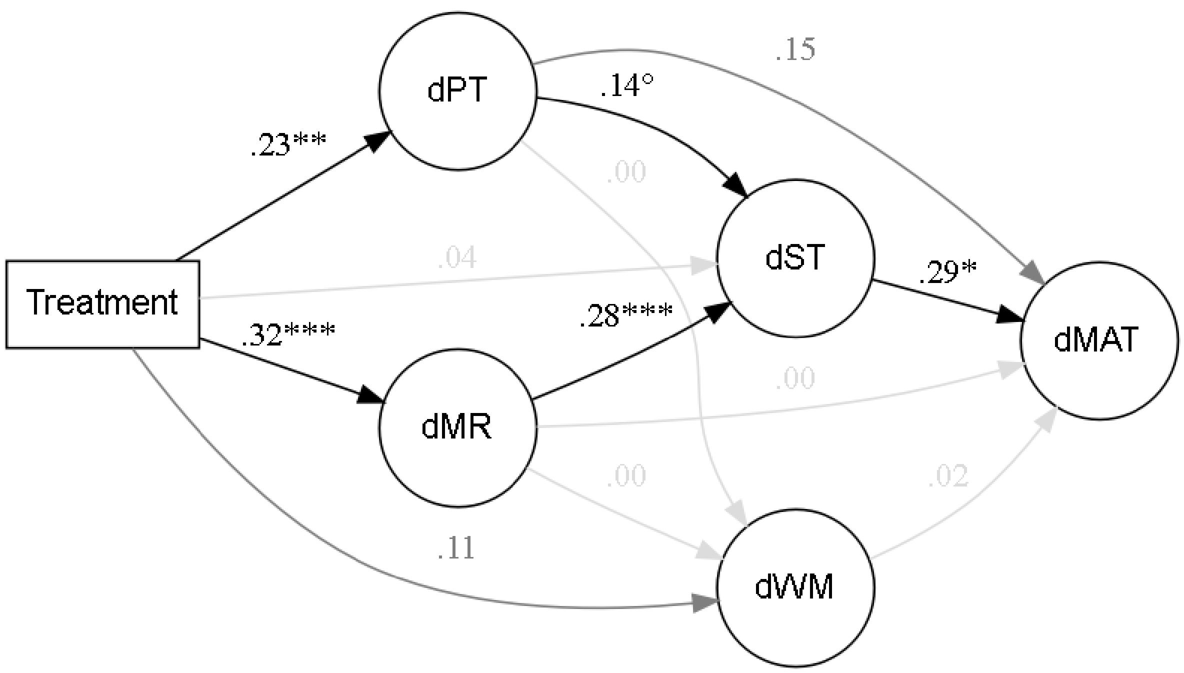
7.4.1 LCSM Mediation model (MODEL 3): Highlighting the mediated effects.

According the analyses, the change on Math (dMAT) was explained directly by the change on VS Short-term memory (dST) (.29, $p = .011$) and by the total effect of change on PT (dPT) (.19, $p = .05$). The total effect of PT is composed by its direct (.15, $p = .15$) and mediated (.04, $p = .16$) effect. The change on Math is also explained by the totally mediated effect of the treatment (.08, $p = .03$).

Besides these diverse effects over the change in Mathematics, an effect of the change on MR (dMR) over the change in VSST memory (dST) was observed (.28, $p < .001$). The treatment also had a significant total effect over the change on VSST memory (dST)

(.16, p = .02); mostly mediated by the direct effects of the treatment over dMR (.32, p <.001) and dPT (.23, p = .004). The direct effect of the treatment over dST was also practically zero (.04, p = .62). Less significant was the total effect of the treatment over Working Memory (.12, p = .08) [See figure 24].

Figure 24: LCSM with mediated effects



7.4.1.1 Leading variables

Although several variables presented some leading effect considering the treatment condition (i.e. variables for which starting values were related to change scores of other variables), only a couple of them were statistically significant (See Table 17).

Mental Rotation scores at pre-test (T1) were positively correlated with improvements in VS Short-Term Memory (.21, $p = .03$) and Perspective Taking (.36, $p < .001$).

In the second transition, Perspective Taking at T1 was positively correlated with the improvement in Mental Rotation at T3.

Table 17: Mediation LCSM model with Covariates

	Transition I					Transition II			
	dPT1	dMR1	dST1	dWM1	dMAT1	dPT2	dMR2	dST2	dWM2
Leading and self-feedback effects (T 1)									
PT	-.08 (.08)	.04 (.07)	.07 (.07)	.01 (.07)	.06 (.08)	-.11 (.09)	.22** (.08)	.05 (.08)	-.07 (.09)
MR	.36*** (.09)	-.63*** (.08)	.21* (.09)	.02 (.10)	.09 (.10)	-.17 (.12)	-.51*** (.08)	.02 (.11)	-.03 (.11)
VSST	.02 (.10)	-.13 (.08)	-.59*** (.08)	.11 (.09)	.15 (.10)	.13 (.11)	-.10 (.11)	-.58*** (.09)	.19° (.10)
VSWM	.10 (.10)	.13 (.08)	.12 (.09)	-.69*** (.06)	.09 (.11)	.06 (.10)	.15 (.09)	-.10 (.11)	-.56*** (.09)
MAT	-.08 (.11)	-.01 (.09)	-.01 (.08)	.13 (.08)	-.48*** (.09)	.11 (.13)	.11 (.10)	.19* (.09)	.05 (.09)
Change-to-change effects									
dPT			.14° (.08)	.00 (.08)	.15 (.10)			-.03 (.10)	.05 (.11)
dMR			.28*** (.08)	-.00 (.08)	-.00 (.09)			.08 (.09)	.14 (.09)
dVSST					.29* (.11)				
dVSWM					.02 (.10)				
Treatment & Covariates effects									
Condition	.23** (.07)	.32*** (.06)	.04 (.07)	.11 (.07)					
Raven		.34** (.12)							.38** (.12)
Oral.Inst				.23* (.10)					
Sex	-.17* (.08)		.24*** (.07)	-.15* (.07)					
School			.24*** (.07)					.30*** (.08)	

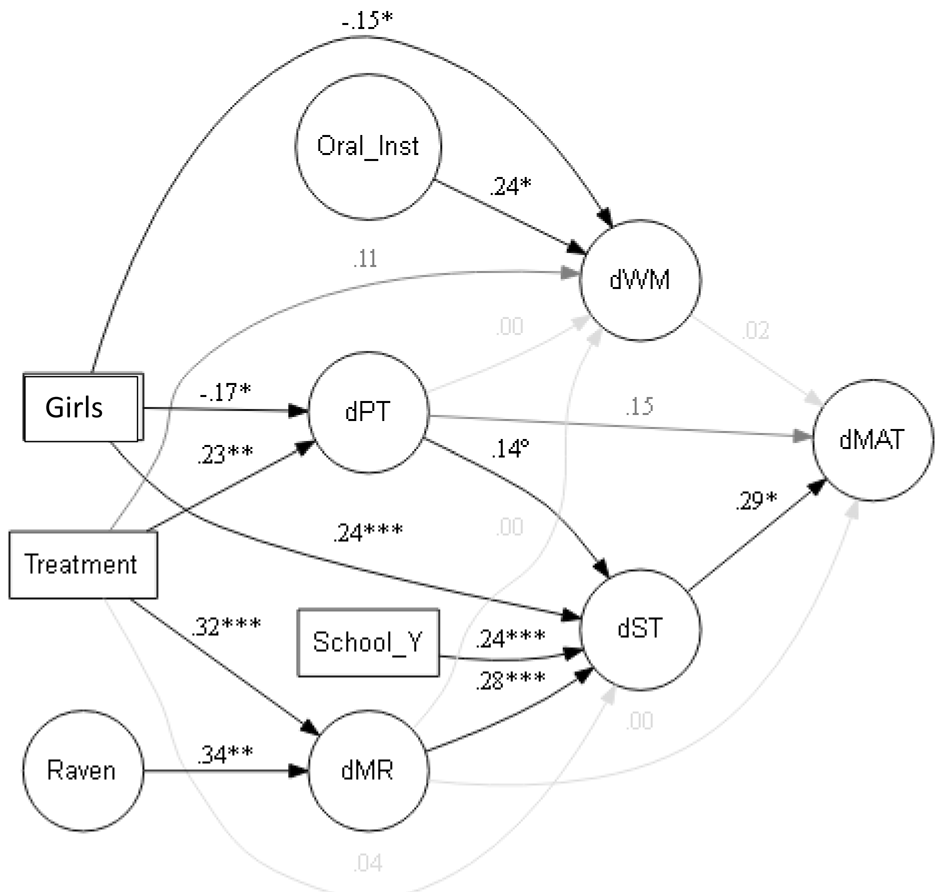
7.4.2 LCSM with mediated model and Covariates (MODEL 3)

Analysed altogether, the effect of treatment was significant for almost all variables, although its effect decreased with ‘distance’ (see Figure 25). The biggest were the near transfer effects over *Mental Rotation* (.32, $p < .001$) and over *Perspective Taking* (.23, $p = .004$). The effects over *VS Short-Term Memory* were less pronounced (.16, $p = .019$) and the small change on *VS Working Memory* was marginally significant (.12, $p = .06$). Finally, the far effect over *Mathematics* was the smallest one (.083, $p = .034$).

Regarding the effects of covariates, they presented significant effects on specific variables. The most transversal was the effect of *sex.* That means that girls, from both conditions, presented less improvement on *Perspective Taking* (-.17, $p = .047$) and *VS Working Memory* (-.15, $p = .044$). On the other hand, girls had a greater improvement in *VS Short-Term Memory* (.24, $p = .001$) than boys.

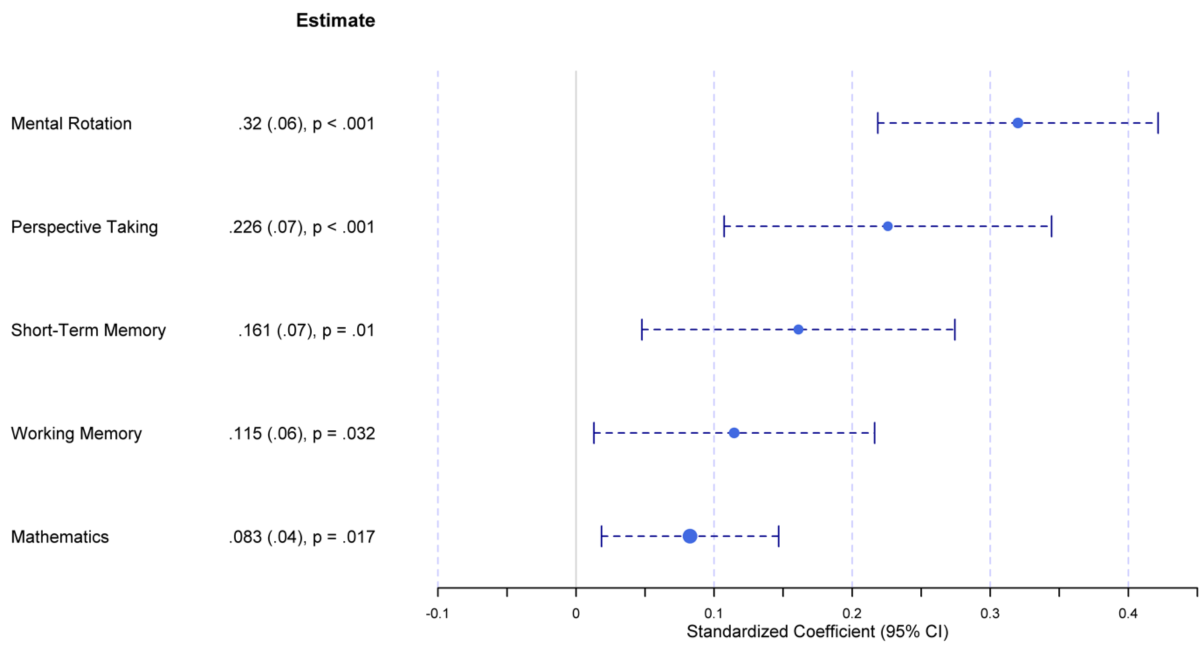
Furthermore, the *Understanding of Oral Instructions* implied a more positive change in *VS Working-Memory* (.24, $p = .018$), just as *Non-verbal Intelligence* (Raven) did over improvements in *Mental Rotation* (.34, $p = .007$). Finally, students of one school (school Y) presented a more significant increase in *VS Short-Term Memory* (.24, $p < .001$).

Figure 25: LCSM with mediated effects and co-variates.



The following plot sums up the magnitude of change attributed to the training for each variable, estimated by the LCSM.

Plot 1: **Total Effect of Treatment Condition**



Overall, the multivariate statistical analyses confirm that the treatment had a direct effect on Near Transfer Skills (PT & MR). Simultaneously, it reveals the treatment had no direct effect on mathematical skills. The treatment had a much-reduced effect on mathematical skills, one that only takes place through a change in the mediating variables (Near and Intermediate transfer skills).

The advantages of this kind of multivariate analyses, compared to univariate Anovas, are that they allow studying the conjoint contribution of the variables measured in order to understand the magnitude of the intervention's effects.

7.5 Research Question 4: How do the students use the spatial language, hand gestures and body movements along the intervention?

Fifteen children in the experimental condition were observed along six training lessons.

The children worked together, in groups of four students, mixed by sex. A total of eight girls and seven boys were observed throughout ten hours of filming.

As explained in the previous chapter, the videos were segmented in time-lapses of 30 seconds to codify spatial language and gestures of every child.

7.5.1 Use of Spatial Language

7.5.1.1 Quantity and Variety of SL

The SL quantity score was obtained by identifying the number of spatial words used by each children per time-lapse. Since the sessions had a different duration, a rate of the quantity of SL used, divided by the number of time-lapses of each session was calculated.

The SL variety score was similarly obtained. In this case, the number of categories of spatial language used by each child per time-lapse was identified and a rate per session was calculated.

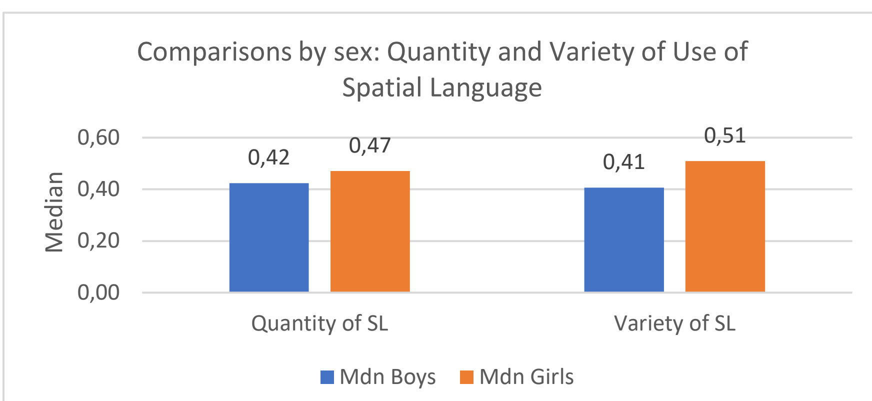
Comparison by sex

A Mann-Whitney U test was run to determine if there were any differences in Quantity and variety of SL used between boys and girls (See plot 2). Distributions of the scores for boys and girls were not similar, as assessed by visual inspection. No significant statistical differences were found for the categories of Gestures & Body Movements used by boys and girls (See Table 18 that summarises the results).

Table 18: Comparison by sex: Quantity and variety of SL used

	Mann-Whitney U	p value	Mdn Boys	Mdn Girls
Quantity of SL	33	.613	0,42	0,47
Variety of SL	33	.613	0,41	0,51

Plot 2



Comparisons by session

In order to facilitate the reader's task, the spatial content and skills targeted in each session are listed in the following table (Table 19).

Table 19: Summary of spatial content and skills targeted in the analysed sessions

Session number	Title of session	spatial contents and skills targeted
1	Can you draw this?	VS working memory and short-term memory
		Visualisation
		Composing/decomposing
		Understand conventions to represent 3D objects into 2D drawings
		Proportional reasoning
		Partitioning Space
5	Symmetry	2D composition
		Location & orientation
		Simmetry
		Visualisation
		Transformation
		VS working memory and short-term memory
		Designing
6	Building with the mind's eyes	Spatial language comprehension
		Visualisation
		Composition of 2D and 3D shapes
		Mental transformations
		VS working memory and short-term memory
		Executive functions (inhibitory control, attention)
8	Playing at being an architect	VS working memory and short-term memory
		Understanding conventions to represent 3D objects into 2D drawings
		Mental transformations (mental rotation and perspective taking)
		To develop positional language
11	Looking for the castle's keys	Mental transformations (mental rotation, translations)
		Composing 2D
		Visualisation
		congruence/ non-congruence
		VS working memory and short-term memory
		Spatial reasoning

12	The cubes' challenge	Composing 3D
		VS working memory and short-term memory
		Mental and physical trasformation

The comparison between sessions (Plot 3) reveals that session 5 (Symmetry) favoured a larger quantity and variety in the use of spatial language.

In order to solve the task presented in this session children had to continuously coordinate themselves with a partner. Therefore, an extensive and effective use of verbal language (and gestural language as well, as will be explained further along) was required.

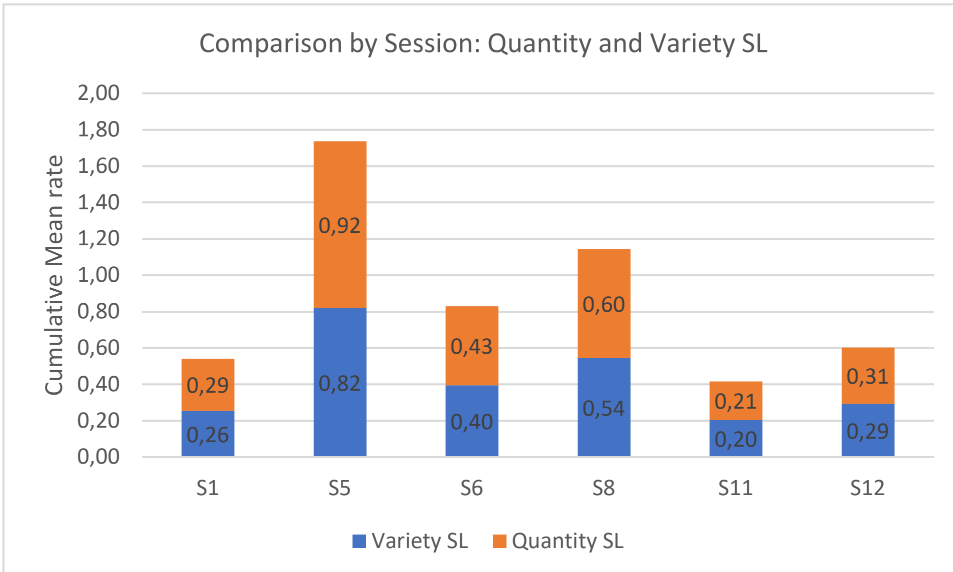
Even though they addressed relevant spatial skills, the session 11 (Looking for the castle's keys) and 12 (the cubes' challenge), involved mostly individual tasks, and therefore, children did not need to communicate their results or processes to others. This might explain less use of spatial language in both of these sessions.

With regard to session 6 (Building up with mind's eyes), the task involved understanding spatial language rather than actually speaking it, which was the observation target.

Finally, even though session 1 (Can you draw this?) involved verbally describing and expresing the figures they could observe in the proyected image, children talked mainly to the researcher and not to other children. This may have had an influence in the small amount and variety of the spatial language observed, since this kind of whole class-teacher interactions tipically favours the participation of only a few students (those who are highly motivated or have a longer attention span).

That said, although the use of spatial language was not expected to be homogeneus and/or incremental over the sessions, it might be interesting to take this issue into account in the future for the design of activities that promote the development of spatial reasoning by increasing the use of spatial language.

Plot 3: Comparison by sessions: Quantity and variety of SL



7.5.1.2 Frequency of Use of different SL categories

To calculate this score, it was identified the frequency with each child used a spatial language category during the coded sessions. Then, that number of words was divided by the number of time-lapse of each session and the rate obtained was multiplied by 100. This last linear transformation was made to facilitate the analytical task and work with fewer decimals. The final score represents the average rate in which each category of spatial language was used by the children throughout the six coded sessions.

The results show the category most frequently used was the Deictics, e.g., connotative words whose meaning is dependent on the context in which they are used, such as “here” and “there” (see Table 20).

The second most used category of Spatial Language were the words to describe Orientations or Transformations on the space (for example, to pull apart). And the third most used one, was the description of Shapes (i.e. words that describe the standard form of two or three-dimensional objects, for instance, a rectangle).

Although no clear ordinality can be established with regard to spatial language's quality, "Deictics" might be viewed as a basic form of spatial language (there, here, this, that). This is also the case of "Shapes", since it involves a language that is more familiar to second graders. On the contrary, "Orientations & Transformations" are words that are not usually present in children's everyday language, and the kind of activities proposed intended to increase this kind of lexicon among the students.

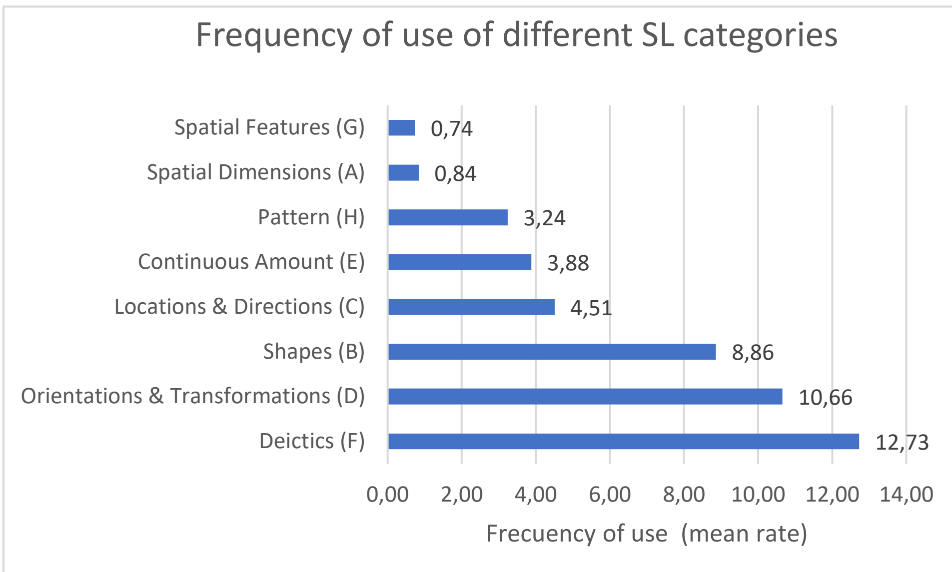
The use of more sophisticated categories of SL, such as "Pattern" and "Spatial Features" (curve, angle, corner, etc.), by the children was rather scarce. Probably, a direct teaching instruction about the terms might be required in order to increase their use.

Table 20: Descriptive statistic Categories of Spatial Language Used

Type of Spatial Language	N	Mean	Std. Deviation
Spatial Dimensions (A)	15	0,84	0,82
Shapes (B)	15	8,86	3,73
Locations & Directions (C)	15	4,51	3,08
Orientations & Transformations (D)	15	10,66	4,26
Continuous Amount (E)	15	3,88	2,76
Deictics (F)	15	12,73	7,04
Spatial Features (G)	15	0,74	1,00
Pattern (H)	15	3,24	1,86

The following plot illustrates the categories of Spatial Language most frequently used by the children evaluated.

Plot 4



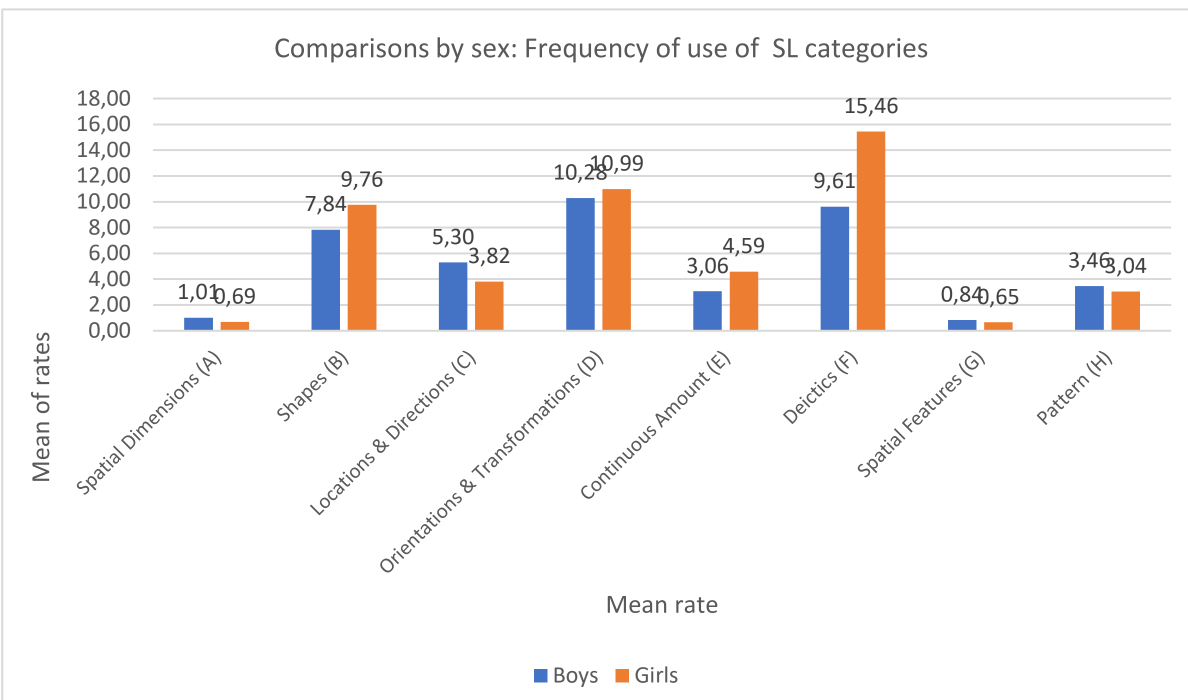
<u>Comparison by sex</u>

A Mann-Whitney U test was run to determine if there were any differences between boys and girls in terms of the categories of Spatial Language they used (See plot 5). Distributions of the scores for boys and girls were not similar, as assessed by visual inspection. There were no statistically significant differences for the categories of Spatial Language used by boys and girls (See Table 21 that summarises the results).

Table 21: Comparison by sex: Categories of Spatial Language Used

	Mann-Whitney U	p value	Mdn Boys	Mdn Girls
Spatial Dimensions (A)	25	.779	0,60	0,87
Shapes (B)	36	.397	8,66	10,90
Locations & Directions (C)	20	.397	4,20	3,12
Orientations & Transformations (D)	30	.867	10,36	10,55
Continuous Amount (E)	37	.336	2,71	5,15
Deictics (F)	42	.121	10,19	16,09
Spatial Features (G)	23	.613	0,50	0,10
Pattern (H)	26	.867	3,08	2,71

Plot 5

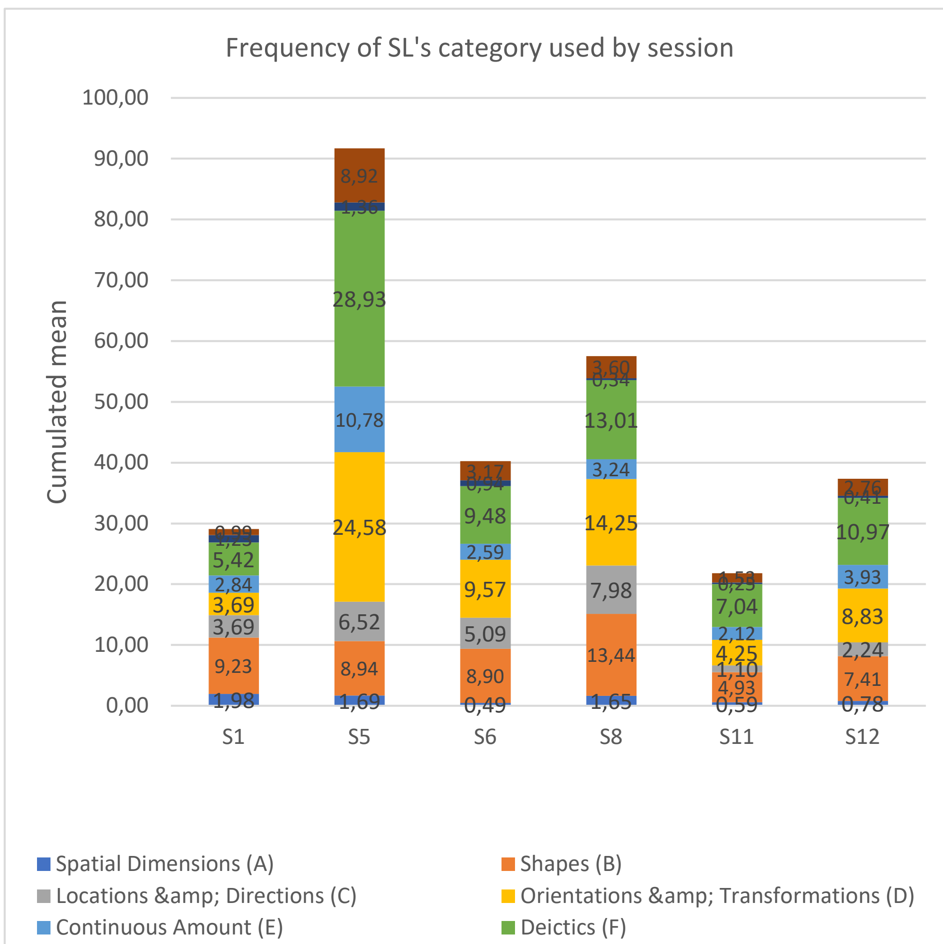


Comparison by session

The analysis of the plot 6 shows that every session elicited the use of the eight categories of SL, although the proportion of use of each category was rather heterogeneous.

In accordance with the results reported above, when analysing the distribution of the categories of SL in each session, the use of "Deictics" is usually the most frequent one, with the exception of session 1 (Can you draw this?), in which the category most frequently used by the students was "Shapes". In fact, the objective of that session was that children described the figures they identified in various 2D images which represented 3D figures.

Plot 6



7.5.2 Use of Hand Gestures and Body Movements

7.5.2.1 Quantity and Variety of Hand Gestures and Body Movements

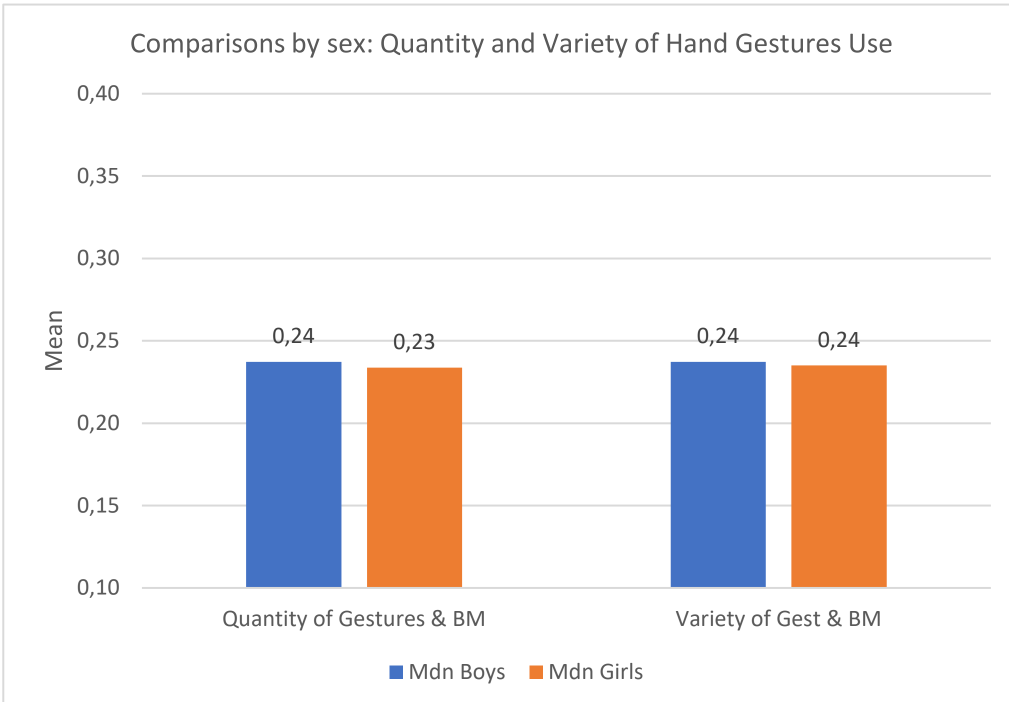
Comparison by sex

A Mann-Whitney U test was run to determine if there were any differences in Quantity and Variety of hand gestures used between boys and girls (See plot 7). Distributions of the scores for boys and girls were not similar, as assessed by visual inspection. There were no statistically significant differences in the types of Hand Gestures & Body Movements used by boys and girls (See Table 22 that summarises the results).

Table 22: Comparison by sex: Quantity and variety of Hand Gestures used

	Mann-Whitney U	p value	Mdn Boys	Mdn Girls
Quantity of Gestures & BM	25	.779	0,24	0,23
Variety of Gest & BM	25	.779	0,24	0,24

Plot 7



<u>Comparison by sessions</u>

Plot 8 reveals that in terms of the differences in quantity and variety of hand gestures used, the sessions can be divided in two categories: sessions 5, 6, and 8 show a larger use and variety of hand gestures, while sessions 1, 11, and 12 reveal less use of them.

As was pointed out when analysing quantity and variety of SL use, sessions 1, 11, and 12 involved special tasks that did not requiere a dialogue with another person to be solved. Therefore, they did not requiere the use of gestural language for comunicative purposes either.

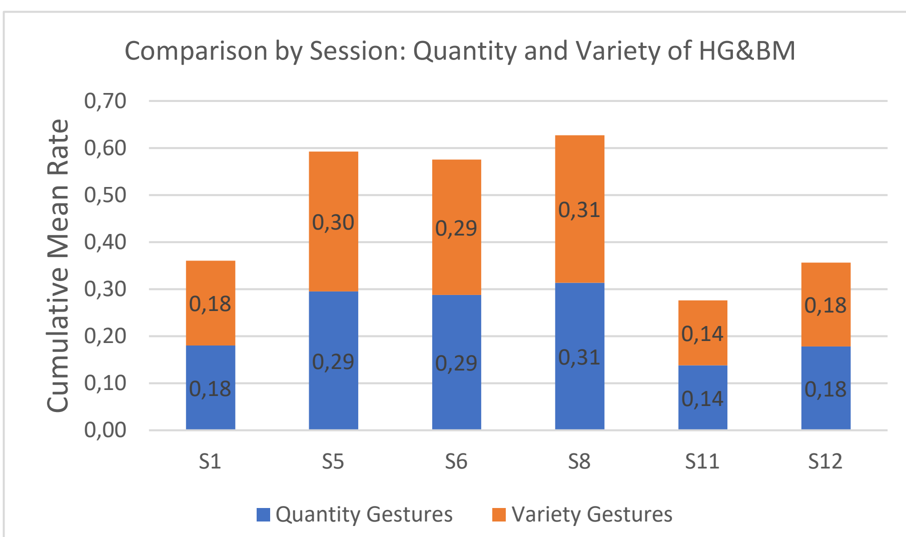
On the contrary, sessions 5 and 8 involved dialogue with peers. Thus, gestural language also contributed to the exchange and construction of meaning.

Even though session 6 had a greater focus on comprehensive rather than expressive language, it is important to note that the activity included a visualisation. In the visualisation, children were invited to close their eyes and imagine the building process of a figure made out of blocks. The building process was verbally described.

As seen during the analysis of these videotapes, children made hands' gestures that reproduced the construction with blocks and the spatial transformations they were listening to in the researcher's narration. One possible hypothesis is that making gestures with their hands helped children to understand and hold in their memory the spatial transformations they where listening to.

As reported in the next section, this activity also explains why the use of hand gestures alone was more frequent in session 6, as compared to other sessions.

Plot 8



7.5.2.2 Use of different Hand Gestures & Body Movements types

To calculate this score, it was identified the frequency with each child used a type of hand gesture and body movements (HG&BM) during the coded sessions. Then, that number of HG&BM was divided by the number of time-lapse of each session and the rate obtained was multiplied by 100. This last linear transformation was made to facilitate the analytical task and work with fewer decimals. The final score represents the average rate in which each type of HG&BM was used by the children throughout the six coded sessions.

Results indicate the HG&BM most used by the students throughout the intervention were to point and to show with the hands (see Table 23).

The third type most used of HG&BM was “to rotate the material”, in order to compare the child’s product with a projected image or with a classmate’s product.

Both the hand gestures of pointing at and showing something are fairly common in daily life. Thus, their frequent use is not surprising.

Additionally, “moving the materials” is a physical transformation that might be used to better understand mental rotation. In other words, objects’ manipulation can be understood as an intermediate step to achieve a greater mastery of mental transformations.

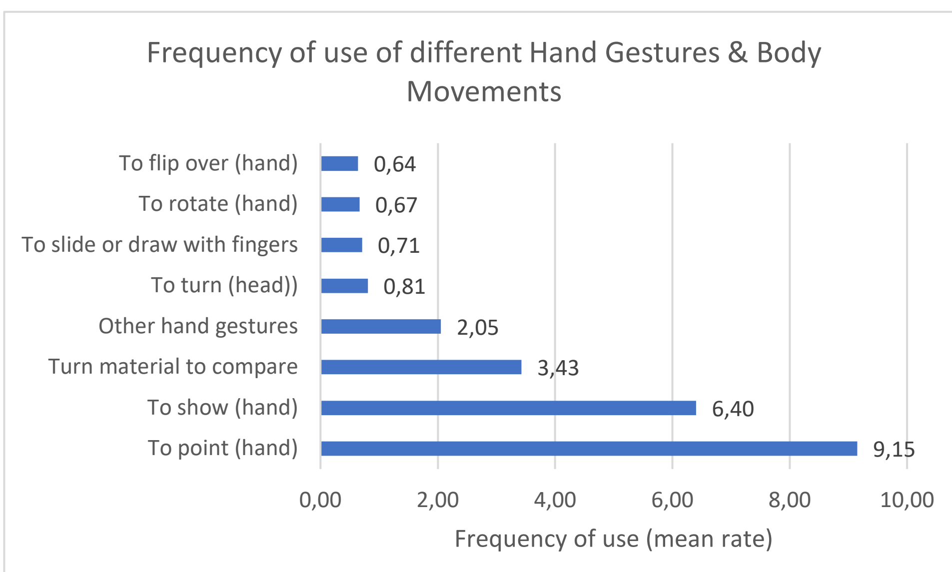
Hand gestures representing “to rotate” and “to flip over” were tought directly during the intervention, but its spontaneous use was unfrequent.

Table 23: Descriptive statistic Types of Hand Gestures & Body Movements used

	N	Mean	Std. Deviation
To point (hand)	15	9,15	4,05
To show (hand)	15	6,40	3,09
Turn material to compare	15	3,43	2,13
To slide or draw with fingers	15	0,71	0,67
Other hand gestures	15	2,05	1,83
To rotate (hand)	15	0,67	0,80
To flip over (hand)	15	0,64	1,20

The following plot illustrates the type of HG&BM most used by the study participants.

Plot 9



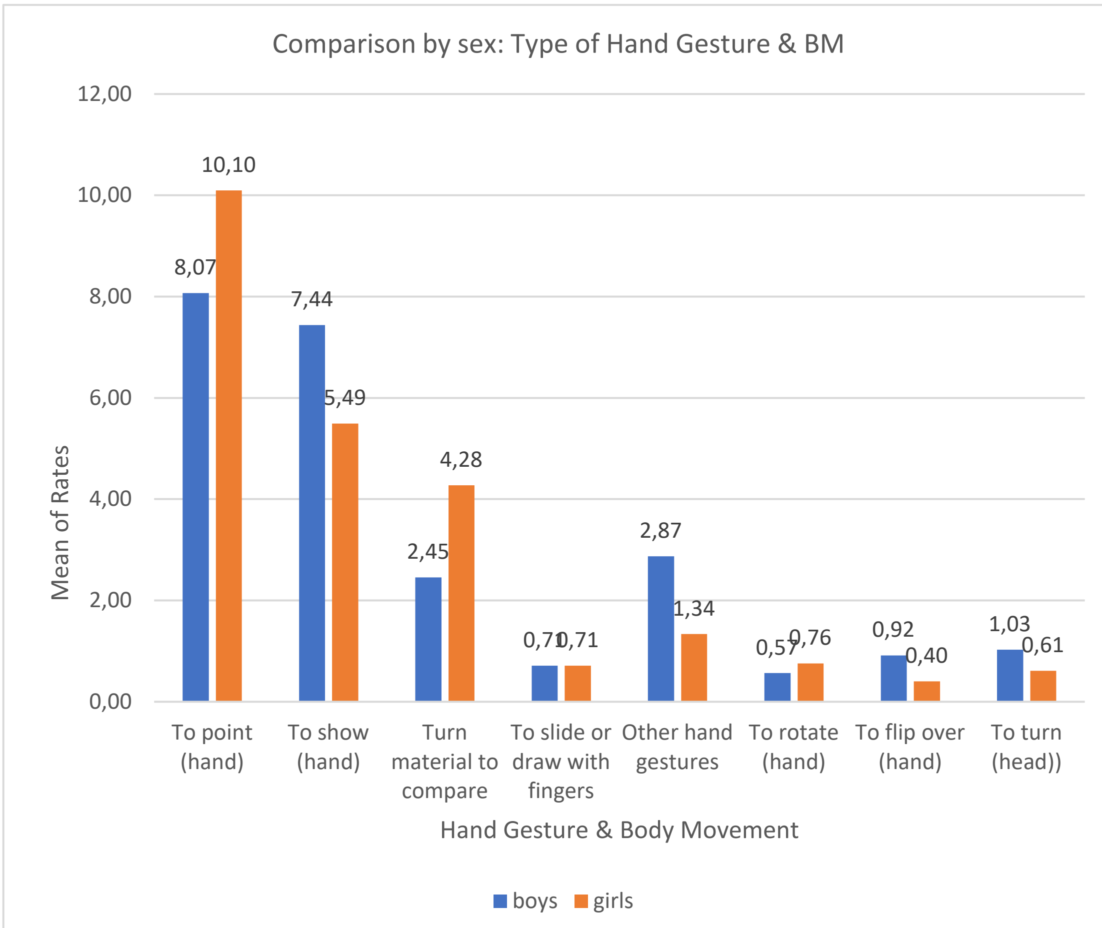
<u>Comparison by sex</u>

A Mann-Whitney U test was run to determine if there were any differences in the types of Hand Gestures & Body Movements used between boys and girls (See plot 10) . Distributions of the scores for boys and girls were not similar, as assessed by visual inspection. There were no statistically significant differences in the types of Gestures & Body Movements used by boys and girls (See Table 24).

Table 24: Comparison by sex: Types of Hand Gestures & Body Movements Used

	Mann-Whitney U	p value	Mdn Boys	Mdn Girls
To point (hand)	36	.397	8,44	10,04
To show (hand)	19	.298	8,76	4,51
Turn material to compare	40	.189	1,94	3,52
To slide or draw with fingers	29	1	0,80	0,51
Other hand gestures	12	.72	2,72	1,11
To rotate (hand)	27	.906	0,50	0,26
To flip over (hand)	23,5	.613	0,17	0,00
To turn (head)	22,5	.536	0,66	0,42

Plot 10

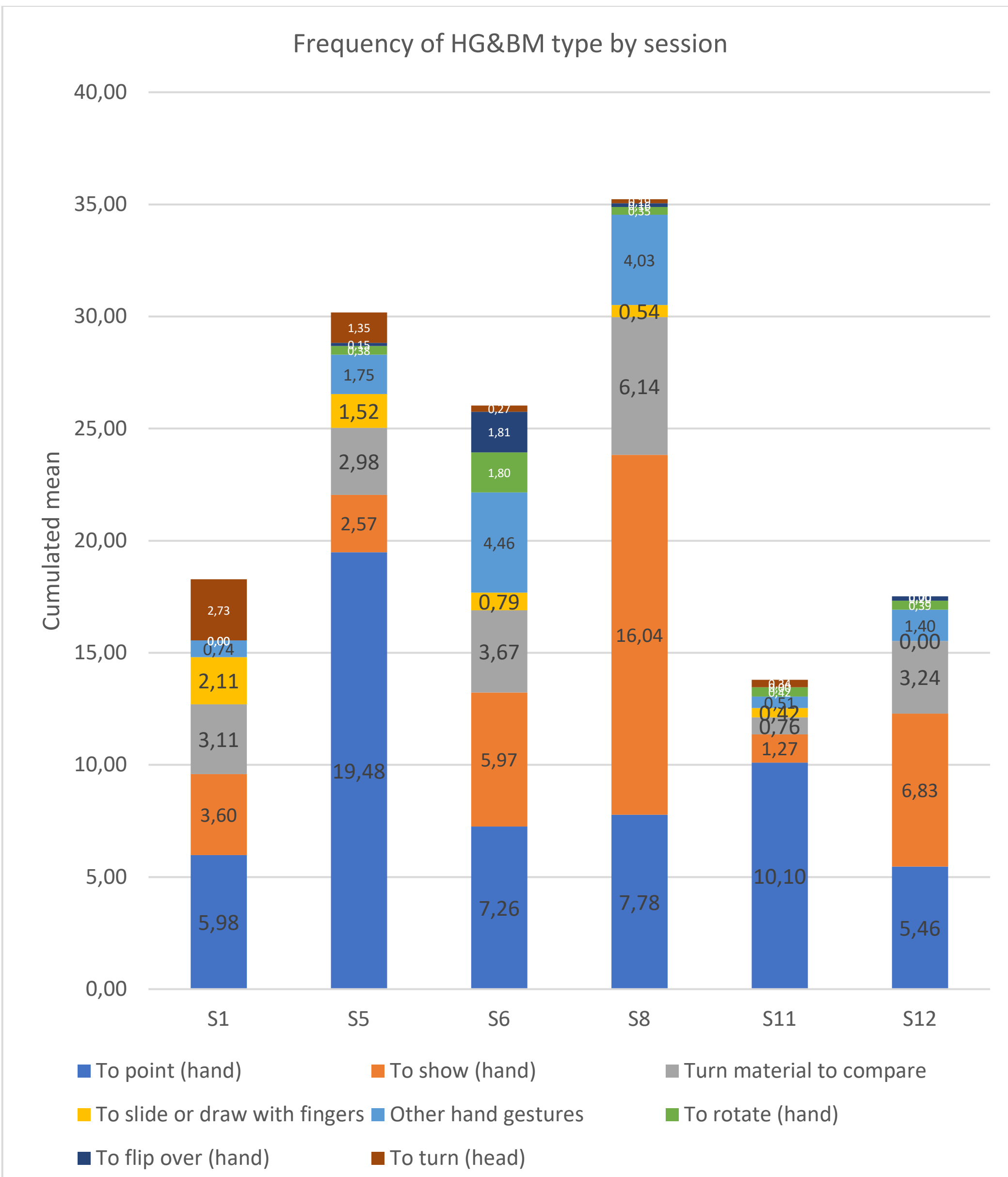


Comparison by session

The distribution of the types of gestures and movement used in different sessions was quite varied.

Compared to other sessions, the most frequent use and higher variety of gestures took place in sessions 8 (Playing at being an architect) and 5 (Symmetry).

Plot 11



7.5.3 Combined use of hand gestures and spatial language

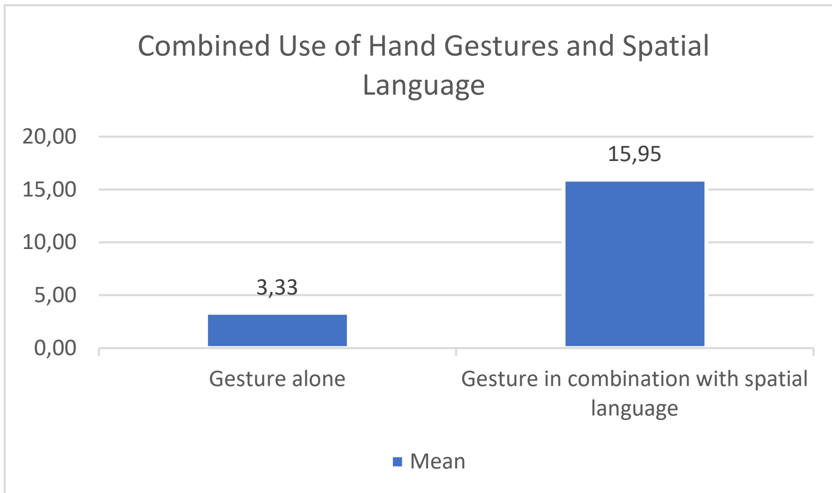
It is worth to note that children mostly used the hand gestures in combination with spatial language (see Table 25 and Plot 12). To communicate with others, the use of both kinds of language (gestural and verbal), seemed to emphasise the intended meanings.

When children used the gesture alone, frequently they were immersed in a spatial task and trying to explain it to themselves. It was some kind of self-talk that took place when the child was reasoning about the space.

Table 25: Descriptive statistics for Use of hand gestures in combination with spatial language

	Mean	Std. Deviation
Gesture alone	3,33	1,99
Gesture in combination with spatial language	15,95	7,60

Plot 12



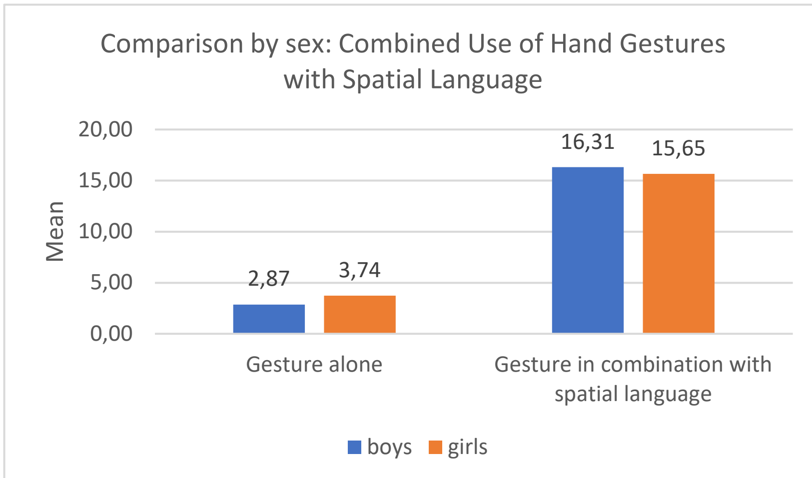
<u>Comparison by sex</u>

A Mann-Whitney U test was run to determine if there were any differences between boys and girls in Combined use of Hand Gestures & Spatial Language (see plot 13). Distributions of the scores for boys and girls were not similar, as assessed by visual inspection.). There were no statistically significant differences in the categories of Gestures & Body Movements used by boys and girls (see Table 26).

Table 26: Comparison by sex: Combined use of Hand Gestures & with Spatial Language

	Mann-Whitney U	p value	Mdn Boys	Mdn Girls
Gesture alone	39	.232	2,57	3,64
Gesture in combination with spatial language	26	.867	19,28	15,68

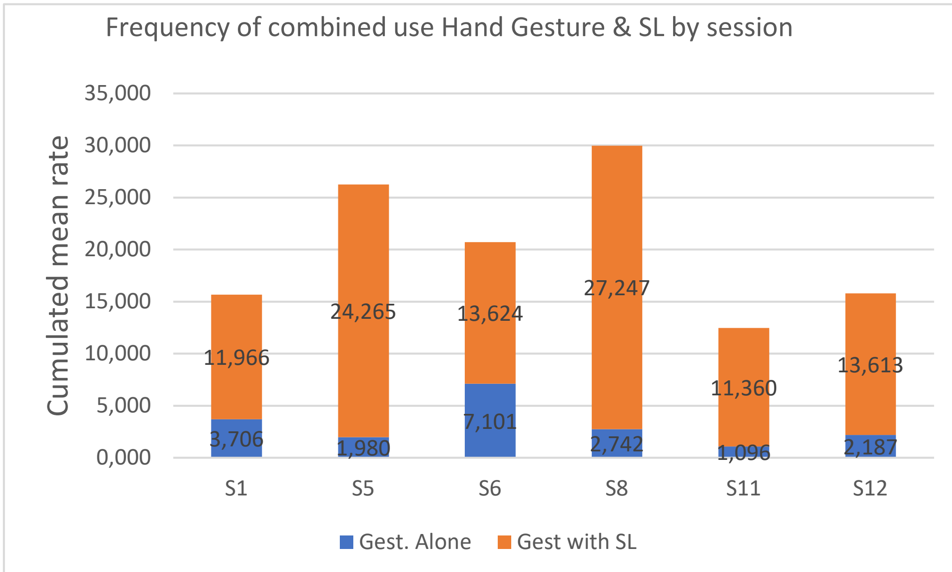
Plot 13



Comparison by session

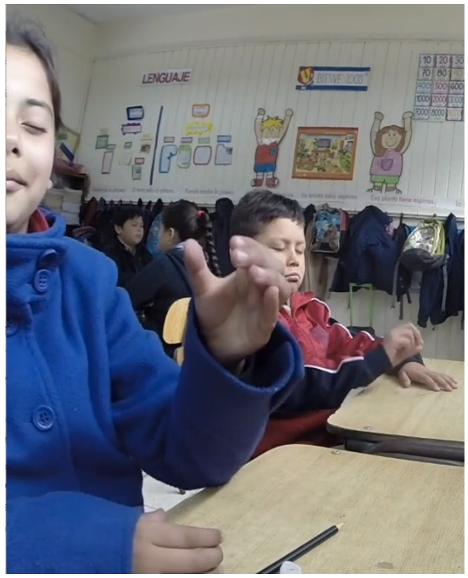
As noted in the analysis of the use of gestures along the sessions, an important increase in the use of gesture alone was observed in session 6 (Building with the mind's eyes) (Plot 14).

Plot 14



Presumably this increment is associated to the visualisation included in that session, during which children built with their hands the images the researcher was describing to them verbally (see pictures). Apparently, children used such strategy to increase their hability to hold in memory the images they were constructing.

Girl "stacking" cubes (building a tower with the mind's eyes)



Boys "flipping over" the tower.

In summary, the evidence analysed to answer research question number four indicates that children use various categories of spatial language, types of hand gestures, and body movements to describe shapes, location, and transformations in space.

Interestingly, children in this study tend to use simultaneously verbal and gestural languages to communicate with others in regard to locations and spatial transformation. On the contrary, while they are reasoning privately to solve a spatial task, they tend to use gestures alone.

Activities designed for each session appear to elicit different kinds of spatial language and gestures. To increase the use of spacial expresive language, it seems to be important to design activities that involve dialogue with peers (ideally in small groups of two or three children to ensure the participation of all students). In this kind of activities the child has to describe what has been constructed, using various spatial concepts.

Comparisons by sex indicate that none of the differences observed turned out to be statistically significant, not in spatial language nor in the use of hand gestures and other body movements.

8 Discussion and Conclusions

There has been renewed interest in spatial reasoning skills during the last decade. Long-term longitudinal studies have revealed that good spatial skills in pre-school predict the choice and successful performance in STEM disciplines during adulthood (Wai et al., 2010).

Even though the association between both kinds of skill, as well as its stability along development is well documented, emphasis has been made in the need to clarify the nature of the relation between both skills. Is there any causal relation between them? If this is the case, in what direction does it work?

Until now, only two studies had explored this area. Using an experimental design and training in a laboratory setting, Chang & Mix (2014) showed that a brief training in mental rotation in a group of 6 to 8-year-olds had a transference effect over their mathematic skills.

On the other hand, aiming to answer the question regarding the causal relation under conditions that improved the external validity of their findings, Hawes, Moss, Caswell, & Poliszczuk (2015), designed a spatial skills training to be carried out in the classroom. However, they could not replicate Chang & Mix's (2014) results—they did not find significant transference effects of training in spatial reasoning over mathematical skills in the children participating in the study. As a possible explanation, Hawes et al. (2015) suggested that Chang & Mix's results might be attributed to a priming effect, meaning an artificial effect resulting from the training in the laboratory setting.

This thesis aimed to contribute to this debate through a quasi-experimental study in a classroom setting. In this respect, it replicates the conditions of Hawes et al.'s (2015) study. However, the kind of spatial training designed for this study is different, since instead of training the children's spatial skills through individual activities in a digital device (tablet), this study favoured small groups' hands-on activities. Moreover, activities were designed according to the guided-play learning approach and embodied cognition theories.

In addition to the contribution of evidence in favour or against a direct causal effect of training in spatial skills over the performance in mathematics, this study also aimed to contribute in the theoretical arena, modelling the causal relation among various variables that have been previously identified by research on these topics. Thus, a chain causality model was tested, which assigned mediating roles to two components of visual-spatial memory system (i.e., working memory and short-term memory) as well as the (potential) role of spatial skills' improvement in the enhancement of mathematical skills. Moreover, the moderator role of child's sex and his/her initial level of spatial skills was examined, as previous research's findings pointed in that direction.

Finally, an additional goal of this thesis was to study how children use spatial language, hand´s gestures and some specific body movements in order to carry out the intervention activities. The aim was to retrieve more precise information that allows to improve the design of future interventions intending to stimulate the development of spatial skills in young children.

The following section discusses the results, according to the research questions.

8.1 Discussion

Research question 1: Does training improve students' near, intermediate, and far transfer skills?

Regarding the effects of training over spatial skills, the results of this study were consistent with the findings of previous researches (Uttal et al., 2013): children in the experimental group improved their scores in mental rotation and perspective-taking as a result of the intervention. In other words, it confirms the malleability of spatial skills and the stability of change, as measured in a three-week follow-up. Additionally, this study provides information about the malleability of the spatial skills for an age group (7 and 8-year-olds) who has been less studied. Indeed, so far, the available evidence tends to focus in adult (Uttal et al., 2013) and pre-school population (Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2014, 2017).

The change on Mental rotation had the higher effect size. Again, this coincides with prior knowledge. Among spatial skills, mental rotation seems to be the most easily trainable. On the contrary, improvement of perspective-taking, appears to require a more significant effort. Differing from Frick, Möhring, & Newcombe's (2014) findings, children in this sample had very low scores in the PT test (mean at T1= 3 raw points/from 13 theoretical maximum score). According to Frick et al. (2014) 8-year-olds are supposedly over cognitive egocentrism and able to solve the PT test. Children in this sample (both groups) not only failed systematically in PT measurement in T1, but also the improvement of the experimental group in T2, though statistically significant, was very small.

As an alternate explanation, it can be hypothesised that the variable of PT might have a different level of complexity and involves a higher degree of abstraction. To begin with, it poses a higher demand on VSWM because it involves performing mental transformations (rotation, translations) and holding the other's point of view simultaneously. Interestingly, children's PT skills came into play when they had to coordinate with a partner in order to solve the task at hand. In other words, they had to understand their own and their partner's point of view at the same time. This was apparent, for instance, in the symmetry activity.

About the intervention's effect on "intermediate transfer skills"—which were indirectly and partially trained during the intervention—the only significant effect was the effect over VS short-term memory. The connection of this finding with previous evidence is not clear enough. There are no previous training studies that considered VS memory system as a dependent variable. In this study, VSWM turned out to be less malleable, and this raises the question of whether the instrument assessed VSWM alone, or also, another component of Executive Functions (such as inhibitory control). It is worth noting that in the task carried out in the Ipad device, the child had to signal the route of the mole in the same sequence of appearance. However, children made frequent mistakes because they impulsively tried to reproduce the series before the complete stimulus was presented.

Finally, regarding the effect of the intervention over "far transfer skills"— skills that were not explicitly trained during the intervention— the results obtained with univariate analysis do not support the existence of a transference effect over children's mathematics skills. This finding confirms those of Hawes et al. (2015), analysed with similar statistical techniques. However, the analysis with a multivariate statistical technique (LCSM), a more sophisticated and sensitive tool to detect effects among the conjoint contribution of intervenient variables, reveals a minimal and utterly mediated effect of the spatial skills intervention over the mathematical abilities (ES=0.08). Hence, the causal effect of spatial skills over mathematical abilities cannot be totally rule out. Furthermore, this finding suggests another possibility: perhaps the effect of spatial skills over mathematical performance is a ‘cascade effect’, that is when the improvement on a specific domain is the result of a cumulative or progressive effect over time (Masten & Cicchetti, 2010). These delayed improvements have been observed in other fields of educational research such as the positive effect of collaborative group argumentation on content knowledge gains (Howe, McWilliam, & Cross, 2005; Larraín, 2017) and suggest the need for carry-out new training studies with a more extended time frame to identify delayed mathematical improvement. One of the limitations of this training study was the impossibility of executing a follow-up assessment of children's mathematical performance, due to the beginning of students’ summer holidays.

Research question 2: Are there any differential training effects between subgroups?

The results of this study did not show any moderator effect of the child’s sex. In other words, for none of the measured variables did the intervention appear to have any differential effect over boys and girls. This result diverges from previous empirical findings, which generally report a difference associated to the sex of the participant: most of the studies reviewed report that at the beginning as well as in post-training gains, boys obtain better scores in spatial skills than girls (Ehrlich et al., 2006; Uttal et al., 2013).

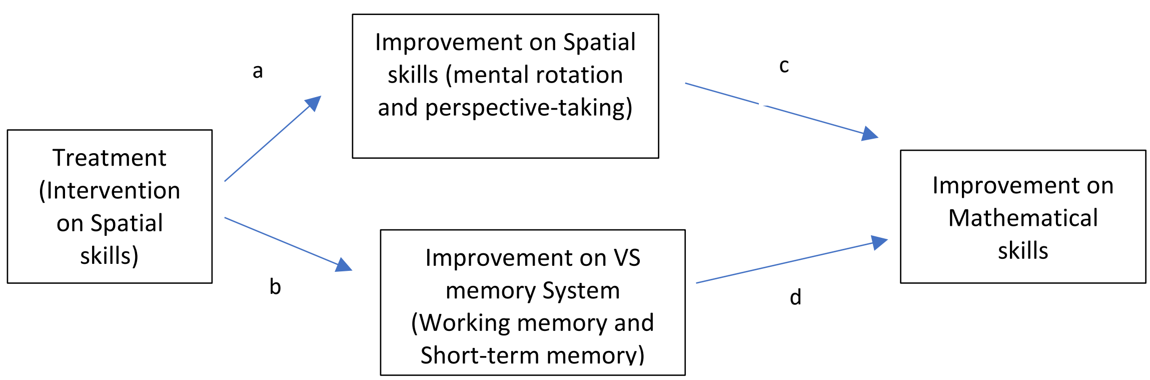
A possible explanation for this finding that contradicts previous research relates to the fact that children of this sample belong mainly to middle-low SES. In such social context, there might be scarce environmental stimulation for the development of spatial skills, which affects boys and girls equally. In this respect, these results are similar to those of Levine et al., (2005), who found a difference in spatial skills in both sexes but only in middle and high SES children, and not in low SES children. This finding led them to conclude that the difference between both sexes is probably related to differences in socialization when resources are available (e.g., create more opportunities to play with toys that favour the development of spatial skills and/or have caretakers that use a richer spatial language for boys than for girls). To confirm the hypothesis of a moderator effect of SES on spatial skills intervention further research will be needed. The study implemented in this thesis could be replicated, testing the intervention with children of both sex and different SES. That to confirm the interaction effect between sex and SES on spatial skills' differences observed by Levine et al.

Regarding the moderator effect of initial level of social skills, the results of this study show that children who initiate the intervention with a lower level of skills obtained greater benefits from training in spatial abilities. This is especially true for Mental Rotation. Because of the intervention, all children in the experimental condition significantly improved their scores in Mental Rotation. However, the increase was higher for those who had lower scores in T1. This finding is consistent with the evidence previously reported by Uttal et al.'s (2013) in their meta-analysis. An explanation of this finding could be that children who start at a lower floor of spatial skills beneficiated more from hands-on activities than their advantaged peers. For children with a higher initial level of spatial skills, the regular instructional practice provided by the school or the inputs available at home is enough.

Research Question 3: How are the relationships among the near, intermediate and far transfer skills?

A "causal-chain model" was tested using a Multivariate Latent Change Score Model (LCSM). The goal was to test whether spatial skills training does have a direct effect over (a) such skills, and (b) the VS memory system. Also, an indirect effect of treatment over mathematical skills was expected, in other words, the effect being mediated by an improvement in (c) spatial skills, and (d) VS memory system. The figure 26 presents the hypothesised model.

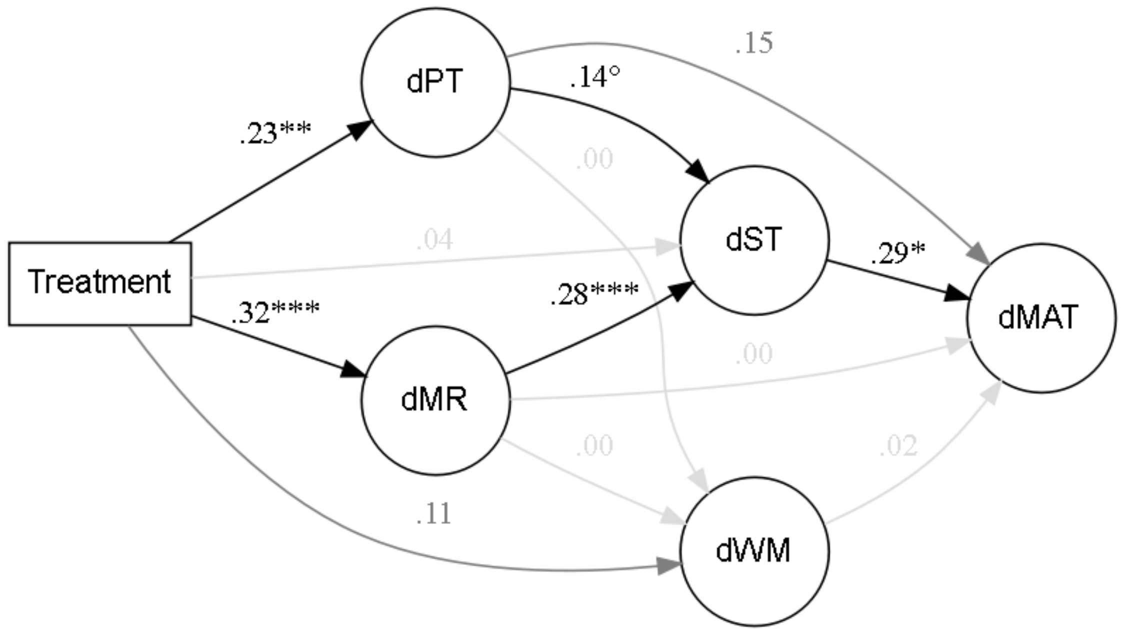
Figure 26: Hypothesised *"causal-chain model"*



Among the models tested, the one that showed better fit indexes confirms the direct effect of treatment over the spatial skills improvement (MR=.32 & PT=.23). However, the treatment did not have the expected direct impact over the change in VS Memory System. Contrary to the hypothesis, improvement in both spatial skills had a direct effect over the improvement in VS short-term memory, and in turn, this change had a direct effect over the change in mathematics (.29). Even if it was small, the direct effect of change in Perspective Taking over the change in mathematics (.15) was novel as well.

Overall, the net effect of treatment over change in mathematics is very small in magnitude and entirely mediated by the variables just mentioned (.08) [See Figure 24]. As was mentioned before it will be important to count with new research that explores this mediated model (Chain-cause model) over an extended time frame, in order to identify delayed mathematical gains (cascade effects).

Figure 24: LCSM with mediated effects



The resultant model, also, provides new possibilities for the exploration of the underlying change's mechanisms between spatial and mathematical skills. In effect, the observed model highlights the role of visual-spatial memory—specifically, VS short-term memory—in the improvement of mathematical skills. Perhaps it reflects a "common-cause model" between both type of abilities, instead of a chain-cause model, as it has suggested by Bailey (2017). In this manner, VS memory may turn out to be the shared cause that explains the lasting and robust correlation between spatial and mathematical skills.

Li & Geary's (2013, 2017) studies about the relationship between various components of memory (See Baddeley & Hitch's model) and mathematical performance along school life, are useful in the formulation of a model of a common cause. Li & Geary

(2013, 2017) followed a cohort of students from 1st to 9th grade. In their first study (1st to 5th grade), they found that once controlling for other factors (EF, phonological memory, parent's education, in-class attention), the gains in visual-spatial memory from 1st to 5th grade predicted end-of-fifth grade mathematics but not reading achievement. In the follow-up study (6th to 9th grade) they showed that this relationship persisted after 5th grade. Taken together, the findings of both studies suggest that VS memory might have a unique influence in facilitating the learning of some mathematical skills and that such influence is increasingly important during school years. A future research agenda to test this common-cause model could include:

a) to implement a longitudinal study following a cohort of children along the primary education and assessing their visual-spatial memory, their spatial skills and their mathematics achievement and,
b) to carry out a training study on children VS memory and investigating its effect both on their spatial and mathematical abilities.

Additionally, the modelling carried out with the variables measured in this thesis' study also suggests that the kind of abilities chosen to operationalise spatial skills and study their relationship with mathematical skills might be relevant. Indeed, the modelling carried out in this study confirms that change in Mental Rotation (intrinsic-dynamic spatial skill) has no direct effect over change in mathematics, a finding that is consistent with those of Hawes et al. (2015). However, the gain in Perspective-Taking (extrinsic-dynamic spatial skills) does have a direct, though modest, role in the change in mathematical skills. This is an interesting line of research that should be explored in the future, with training studies specifically focused on the development of more complex spatial skills, such as perspective-taking or navigational skills (both are extrinsic-dynamic spatial skills). The goal here would be to evaluate a possible transference effect over mathematical skills.

In summary, the results of this modelling do not rule out entirely the "causal-chain model". These results offer the possibility of identifying more clearly the mediator role that VS memory system and Perspective-taking might have. But this has yet to be demonstrated in future studies. Likewise, a common cause model that places VS memory system as a shared cause of spatial and mathematical skills should be tested in the future.

Research Question 4: How do the students use the spatial language, hand gestures and body movements along the intervention?

As mentioned previously, this research question had an exploratory purpose.

This study contributes with evidence that shows children use various categories of spatial language, different kinds of hand gestures and body movements to describe shapes, locations and transformations in space.

However, the most frequent kind of categories of spatial language and hand gesture used by these children tended to be more basic. In the case of spatial language, the most used category was the "deictic", that is, words used to point out a location, but whose meaning is relative to speaker's position ("here", "there", "this", "that"). Concerning the most used gestures, the taxonomy offered by McNeill (1992) allow to classify them according their semiotic level (Basilio & Rodríguez, 2017; Pine, Lufkin, Kirk, & Messer, 2007). In that manner, the most used (pointing) is of indexical nature (i.e. sign and referent are distant), while the second most used (showing) is an ostensive or iconic gesture (i.e. sign and referent coincide). The symbolic hand gesture (for instance, flipping over), which doesn't have any relationship between sign and referent, were infrequently used by observed children. Exploring whether the use of more sophisticated verbal and gestural language associates with a better performance in spatial tasks is another interesting issue for future research.

On the other hand, this subsample of children showed a highly frequent use of combined verbal and gestural language. This result is similar to findings reported by Pine et al. (2007). Analysing specific contexts when this occurred, it showed that children conjointly use words and hand gestures when they were trying to communicate their spatial reasoning to others. It might be a strategy to emphasise the spatial meanings.

However, when the children were involved in an internal dialogue to solve a spatial problem, they frequently used hand gestures alone. This evidence supports the idea claimed by several researchers: hand gestures would have a role in developing abstract thinking, such as spatial reasoning (Antle, 2012; Goldin-Meadow, 2015; Pine et al., 2007).

From an instructional design perspective, the activities designed for each session, also seem to elicit diverse kinds of spatial language and gestures. For future interventions, it seems important that the activity designed favours the dialog among peers (ideally pairs or trios to foster everybody participation), in order to increase the use of expressive spatial language. This way the child would have to describe what has been built using various spatial concepts.

Comparisons per sex show that none of the differences observed between girls and boys were statistically significant, both in spatial language and in the use of hand gestures and other body movements. Regarding the use of gesture, this finding is different compared with the results of (Ehrlich et al., 2006). In their study with pre-schoolers, they found that boys used more gestures than girls. Nevertheless, the small size of the subsample in this study (n=15) might explain the difficulty to find statistically significant differences of a small size effect. The small sample size was an obstacle, also, to identify some trends between the quantity of spatial language or gestures used by observed children and their near, intermediate and far transfer skills. In the future, it is required to carry out further research to establish whether a more sophisticated use of hand gestures and spatial language are related to increased effectiveness in spatial problem-solving.

8.2 Conclusions

According to Gabrieli's model (2016), this thesis aimed to advance from the phase of Basic Research to the phase of Small-Scale applications. To that end, empirical evidence obtained mostly from previous basic research at a behavioural level was thoroughly examined. There is extensive research evidence accumulated so far, with regard to different variables studied in connection with spatial skills and mathematics. Nevertheless, the attempts to bring previous evidence together in the design of an integrative and coherent intervention have been scarce. The aim here was to answer the question about the causality of spatial skills on mathematical calculation skills, by means of an intervention based on the accumulated empirical evidence and a pertinent research design.

As mentioned before, one of the limitations of this study was the impossibility to assess students' mathematical calculation skills in Time 3. Some educational researchers highlight the need to consider the timing of the development/acquisition of more complex skills. Hence the importance of including follow-up measures in the educational research designs, in several opportunities when possible. The rationale is the need to study delayed changes that take place in more extended time frames, as well as verifying the degree of stability of determined gains attributed to an intervention. The time frame of this study was highly restricted.

Additionally, since the sample in this study was homogeneous in relevant attributes (SES, age, urban), caution is required before generalising the findings to populations with different characteristics.

Regardless of these limitations, the study reported in this doctoral thesis has contributed with evidence concerning the issues explored. Generally speaking, the findings suggest the need to maintain an open exchange between basic and applied research before escalating the results to broader levels of intervention, such as the classroom or the school curriculum.

At the same time, the results of this study offer new paths to explore this primary circuit: Is VS memory the common cause for both kinds of skills? Are some spatial skills more sophisticated than others? And if so, what spatial skill is the best predictor of mathematical performance? How can verbal and gestural language be used more effectively to promote the development of spatial skills? Given the preliminary available evidence regarding shared neural circuits that activate while solving spatial and mathematical tasks, can behavioural and neural level evidence be integrated in future studies?

A future research agenda in spatial reasoning field has several strands of development. It will be important, for instance, to replicate this study with a broader time frame to identify if there are delayed mathematical gains. Similarly, this study could be replicated with children from different sex and SES to test the hypothesis of SES' moderator role on intervention effects, and the interaction between sex and SES. Another useful line of research will be to test a common cause model that explores the VS memory system as the shared cause. If it is confirmed the protagonist role of VS memory, it will enlighten instructional design to foster both spatial and mathematical abilities, improving future intervention's efficiency and effectiveness. And finally, it will be informative to study the effects of an intervention that promotes children's use of more sophisticated hand gestures and spatial language to improve their spatial skills.

As it can be appreciated, the research about children spatial reasoning results promising.

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10 Appendix

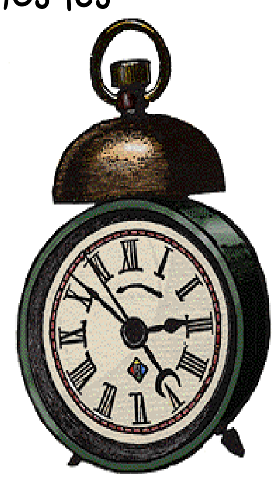
10.1 Ethical procedures documents

For the experimental group's children: assent booklet that explained the research activities.

¿De qué se trata el taller?

1. Te invitaremos a jugar, copiar algunos diseños y elaborar tus propios diseños con distintos materiales.
2. Nos vamos a juntar durante 6 semanas aquí en tu sala.
3. El Taller lo va a dirigir Carolina con otra sicóloga. Siempre estará tu profesora jefe presente.
4. Vas a estar con todo tu curso, pero haremos las actividades en grupos pequeños de no más cuatro compañeros.
5. Con una tómbola, vamos a elegir 5 grupos que serán filmados con una cámara de video durante todo el taller, mientras están realizando las actividades. Estos videos van a servir, después, para entender qué te ayudó a aprender más y mejor.
6. Además, antes de empezar la primera sesión de juego y cuando terminemos la última sesión, te haremos algunas preguntas en forma individual. Eso nos ayudará a saber cuánto te han servido las actividades y qué cosas nuevas has aprendido.

A las reuniones que tendremos les llamaremos "sesiones"



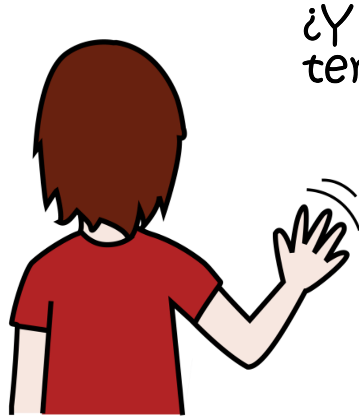
- ✓ Nuestro Taller va a durar 12 sesiones
- ✓ Las sesiones serán 2 vez a la semana y durarán 45 minutos cada una.
- ✓ Antes de empezar el taller y después que lo terminemos, Carolina nos hará unas preguntas a todo el curso para saber cuánto hemos aprendido durante el taller.

¿Qué se hace en las sesiones?

√ Haremos distintas cosas. Algunos días jugaremos armando figuras con bloques de LEGO, a partir de un modelo que observaremos en un dibujo.

√ Otros días, jugaremos haciendo origamis o reproducciones con tangramas

¿Y que pasará cuándo terminen las 12 sesiones?



✓ Llegará el momento de decir ADIOS al Taller

✓ **Sin embargo, volveré a ver a las psicólogas en dos ocasiones más, cuando nos juntemos a evaluar cuánto hemos aprendido.**

Un mensaje para ti...

La directora de tu colegio y tus padres están informados y nos han dado permiso para invitarte a participar en este taller.

Es importante contarte que no estás obligado u obligada a participar. Si no te interesa, podremos buscar alguna alternativa para ti durante el Taller. También contarte que si en algún momento quieres retirarte del taller y no participar más, está bien. Nadie se enojará contigo por eso.

¿Tienes alguna pregunta que me quieras hacer? Si es así, levanta la mano y me acercaré a contestarlas.

¡Esperamos que sea una forma divertida de aprender para ti!

Con cariño,

Carolina Araya R

Después de todo lo que te he contado, quiero preguntarte si deseas participar y pedir tu permiso para mostrar algunos pedazos de los videos a otras personas. **Marca con una X la celda que represente tu respuesta**:

Quiero participar en el Taller	**Sí**	**No**
Le doy permiso a Carolina para que muestre partes de los videos en que aparezco con mis compañeros, mientras realizo las actividades del Taller. Esos trozos de videos serán mostrados sólo en congresos o en clases para otros profesores y psicólogos. Nunca pondremos tu nombre u otros datos que permitan identificarte.	**Sí**	**No**

Santiago, Julio de 2016

Mi nombre:________________________________

¡Esta copia es para Carolina!

Ahora te invito a hacer un dibujo sobre cómo te imaginas el Taller…

CARTA DE CONSENTIMIENTO INFORMADO PARA PADRES (Grupo Experimental)

Proyecto

Juego y razonamiento espacial:

efectos de un taller para promover las habilidades de razonamiento espacial en el aula a través del juego.

Ps. Carolina Araya Ramírez

Tesis para obtener grado de Doctor en Psicología

Su pupilo (a) ha sido invitado a participar en el Proyecto de investigación "Juego y razonamiento espacial: efectos de un taller para promover las habilidades de razonamiento espacial en el aula a través del juego", a cargo de la investigadora Carolina Araya Ramírez, psicóloga y candidata a Doctor en Psicología de la Pontificia Universidad Católica de Chile. El objeto de esta carta es ayudarlo a tomar la decisión de participar o no en la presente investigación.

¿Cuál es el propósito de esta investigación?

Este estudio tiene por objetivo evaluar los efectos de un taller diseñado para desarrollar y fortalecer las habilidades de razonamiento espacial de los escolares chilenos a través del juego. En especial, interesa investigar de qué manera las actividades lúdicas propuestas, pueden favorecer la capacidad de los niños para imaginar y transformar objetos en su mente. Asimismo, interesa estudiar de qué manera este entrenamiento puede mejorar sus habilidades de pensamiento matemático.

¿En qué consiste la participación de su hijo(a)?

Si ud. autoriza la participación de su hijo(a) en este estudio, él o ella podrá participar en un Taller de 12 sesiones que se hará en horario de clases y en presencia de la profesora jefe. Durante 4 semanas, y con una frecuencia de 3 sesiones semanales de 45 minutos cada una, los niños participarán en actividades lúdicas y grupales. Estas actividades fueron diseñadas con el fin de favorecer en los niños el desarrollo de algunas habilidades para razonar sobre el espacio (por ejemplo, girar en la mente algunas imágenes, aprender a leer mapas y localizar objetos o rutas, diagramar, componer estructuras etc.).

Si bien todo el curso llevará a cabo las actividades, se sortearán 5 grupos que serán filmados durante todas las sesiones. Estos videos serán analizados con posterioridad para estudiar los procesos de aprendizaje de estas habilidades. Eventualmente, algunos segmentos serán editados para ser presentados en futuras conferencias.

Los niños participantes serán evaluados grupal e individualmente en tres momentos: antes de empezar el taller, inmediatamente terminada la intervención y tres semanas después de haber finalizado la intervención. La evaluación grupal se realizará con todo el curso al mismo tiempo en su sala de clases y no dura más de 45 minutos. La evaluación individual será realizada por la investigadora o por una psicóloga educacional entrenada. Cada sesión de evaluación individual no debiera durar más de 45 minutos y se realizará en una sala dispuesta por las autoridades del colegio.

¿Cuánto durará la participación de su hijo(a)?

Implica participar en ***tres momentos de evaluación*****:** antes de empezar el taller, inmediatamente terminada la intervención y tres semanas después de haber finalizado la intervención. ***Cada fase de evaluación incluye***:

- Una sesión grupal de 45 minutos
- Una sesión individual de 45 minutos

El ***taller dura 4 semanas seguidas, con una frecuencia de 3 sesiones semanales de 45 minutos cada una***. Las sesiones se realizarán durante la jornada escolar entre septiembre y octubre de 2016.

¿Qué riesgos corre su hijo(a) al participar?

No se estiman riesgos asociados para los participantes

¿Qué beneficios puede tener la participación de su hijo(a)?

Al participar, su pupilo(a) está contribuyendo a la generación de conocimiento respecto a estrategias efectivas para desarrollar habilidades de razonamiento espacial en el aula. Sin embargo, no habrá beneficio notorio e inmediato para usted o su hijo(a). Con todo, puede beneficiarse del entrenamiento de habilidades tales como: incrementar velocidad para rotar imágenes mentalmente, construir estructuras de tres dimensiones a partir de planos bidimensionales y viceversa, imaginar objetos desde distintas perspectivas, incrementar capacidad de almacenamiento de memoria de trabajo viso-espacial, entre otras.

¿Qué pasa con la información y datos que usted y/o su hijo(a) entregue?

Previa autorización del padre o apoderado y asentimiento del niño(a), las sesiones del taller serán grabadas en video y posteriormente serán transcritas por parte del equipo de investigación. Los registros de los test aplicados individual o grupalmente a su hijo(a) serán identificados con un pseudónimo para garantizar el anonimato. Su nombre o el de su hijo(a) no será utilizado.

Los datos recogidos en las filmaciones y sus transcripciones serán digitalizadas y codificadas con una contraseña alfanumérica. Los registros serán guardados en la oficina de la investigadora responsable, almacenados en un lugar seguro al cual solo tendrán acceso las investigadoras a cargo del proyecto.

Los profesores y director(a) del establecimiento no tendrán acceso a los resultados individualizados de su hijo(a) en ninguna de las pruebas aplicadas. Solo accederán a los puntajes promedios del curso, con el fin de darles un uso pedagógico, por ejemplo, para orientar ciertos objetivos de enseñanza.

Los resultados de esta investigación tendrán como productos informes de investigación, publicaciones y comunicaciones científicas donde podrán ser utilizados extractos de las sesiones filmadas sin que aparezcan datos de identificación personal suyos o de su pupilo(a).

Usted tiene derecho a conocer los resultados finales del estudio. Si está interesado (a), usted puede escribir al correo del investigador principal y recibirá un informe resumen con los resultados agregados.

¿Mi hijo(a) está obligado a participar? ¿Puede arrepentirse después de participar?

Su pupilo (a) NO está obligado de ninguna manera a participar en este estudio. Si accede a participar, puede dejar de hacerlo en cualquier momento sin repercusión alguna para su relación con el establecimiento.

En cualquier momento usted puede solicitar a la investigadora que le responda todo tipo de inquietudes respecto al estudio y pedir mayor información sobre las implicancias de su participación.

¿A quién puede contactar para saber más de este estudio o si le surgen dudas?

Si tiene cualquier pregunta acerca de esta investigación, puede contactar a Carolina Araya Ramírez de la Escuela de Psicología de la Pontificia Universidad Católica de Chile. Su teléfono es el 9-1594894 y su email: carayar@uc.cl

Si usted tiene alguna consulta o preocupación respecto a sus derechos como participante de este estudio, puede contactar al Comité Ético Científico en Ciencias Sociales Artes y Humanidades de la Pontificia Universidad Católica de Chile al siguiente email: eticadeinvestigacion@uc.cl

HE TENIDO LA OPORTUNIDAD DE LEER ESTA DECLARACIÓN DE CONSENTIMIENTO INFORMADO, HACER PREGUNTAS ACERCA DEL PROYECTO DE INVESTIGACIÓN Y ACEPTO QUE MI HIJO(A) PARTICIPE EN ESTE PROYECTO.
Mi firma significa que estoy de acuerdo con que mi hijo(a) participe en este estudio.
Recibo una copia del presente consentimiento informado.

Por favor, marque lo siguiente:

- Acepto que mi pupilo (a) participe en el Taller "juego y razonamiento espacial" y que participe en las instancias de evaluación individual y grupal. SI___ NO____
- Acepto que mi pupilo (a) sea eventualmente filmado durante las actividades descritas más arriba.

  SI___ NO____

Nombre del(a) Apoderado(a): ____

Nombre del pupilo(a): ____

Establecimiento: ____

______________________________	______________________
Firma del(a) Apoderado(a)	Fecha
______________________________	Agosto 2016
Firma de la Investigadora	Fecha

(Firmas en duplicado: una copia para el participante y otra para el investigador)

CARTA DE CONSENTIMIENTO INFORMADO PARA PROFESORES

(Grupo Experimental)

Proyecto

Juego y razonamiento espacial:

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Ps. Carolina Araya Ramírez

Tesis para obtener grado de Doctor en Psicología

Por medio de la presente, la estamos invitando a Ud. y a sus alumnos de 2° básico a participar en el Proyecto de investigación "Juego y razonamiento espacial: efectos de un taller para promover las habilidades de razonamiento espacial en el aula a través del juego", a cargo de la investigadora Carolina Araya Ramírez, psicóloga y candidata a Doctor en Psicología de la Pontificia Universidad Católica de Chile. El objeto de esta carta es ayudarla a tomar la decisión de participar o no la presente investigación.

¿Cuál es el propósito de esta investigación?

Este estudio tiene por objetivo evaluar los efectos de un taller diseñado para desarrollar y fortalecer las habilidades de razonamiento espacial de los escolares chilenos a través del juego. En especial, interesa investigar de qué manera las actividades lúdicas propuestas, pueden favorecer la capacidad de los niños para imaginar y transformar objetos en su mente. Asimismo, interesa estudiar de qué manera este entrenamiento puede mejorar sus habilidades de pensamiento matemático.

¿En qué consiste su participación?

Si Ud. acepta participar, se le pedirá estar presente en las evaluaciones grupales de sus estudiantes de 2° básico, así como facilitar la evaluación individual de cada uno de ellos. Los niños serán evaluados en tres momentos: antes de empezar el taller, inmediatamente terminada la intervención y tres semanas después de haber finalizado la intervención. La evaluación grupal se realizará con todo el curso al mismo tiempo en su sala de clases y no dura más de 45 minutos. La evaluación individual será realizada por la investigadora o por una psicóloga educacional entrenada. Cada sesión de evaluación individual no debiera durar más de 45 minutos y se realizará en una sala dispuesta por las autoridades del colegio.

Asimismo, Ud. será invitada a participar como observadora a un Taller de 12 sesiones que se hará en horario de clases y en su presencia, en calidad de profesora jefe. Durante 4 semanas, y con una frecuencia de 3 sesiones semanales de 45 minutos cada una, los niños participarán en actividades lúdicas y grupales. Estas actividades fueron diseñadas con el fin de favorecer en los niños el desarrollo de algunas habilidades para razonar sobre el espacio (por ejemplo, girar en la mente algunas imágenes, aprender a leer mapas y localizar objetos o rutas, diagramar, componer estructuras etc.). El taller se realizará durante julio y agosto de 2017.

Si bien todo el curso llevará a cabo las actividades, se sortearán 5 grupos que serán filmados durante todas las sesiones. Estos videos serán analizados con posterioridad para estudiar los procesos de aprendizaje de estas habilidades. Eventualmente, algunos segmentos serán editados para ser presentados en futuras conferencias.

¿Cuánto durará la participación de sus estudiantes?

Implica participar en ***tres momentos de evaluación*****:** antes de empezar el taller, inmediatamente terminada la intervención y tres semanas después de haber finalizado la intervención. ***Cada fase de evaluación incluye***:

- Una sesión grupal de 45 minutos
- Una sesión individual de 45 minutos

El ***taller dura 4 semanas seguidas, con una frecuencia de 3 sesiones semanales de 45 minutos cada una***. Las sesiones se realizarán durante la jornada escolar entre julio y agosto de 2017.

¿Qué riesgos corren Ud. y sus estudiantes al participar?

No se estiman riesgos asociados a la participación de sus estudiantes ni a su participación como profesora.

¿Qué beneficios puede tener su participación y la de sus estudiantes?

Al participar, Ud. y sus estudiantes estarán contribuyendo a la generación de conocimiento respecto a estrategias efectivas para desarrollar habilidades de razonamiento espacial en el aula. Sin embargo, no habrá beneficio notorio e inmediato para usted o sus estudiantes. Con todo, ellos pueden beneficiarse del entrenamiento de habilidades tales como: incrementar velocidad para rotar imágenes mentalmente, construir estructuras de tres dimensiones a partir de planos bidimensionales y viceversa, imaginar objetos desde distintas perspectivas, incrementar capacidad de almacenamiento de memoria de trabajo viso-espacial, entre otras.

¿Qué pasa con la información y datos que usted y/o sus estudiantes entreguen?

Previa autorización del padre o apoderado y asentimiento del niño(a), las sesiones del taller serán grabadas en video y posteriormente serán transcritas por parte del equipo de investigación. Los registros de los test aplicados individual o grupalmente a sus estudiantes serán identificados con un pseudónimo para garantizar el anonimato. Su nombre, el de sus estudiantes o de su establecimiento educacional no será utilizado.

Los datos recogidos en las filmaciones y sus transcripciones serán digitalizadas y codificadas con una contraseña alfanumérica. Los registros serán guardados en la oficina de la investigadora responsable, almacenados en un lugar seguro al cual solo tendrán acceso las investigadoras a cargo del proyecto.

Los profesores y director(a) del establecimiento no tendrán acceso a los resultados individualizados de los estudiantes en ninguna de las pruebas aplicadas. Solo accederán a los puntajes promedios del curso, con el fin de darles un uso pedagógico, por ejemplo, para orientar ciertos objetivos de enseñanza.

Los resultados de esta investigación tendrán como productos informes de investigación, publicaciones y comunicaciones científicas donde podrán ser utilizados extractos de las sesiones filmadas sin que aparezcan datos de identificación personal suyos, de sus estudiantes o establecimiento educacional.

Usted tiene derecho a conocer los resultados finales del estudio. Si está interesado (a), usted puede escribir al correo del investigador principal y recibirá un informe resumen con los resultados agregados.

¿Yo y/o mis estudiantes estamos obligado a participar? ¿Podemos arrepentirse después de participar?

Tanto Ud. como sus estudiantes NO están obligado de ninguna manera a participar en este estudio. Si accede a participar, puede dejar de hacerlo en cualquier momento sin repercusión alguna para su relación con el establecimiento.

En cualquier momento usted puede solicitar a la investigadora que le responda todo tipo de inquietudes respecto al estudio y pedir mayor información sobre las implicancias de su participación.

¿A quién puede contactar para saber más de este estudio o si le surgen dudas?

Si tiene cualquier pregunta acerca de esta investigación, puede contactar a Carolina Araya Ramírez de la Escuela de Psicología de la Pontificia Universidad Católica de Chile. Su teléfono es el 9-1594894 y su email: carayar@uc.cl

Si usted tiene alguna consulta o preocupación respecto a sus derechos como participante de este estudio, puede contactar al Comité Ético Científico en Ciencias Sociales Artes y Humanidades de la Pontificia Universidad Católica de Chile al siguiente email: eticadeinvestigacion@uc.cl

HE TENIDO LA OPORTUNIDAD DE LEER ESTA DECLARACIÓN DE CONSENTIMIENTO INFORMADO, HACER PREGUNTAS ACERCA DEL PROYECTO DE INVESTIGACIÓN Y ACEPTO PARTICIPAR EN ESTE PROYECTO.
Recibo una copia del presente consentimiento informado.

Nombre de la participante: ____

Establecimiento: ____

_________________________________	________________________
Firma del/la Participante	Fecha
__________________________________	__________________________
Firma de la Investigadora	Fecha

(Firmas en duplicado: una copia para el participante y otra para el investigador)

Carta de autorización para Director(a) del Establecimiento.

Santiago, Agosto de 2016

Sr(a).

Director

<u>Presente</u>

Estimado(a) Sr(a) Director(a):

En calidad de investigador responsable me dirijo a usted para invitar a miembros de su escuela a participar en mi estudio "**Juego y razonamiento espacial: efectos de un taller para promover las habilidades de razonamiento espacial en el aula a través del juego."** Se trata de un proyecto de investigación doctoral financiado por la Comisión Nacional de Ciencia y Tecnología (Conicyt) con potencial impacto para el diseño de políticas educativas (diseño curricular, formación inicial docente, didáctica de las matemáticas y ciencias).

El proyecto considera la participación de profesores jefes y de los estudiantes de 2° básico. Supone contar con la autorización de los apoderados de los niños para que estos participen en el taller y con el asentimiento de los niños. Además, se requiere el consentimiento informado de los profesores jefes.

Las características del estudio se detallan en el anexo (Resumen ejecutivo del proyecto).

En lo que respecta a su autorización para que los miembros de su comunidad puedan participar en este estudio, se requiere contar con su apoyo para la realización de las siguientes acciones:

- Autorizar la realización de dos sesiones de entrenamiento semanal de 45 minutos cada una durante 6 semanas seguidas en ambos segundos básicos (aunque no en paralelo. Un curso tendría el taller el 2° semestre 2016 y el otro, el primer semestre 2017, cuando estén cursando 3°básico). En total serán 12 sesiones, a realizarse durante horario lectivo.
- Autorizar la realización de tres fases de evaluación (con actividades grupales e individuales, cuyas fechas y características se indican en el Resumen ejecutivo del proyecto)
- Facilitar la participación de los profesores jefes en las sesiones del Taller.

- Facilitar dependencias para evaluar individualmente a los niños antes y después de la intervención (dos semanas antes de iniciar el taller, inmediatamente terminado el entrenamiento y tres semanas después).

¿Qué pasa con la información y datos que entregue los estudiantes y/o sus padres?

Previa autorización del padre o apoderado y asentimiento del niño(a), las sesiones del grupo experimental serán grabadas en video y posteriormente serán transcritas por parte del equipo de investigación. Los registros de los test aplicados individual o grupalmente a los estudiantes, tanto del grupo control como experimental, serán identificados con un pseudónimo para garantizar el anonimato. El nombre de los estudiantes, padres, educadores y establecimiento educacional no será utilizado.

Los datos recogidos en las filmaciones y sus transcripciones serán digitalizadas y codificadas con una contraseña alfanumérica. Los registros serán guardados en la oficina de la investigadora responsable, almacenados en un lugar seguro al cual solo tendrán acceso las investigadoras a cargo del proyecto.

Es importante aclarar, que los profesores y director(a) del establecimiento no tendrán acceso a los resultados individualizados de los estudiantes en ninguna de las pruebas aplicadas. Solo accederán a los puntajes promedios del curso, con el fin de darles un uso pedagógico, por ejemplo, para orientar ciertos objetivos de enseñanza.

Los resultados de esta investigación tendrán como productos informes de investigación, publicaciones y comunicaciones científicas donde podrán ser utilizados extractos de las sesiones filmadas sin que aparezcan datos de identificación personal de los estudiantes, padres, profesores o establecimiento educacional.

Usted tiene derecho a conocer los resultados finales del estudio. Si está interesado (a), usted puede escribir al correo del investigador principal y recibirá un informe resumen con los resultados agregados.

Tal como se señaló previamente, para garantizar la correcta conducción del proyecto y cumplir con los requerimientos éticos de la investigación con personas, a todos los actores invitados a participar se les solicitará su consentimiento informado, y asentimiento informado en los casos en que sea pertinente, antes de involucrarlos en el estudio.

Frente a cualquier duda que le suscite la participación en este proyecto, Ud. podrá contactarse conmigo como investigador responsable (Carolina Araya Ramírez, teléfono 9-1594894, email: carayar@uc.cl) y/o con el Comité Ético Científico en Ciencias Sociales Artes y Humanidades de la Pontificia Universidad Católica de Chile, cuya presidenta es María Elena Gronemeyer. Email de contacto: eticadeinvestigacion@uc.cl

Si le interesa ser parte de este estudio, los iremos a visitar a su establecimiento para explicarles más detalles del proyecto y llevar consentimientos informados para los directivos, profesores, niños y sus padres. Le agradecería su respuesta vía correo electrónico a carayar@uc.cl, o al teléfono móvil 9-1594894. De esta forma podremos concertar una reunión durante las próximas semanas.

Agradezco de antemano la acogida y valioso apoyo que usted pueda brindar a este proyecto.

Saludos cordiales,

Carolina Araya Ramírez - Investigador Responsable

Pontificia Universidad Católica de Chile

AUTORIZACIÓN

Yo_____________________________________ Director de ______________________, autorizo y apoyo la participación de este establecimiento en el proyecto "**Efectos de un programa de intervención a través del juego para desarrollar habilidades de razonamiento espacial en niños de escolaridad básica".** El propósito y naturaleza de la investigación me han sido explicados por la investigadora responsable, Sra. Carolina Araya Ramírez.

Para efectos de dar curso a esta autorización, la investigadora responsable cuenta con la certificación previa de un Comité Ético Científico que corresponde de acuerdo a la normativa legal vigente.

La investigación constituirá un potencial aporte para el diseño de políticas educativas, por ejemplo, favoreciendo futuros diseños curriculares, formación inicial docente, didáctica de las matemáticas y ciencias, etc. Beneficiará directamente a los estudiantes de 2° básico en el desarrollo de habilidades de razonamiento espacial relevantes para el aprendizaje de matemáticas y ciencias.

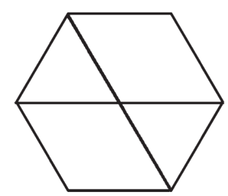
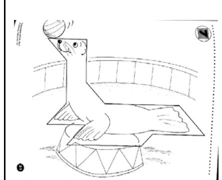
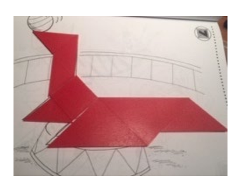
Me han quedado claras las implicancias de la participación de nuestro establecimiento en el proyecto y se me ha informado de la posibilidad de contactar ante cualquier duda a la investigadora responsable del estudio (Carolina Araya Ramírez, teléfono 9-1594894, email: carayar@uc.cl) o al el Comité Ético Científico en Ciencias Sociales Artes y Humanidades de la Pontificia Universidad Católica de Chile, cuya presidenta es la Sra. María Elena Gronemeyer. Email de contacto: eticadeinvestigacion@uc.cl

Nombre del Director: ____

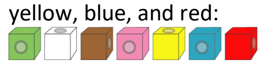
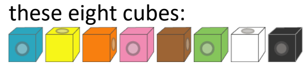
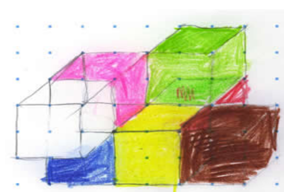
Firma del Director: ________________ Fecha: ______________________

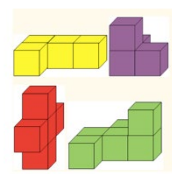
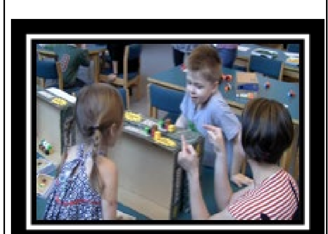
(Este documento se firma en duplicado, quedando una copia para el Director del Establecimiento y otra copia para el investigador responsable

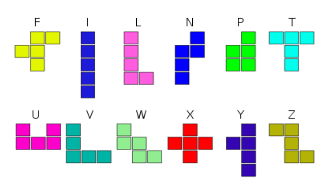
10.2 Appendix 2: Intervention Design

Session number	Title of session	Geometry and spatial skills targeted	Description	Source
1	Can you draw this?	VS working memory and short-term memory Visualisation Composing/descomposing 2D To understand conventions to represent 3D objects into 2D drawings Proportional reasoning Partitioning Space	Children were provided with pieces of paper with an outline of a square on it Children were then shown a geometric design composed within the square boundaries After viewing the design for 10 seconds, children attempted to re-create (using a pencil) the exact design within the boundaries of their own square Teachers facilitated discussions around strategies and different ways of remembering the designs	Math for Young children [M4YC] – University of Toronto, Based on Wheatley (1996) (Moss, Hawes, Naqvi, & Caswell, 2015; Hawes, Tepylo & Moss, 2015, Tzuriel & Egozi, 2010) 
2	Tangrams 1	Composing/descomposing 2D Spatial language Visualisation Spatial Transformations (mental and physical rotation; perspective-taking) Scaling (fill-in tasks)	Here children use a combination of tangram pieces to fill out contours that represent familiar objects drawn on the sheet. The contours help the children to use the imagination, because they must visualise the work once finished. Activities show the borders of each of the pieces that make up the drawing	Marschinke, J. & McDonell, J. (1997). *Tangramables, libro de actividades*. Learning Resources Pub. Vernon, Ilinois, USA. 
3	Tangrams 2	Composing/decomposing 2D Spatial language Visualization Spatial Transformations (mental and physical rotation; perspective-taking) Scaling (fill-in tasks)	The activities only offer the main outline, stimulating the children to apply what they know about the pieces of the tangram (length of the sides, size of the angles, etc.) and explore the different ways of manipulating them	
4	Shapes puzzle	Spatial Language VS working memory and short-term memory	The intention of this problem is that children will work together as a team. It should help in developing mathematical language about shape and position. This problem encouraged you to work as a group to discover all of the different shapes on the cards. Part of the challenge	http://nrich.maths.org Faculty of Education, University of Cambridge.

			was to describe the shapes (or part of them) on your own card and understand the explanation of others. In this way, you could work together to determine all of the different shapes in the Jig Shapes challenge. To begin with, give children time to look carefully at the shapes and part-shapes on their own cards and to describe what is on the card without showing them to others. After a suitable period of time, encourage them to ask each other about the other cards. The cards have been designed to join together like a jigsaw so that the pictures of the shapes are complete, but it may be better not to tell children this immediately. Instead, invite the group to find a way to organise or sort the cards. At this stage, members of the group can help each other find adjoining cards but discourage them from simply giving someone else their card. Encourage the children to describe the shapes they can see as the whole 'jigsaw' is built up.	
5	Symmetry	2D composition Location & orientation Symmetry Visualisation Spatial Transformations (mental and physical rotation; perspective-taking) VS working memory and short-term memory To design	The lesson has three distinct parts: In the first part, the teacher introduces the concept of symmetry through the cutting of folded symmetrical shapes. In the second part, the teacher (and a helper), work with the whole class using the large magnetic whiteboard to establish the concepts of symmetry and pattern building by modeling a paired- activity that the children will then play with a partner. In the third part, pairs of students will work together using the small magnetic trays to build symmetrical designs.	Math for Young children M4YC] - (St. Andrews Team) University of Toronto (Moss, Hawes, Naqvi, & Caswell, 2015; Hawes, Tepylo & Moss, 2015) 
6	Building with the	Spatial language comprehension	Children were given oral instructions in how to build a	Math for Young children M4YC]– University of Toronto

	mind's eyes	Visualisation Composition of 2D and 3D shapes Spatial Transformations (mental and physical rotation; perspective-taking) VS working memory and short-term memory Executive functions (inhibitory control, attention)	2D or 3D shape (e.g., “Take two blue cubes and attach them together, one on top of the other. Stand up the two attached cubes and make them look like a tower. Now take a red cube and attach it to ...”) Children built images of the shape in mind, based on instructions given. After giving instructions, teacher showed children multiple shapes and had children discuss/reason which one perfectly matched the description	(Moss, Hawes, Naqvi, & Caswell, 2015; Hawes, Tepylo & Moss, 2015)
7	Can you build this?	Visualisation Composing/decomposing 3D Spatial Language (expressive and comprehensive) VS working memory and short-term memory	A. You have seven cubes. They are green, white, brown, pink, yellow, blue, and red:  Now, try to make this building following these oral instructions: Start with the blue and yellow cubes. Put them next to each other. The blue cube is on the left. It is underneath a pink cube. Put the red cube just behind the yellow cube. Put the green cube on top of the red cube. Put the brown cube on the right of the yellow cube. Put the white cube in front of the pink cube. What does your building look like? Try to check with the projected image whether you did it correctly. B. Now make a building with these eight cubes:  Start with three cubes in a row. The centre cube is pink. The blue cube is on the right of the pink cube. The orange cube is on the left of the pink cube. The blue cube is also underneath a yellow cube.	Adaptated from http://nrich.maths.org Faculty of Education, University of Cambridge 

			Put the black cube behind the orange cube. Put the brown cube on top of the green cube and put them both behind the black cube. Finally, put the white cube on top of the orange cube. What does your building look like? Try to check with the projected image whether you did it correctly.	
8	Playing at being an architect	VS working memory and short-term memory To understand conventions to represent 3D objects into 2D drawings Spatial Transformations (mental and physical rotation; perspective-taking) To develop positional language	Here are some pictures of 3D shapes made from cubes. Can you make these shapes yourself? What do they look like from different positions?	http://nrich.maths.org Faculty of Education, University of Cambridge 
9	The world is upside down	Visualisation Composing/decomposing 3D VS working memory and short-term memory Spatial Transformations (mental and physical rotation; perspective-taking) Comparing Spatial Language (expressive and comprehensive)	Students are presented with a brief narrative about a world that gets flipped upside down. They are then given a small set of buildings that have been flipped upside down and are challenged to think about what the figures would look like right side up. They are provided with bags of their own cubes and take turns describing to one another how to re-build the structure right side up.	Math for Young children M4YC] - (Thorncliffe School Team) University of Toronto (Moss, Hawes, Naqvi, & Caswell, 2015; Hawes, Tepylo & Moss, 2015)
10	Barrier Game	Visualisation Composing/decomposing 3D Spatial Language (expressive and comprehensive) VS working memory and short-term memory Designing	The Barrier game requires a listener and a speaker, two identical sets of materials and a barrier such as a large book or science board. The materials for this particular game include the use of unfix cubes, although other manipulatives such as blocks, and Lego can be used. Each player has one set of identical cubes. Children should sit facing each other with the barrier between them. Explain to the children that they are going to play a game where they will take turns building a shape using cubes.	Math for Young children M4YC] - (Blantyre Team). University of Toronto (Moss, Hawes, Naqvi, & Caswell, 2015; Hawes, Tepylo & Moss, 2015) 

			Once the first child has finished building, they are to describe it to their partner so that he/she can build the identical shape. Children may be using spatial orientation language such as: above, below, to the side, left, right, behind etc. Once the second child has built the shape, remove the barrier and have the children identify if the shapes are the same. If they are simply rotated or flipped, but appear different to the children, ask them if they could move the second shape to make it look like the first. If it is completely different (error in explanation or understanding), ask the children what other words they could use to explain their shape if they were to do it again. You may want to start from the beginning and guide the child through their explanation. Play again, allowing the children to take turns describing their shapes.	
11	Looking for the castle's keys	Mental transformations (mental rotation, translations) Composing 2D Visualisation congruence/ non-congruence VS working memory and short-term memory Spatial reasoning	Narrative: Picture of princess (Kate) and prince (William). Witch appears on screen and puts spell on prince and locks him in castle. (Teacher touches screen and prince disappears). Good fairy appears and says that the princess can help free the prince by meeting the following challenge: unlocking 12 of the castle doors by creating 12 special keys (which will be pentominoes). Review the challenge with the students - for each of the 12 pentominoe shapes they create, they will receive a key (this is a plastic pentominoe form).	Math for Young children M4YC] - (Harrison/Thorncliffe Team) University of Toronto (Moss, Hawes, Naqvi, & Caswell, 2015; Hawes, Tepylo & Moss, 2015) 
12	The cubes' challenge	Composing 3D VS working memory and short-term memory	In this lesson students will be challenged to build unique 3-dimensional shapes using 3, 4,	Math for Young children M4YC] - (Blantyre Team)

		Spatial Transformations (mental and physical rotation)	or 5 interlocking cubes. Through teacher-led discussion students will come to the realization that certain 3D shapes are the same despite differences in their orientations. For example, a 3-dimensional 'L' shape can be made to look like a '7' if rotated 180°. As the student progress from building with 3 interlocking cubes to eventually building with 5 interlocking cubes, students will be increasingly challenged to think of the multiple combinations in which the interlocking cubes can be combined to create new and unique 3D figures.	University of Toronto (Moss, Hawes, Naqvi, & Caswell, 2015; Hawes, Tepylo & Moss, 2015)  Figure 6.18: Unique configurations that can be built using sets of 4 cubes.

10.3 Appendix 3: Spatial language (SL) code scheme

10.3.1 In English (developed by Cannon, Levine, & Huttenlocher (2007).

A. Spatial Dimensions

Definition: Words that describe the size of objects, people, and spaces.

Parameters/Notes: We do not include references to weight or density because they refer to dimensions that do not have a tangible presence in the 2D or 3D world. References to standard measurement units, although closely related to this category, were included under Category E (Continuous Amount).

Concept *Terms that refer to:*	**Words**	**Additional forms**
"unconstrained" spatial dimensions (i.e., these words can refer to length, height, or both dimensions)	Big Little Small Large Tiny Enormous Huge Gigantic Teeny Itsy-bitsy Itty-bitty	 -er, -est – er, -est -er, -est -er, -est -er, -est
only horizontal or vertical extent	Long Short	-er, -est
only vertical extent	Tall	-er, -est
only horizontal extent	Wide Narrow Thick Thin Skinny Fat	-er, -est -er, -est -er, -est -er, -est -er, -est -er, -est
only vertical or horizontal extent of a 3D object/ space	Deep Shallow	-er, -est -er, -est
only internal extent of an, at least partially, enclosed 3D object/ space	Full Empty	-er, -est -er, -est

the superordinates of the above	Size Length Height Width Depth Volume Capacity Area (as in of a square) Measure	-s -s -s -s -s -s -s -s -s, -ment(s)

B. Shapes

Definition: Words that describe the standard or universally recognized form of enclosed two- and three-dimensional objects and spaces.

Parameters/Notes: This list does not include words that describe portions of shapes (e.g., lines, arcs, etc.) – those are included in Category G (Spatial Features and Properties). We also did not include words such as "heart" and "star" because it is unclear whether individuals encode these words as referring to the shape of the object or its identity. In addition, we do not include usages such as "ice cream *cone*" & "ice *cube*" because they do not always have the standard form of these shapes (e.g., the cone portion of an ice cream cone can be conical or the shape of a cylinder, an ice cube is still an ice cube even if it is only part of a cube or if it is distorted as a result of melting).

Concept *Terms that refer to:*	**Words**	**Additional forms**
2D enclosed shapes that do not have any sides or angles or do not have all straight sides	Circle Oval Ellipse Semicircle	-s -s -s -s
2D shapes with at least 3 straight sides and angles	Triangle Square Rectangle Diamond Pentagon Hexagon Octagon Parallelogram Quadrilateral Rhombus Polygon	-s -s –s -s -s -s -s -s -s -s

3D shapes	Sphere Globe Cone Cylinder Pyramid Cube Rectangular Prism	-s -s -s -s -s -s -s
the superordinate of above	Shape	-s

C. Location and Direction

Definition: Words that describe the relative position of objects, people, and points in space.

Parameters/Notes: This is our largest category and includes terms that function in numerous parts of speech. The reader should refer to the parameters section of Category G (Spatial Features and Properties) as some terms are included in both that category and here.

Concept *Terms that refer to a position (or movement towards a position) that is:*	**Words**	**Additional forms**
the noun that follows the term (in the case of "from" the reference is to movement *away* from the noun)	At To From	-ward(s)
resting/ not resting along a surface (including an "invisible" surface that is a boundary of a space such as in "on the side" and "on the bottom")	On Off	-to, up-
within or outside of the boundaries of an area or confines of a volume	In Out (of)	-to, -side, with- -side
along a vertical axis (in the case of "top" and "bottom" this includes the intrinsic vertical axis of the object/ person)	Under Beneath Below Over Above Up Down (On) top Bottom High	neath -er, -ward -er, -ward -er, -est – er, -est -s -ly

	Low Column Vertical	
along a horizontal axis (in the case of “front”, “back”, “left”, and “right” this includes the intrinsic horizontal axis of the object/ person)	Left Right (In) front (In) back Ahead Behind Sideways Row Horizontal	-ward – ward -s –ly
proximal/ distal to another point	By Near Close Next to With Beside Far Away Beyond Further Past Against Together Separate Join Apart	-by, -er,-est -er, -est -er, -est -d -d
defined with respect to the location of at least two other object/ people/ points	Between Among	
an equal distance from the extremities of something	Middle Center	
in the broad vicinity of another point	About Around Throughout	
defined with respect to the length of an object/ person/ point	Along Lengthwise	
in a cardinal direction	North South East West	-ern – ern -ern -ern
from one side to another side of (or circumvents) another object/ person/ point	Around Through	
on the (other) side of another object/ person/ point	Across Over Opposite	

	Aside Reverse	
defined by the direction that an object/person/point/plane is oriented	Around Reverse Back *(verb)* Backward Forward Parallel Perpendicular Diagonal Down (as in “down the street”) Up (as in “up the street”)	-d
the superordinates of above	Location Position Direction Route Path Head Place Distance	-s -s -s -s -s -s, -d, -ing -s -s

D. Orientation and Transformation

Definition: Words that describe the relative orientation or transformation of objects and people in space.

Parameters/Notes: Theoretically, many verbs would fall into this category (i.e., any verb that encodes the direction or location of movement). A common distinction in the literature is between manner verbs and path verbs (with path verbs often thought of as not requiring a preposition to describe the direction of motion). However, we have found that there is much debate, both in the literature and amongst ourselves, about what verbs can be considered path verbs and can be considered to carry spatial meaning. For example, some define “turn” as a path verb (it describes movement around an axis), others a manner verb (a preposition such as “around” or “over” clarifies which axis). “Swim” is clearly a manner verb in the path vs. manner distinction, yet it implies that the person swimming is in, not outside, of water. “Jump” and “bounce” encode manner and path. At the moment, because we have not reached consensus on which verbs are and are not spatial, we do not code them in our system. We explicitly state this as a limitation in all of our papers on our current work; we hope in the future to rectify this limitation. The transformation verbs listed below are the *only* ones we currently count in our coding system because, when creating the coding system, we were particularly interested in language relevant to object transformations around an axis.

Concept *Terms that refer to:*	**Words**	**Additional forms**
the orientation of an object or person	Upside down Right side up Upright	
the superordinate of the above	Orientation	-s
a transformation around an axis	Turn Flip Rotate	-s, -ed, -ing -s, -ed, -ing -s, -ed, -ing
the superordinate of the above	Rotation	-s

E. Continuous Amount

Definition: Words that describe amount (including relative amount) of continuous quantities (including extent of an object, space, liquid, etc.).

Parameters/Notes: We did not include in our analyses of these terms' references to discrete quantities (e.g., "some cookies"). We also do not include continuous quantities that refer to non-spatial dimensions (e.g., time, temperature, weight, money, etc.).

Concept *Terms that refer to:*	**Words**	**Additional forms**
the entire amount of a continuous object or space	Whole All	-s
an exact part of a continuous object or space	Half Third Quarter Fifth Sixth Seventh Eight Ninth Tenth *Etc.*	-s -s -s -s -s
the absence of a continuous amount	None	
a comparison between continuous amounts	More Less Same Equal	

standard spatial measurement units	Inch Foot Mile Centimeter Meter *Etc.*	-s -s -s -s -s
the superordinates of above	Amount Room Space Area (as in "space")	-s -s -s -s

F. Deictics

Definition: Words that are place deictics/ pro-forms (i.e., these words rely on context to understand their referent).

Concept *Terms that refer to:*	**Words**	**Additional forms**
the location of the speaker	Here	
a location other than that of the speaker	There	
a request for identification of a location	Where	
no, any, some, or all location(s)	Anywhere Somewhere Nowhere Everywhere Wherever	

G. Spatial Features and Properties

Definition: Words that describe the features and properties of 2D and 3D objects, spaces, people, and the properties of their features.

Parameters/Notes: Some of the words on this list are also on the list of terms pertaining to category C (Location and Direction). The distinction is that they are coded as being a member of the current category if they are referring solely to the features/ properties of a single shape or space (e.g., "parallel sides of a square"). If they are used to refer to the relation between two or more objects, spaces, or people they would be coded as a member of Category C (e.g., "the river runs parallel to our house"). In addition, it should be noted that terms such as top and bottom, although often used to refer to a feature of a shape (e.g., “the top of the box”), are coded under category C.

Concept *Terms that refer to:*	**Words**	**Additional forms**
the flat surface of an object	Side Edge Border Line	-s, -d -s, -d -s, -d -s
curvature of an object or the curved portion of an object	Round Curve Bump Bent/d Wave Lump Arc Sector	-er, -est, -ed -s, -ed, -y -s, -ed, -y -d, -s, -ed, -y -s, -y -s, -y -s -s
lack of curvature of an object	Straight Flat	-er, -est -er, -est
the place where two or more sides of an object meet	Angle Corner Point	-s -s -s, -ed, -y
a surface of a 3D object	Plane Surface Face	-s -s -s
having the form of standards shapes, or in the case of “shaped” used with an object noun to describe the outline of a 2D or 3D shape or space (e.g., “heart-shaped”)	Circular Rectangular Triangular Conical Spheric Elliptical Cylindric Shaped	-al -al
the orientation of an element of a 2D or 3D shape or space	Horizontal Vertical Diagonal Axis	-s -s
the relation between elements (e.g., sides, halves) of 2D or 3D shapes or spaces	Parallel Perpendicular Symmetry	-ic(al)

I. Pattern

Definition: Words that indicate a person may be talking about a spatial pattern (e.g., big, little, big, little, etc. or small circle, bigger circle, even bigger circle, etc.).

Parameters/Notes: As opposed to most of our other categories, there is not a clear-cut list of words that pertain to patterns. The following words help identify where pattern discussion **may** occur. However, we have found that if a child, parent, or early childhood teacher is talking about patterns, they often use one of these words. We do not include here numeric patterns (e.g., 1, 3, 1, 3) or patterns of non-spatial dimensions (e.g., light gray, gray, darker gray, etc.)

Concept *Terms that refer to:*	**Words**	**Additional forms**
a spatial array having a consistent regularity or rule to its organization	Pattern Design Sequence Order	-s -s -s -s
the relative location of an element in a patterned spatial array	Next First Last Before After	
the type of organization of a patterned spatial array	Repeat (repetition) Increase Decrease	-s, -ed, -ing -s, -ed, -ing -s, -ed, -ing
the superordinates of above	Pattern Design Sequence Order	-s -s -s -s

10.3.2 In Spanish

Conceptos Espaciales	**Código & Descripción** Términos que refieren a:	**Palabras**	**Ejemplos**
A. **Spatial Dimensions:** <u>Words that describe the size</u> of objects, people, and spaces. NOTA: No incluimos referencias a peso o densidad porque se refieren a dimensiones que no tienen una presencia tangible en el mundo 2D o 3D. Las referencias a las unidades de medida estándar, aunque estrechamente relacionadas con esta categoría, se incluyeron en la Categoría E (cantidad continua).	A.1. Dimensiones espaciales "no restringidas" (es decir, estas palabras pueden referirse a longitud, ancho o ambas dimensiones)	Grande Pequeño Chico Diminuto Minúsculo Enorme Gigantesco	"después la grande"
	A.2. En extensión horizontal o vertical	Largo Corto	
	A.3. Solo en extensión vertical	Alto (bajo?)	
	A.4. solo en extensión horizontal	Ancho, estrecho, grueso, delgado, flaco, gordo	
	A.5. la extensión vertical u horizontal de un objeto/espacio 3D	Profundo Superficial	
	A.6. Solo referido a extensión interna de un objeto /espacio 3D cerrado, al menos parcialmente	Lleno Vacío	
	A.7. Categorías generales o inclusivas (superordinate) de los anteriores	Tamaño Longitud Altura Anchura Profundidad Volumen Capacidad Área (como en un cuadrado) Medida	
B. ***Shapes***: Words that describe the standard or universally recognized form of enclosed two- and three-dimensional objects and spaces. NOTA: Esta lista no incluye palabras que describan partes de formas (por ejemplo, líneas, arcos, etc.), que se incluyen en la Categoría G (Características espaciales y Propiedades). Tampoco incluimos palabras como "corazón" y "estrella"	B.1. Figuras 2D encerradas, que no tienen lados ni ángulos, ni tienen todos los lados rectos	Círculo Ovalo Elipse Semicírculo	
	B.2. Figuras 2D con al menos 3 lados y ángulos rectos	Triángulo Cuadrado Rectángulo Diamante Pentágono Hexágono Octágono Cuadrilátero Rombo Polígono	"ahora va el *cuadrado*" "ese que se parece al diamante ponla ahí
	B.3. Forma/cuerpos 3D	Esfera	

porque no está claro si los individuos usan estas palabras como referencias a la forma del objeto o su identidad. Además, no incluimos usos como "cono de helado" y "cubo de hielo" porque no siempre tienen la forma estándar de estas formas (por ejemplo, la parte del cono de un helado puede ser cónica o la forma de un cilindro. Un cubo de hielo sigue siendo un cubo de hielo, incluso si es solo parte de un cubo o si está distorsionado por haberse derretido)		Globo Cono Cilindro Pirámide Cubo Prisma rectangular	
	B.4. Categorías generales o inclusivas (superordinate) de los anteriores	Forma Figura	
C. *Locations and Directions*: (UBICACION) Words that describe the relative position of objects, people, and points in space. Términos que se refieren a una posición (o movimiento hacia una posición). NOTAS: Esta es la categoría más grande e incluye términos que funcionan en numerosas partes del discurso. El codificador debe consultar la sección de parámetros de la Categoría G (Características espaciales y Propiedades) ya que algunos términos están incluidos en esa categoría y aquí.	C.1. el sustantivo que sigue al término (en el caso de "desde" la referencia es al movimiento hacia fuera (away) del sustantivo)	En Hacia A Desde	
	C.2. Apoyado/no apoyado a lo largo de una superficie (incluida una superficie "invisible" que es un límite de un espacio como "en el lado" y "en el fondo")	Sobre En	
	C.3. Dentro o fuera de los límites de un area, o de los confines de un volumen	En Fuera de Adentro Afuera Interior Exterior Encajado*	"así no *encaja*"
	C.4. A lo largo de un eje vertical	Arriba Abajo Debajo Encima Superior Inferior Fondo Alto Bajo Columna Vertical Levantado* Parado*	"o algo levantado para allá *arriba*, [gesto ve verticalidad] no cierto?" "no va así, *parado*, mira"

	C.5. A lo largo de un eje horizontal	Izquierda Derecha Al frente Detrás Adelante Atrás Lateral Costado Oblicuo Lado Fila Horizontal	"se parece cuando fuimos al MIM con el tío, se acuerdan cuando se vayan pa atrás y se ve"
	C.6. Proximal/Distal de otro punto	Por Cerca (de) Con Junto a Lejos Más allá Adelante Anterior Posterior Opuesto Juntos Separados Unidos Aparte	
	C.7. Definido con respecto a la locación de al menos 2 objetos, personas o puntos	Entre Entre medio	
	C.8. En una dirección cardinal	Sur Norte Este Oeste	
	C.9. De un lado a otro o circunvalando un objeto, persona o punto	Alrededor A través	
	C.10. Una distancia igual a los extremos de algun objeto	Centro Al medio	
	C.11. en las proximidades de otro punto	Acerca de Alrededor A través de	
	C.12. En el otro lado de un objeto, persona o punto	Al frente Cruzando Opuesto Reverso Al revés	"Y después el otro va, *al revés*" "tú no trabajai conmigo, tú trabajai con *en frente"*
	C.13. Definido por la dirección en que	Aproximado Reverso	

	está orientado un objeto, persona, punto, plano	Retroceder (verbo) Hacia atrás Adelante Paralela Perpendicular Diagonal Abajo (como en "calle abajo") Arriba (como en "calle arriba")	
	C.14. Categorías generales o inclusivas (superordinate) de los anteriores	Ubicación Posición Dirección Ruta Camino Encabezado Lugar Distancia	
D. ***Orientations and Transformations***: Words that describe the relative orientation or transformation of objects and people in space. NOTA: lenguaje relevante para las transformaciones de objetos alrededor de un eje.	D.1. Orientación de un Objeto o Persona	Boca abajo Boca/patas arriba	
	D.2. Categorías generales o inclusivas (superordinate) de los anteriores	Orientación	
	D.3. Transformación alrededor de un eje	Girar (turn) Rotar Dar la vuelta (flip) Voltear Deslizar, resbalar *(slide) Trasladar (translation)* Enderezar*	"se parece a un limón, pero girado [gesto con brazos abiertos + inclinación corporal] "si lo *day vuelta*, se parece a un limón [rotación de material]
	D.4.Componer/descomponer/recomponer[6]	Separar Juntar Reunir Volver a juntar Encajar (esta parte va en dentro de otra)	
	D.5. Categorías generales o inclusivas (superordinate) de los anteriores	Rotación	
E. ***Continuous Amount***: Words that describe amount (including relative amount) of continuous quantities (including extent of an	E.1. la cantidad total de un objeto o espacio continuo	Todo Completo	
	E.2. Una parte inexacta de un objeto o espacio continuo	Parte Pieza Sección	

[6] Añadido por Araya, C. (2018)

object, space, liquid, etc.). NOTA: No incluimos en nuestros análisis de estos términos referencias a cantidades discretas (por ejemplo, "algunas cookies"). Tampoco incluimos cantidades continuas que se refieren a dimensiones no espaciales (por ejemplo, tiempo, temperatura, peso, dinero, etc.).		Poco Segmento Parte Fragmento Fracción Algunos Un poco Mucho Suficiente	
	E.3. Una parte exacta de un objeto o espacio continuo	Mitad Tercio Cuarto Quinto Sexto Etc.	
	E.4. Ausencia de una cantidad continua	Ninguno Nada	
	E.5. Una comparación entre cantidades continuas	Mas Menos Lo mismo Igual	
	E.6. Unidades estándares de medición espacial	Centímetros Metros Kilómetros	
	E.7. Categoría superior o inclusiva de lo anterior	Cantidad Espacio Cupo/cabida Area	
F. ***Deictics***: Words that are place deictics/ pro-forms (i.e., these words rely on context to understand their referent). NOTA: Deíctico refiere al señalamiento a una per sona, un lugar o un tiemp o, o a una expresión lingüística mediante cie rtos elementos gramaticales (RAE).	F.1. Referente: la ubicación del hablante	Aquí	
	F.2. Referente: la ubicación de otro distinto al hablante	Allá	
	F.3. Solicitud para identificar una ubicación	¿Dónde?	
	F.4. Ninguna, alguna o todas las ubicaciones	En cualquier sitio Algun lado En ninguna parte En todos lados Donde sea	
G. ***Spatial Features and Properties***: Words that describe the features and properties of 2D and 3D objects, spaces, people, and the properties of their features. NOTA: Algunas de las palabras en esta lista también están en la	G.1. La superficie plana de un objeto	Lado Borde Frontera Línea	
	G.2. Curvatura de un objeto o parte curva de un objeto	Redondo Curvo Bache Doblado Onda Bulto Chichón Arco	

lista de términos pertenecientes a la categoría C (Ubicación y Dirección). La diferencia es que están codificados como miembros de la categoría actual si se refieren únicamente a las características / propiedades de una sola forma o espacio (por ejemplo, "lados paralelos de un cuadrado"). Si se usan para referirse a la relación entre dos o más objetos, espacios o personas, se codificarían como miembros de la Categoría C (por ejemplo, "el río corre paralelo a nuestra casa"). Además, debe tenerse en cuenta que los términos superior e inferior, aunque a menudo se utilizan para referirse a una característica de una forma (por ejemplo, "la parte superior de la caja"), están codificados en la categoría C.		Sector	
	G.3. Falta de curvatura de un objeto	Tiezo Recto Liso Plano	
	G.4. El lugar donde 2 o más lados de un objeto se encuentran	Ángulo Esquina Punto	
	G.5. La superficie de un objeto 3D	Plano Superficie Cara	
	G.6. Tiene la forma de una forma estandar (adjetivo que acompaña un sustantivo)	Circular Rectangular Triangular Cónico Esférico Elíptico Cilíndrico Formateado	
	G.7. Orientación de un elemento de una figura o espacio 2D o 3D	Horizontal Vertical Diagonal Eje	
	G.8. Relación entre elementos (lados, mitades) deformas o espacios 2D o 3D	Paralelo Perpendicular Simetría	Ej simetría: “es lo mismo a ambos lados”, “es lo mismo que la otra mitad” “es lo mismo que al otro lado”
H. ***Pattern***: Words that indicate a person may be talking about a spatial pattern (e.g., big, little, big, little, etc. or small circle, bigger circle, even bigger circle, etc.).	H.1. Arreglo espacial que tiene una regularidad consistente o regla en su organización	Patrón Diseño Secuencia Orden	
	H.2. Ubicación relativa de un elemento en un arreglo espacial	Junto a Primero Al Final Antes Después	
	H.3. El tipo de organización de un arreglo espacial de patrones	Repetir Incrementar, aumentar Disminuir	
	H.4. Categoría inclusiva de las anteriores	Patrón Diseño Secuencia Orden	