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Parental Spatial Input During Parent-Child Interactions: A Two-Dimensional versus a Three-Dimensional Learning Experience

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by

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Abstract

Children's spatial ability is predictive of their future achievement in many academic and occupational domains, including science, technology, engineering, and mathematics (STEM; e.g., Wai at el., 2009). During the early years, experiences such as hearing spatial language (e.g., Ferrara et al., 2011) and engaging in spatial activities with three-dimensional (3D) blocks or puzzles (e.g., Casey et al., 2008) are found to facilitate children's spatial learning. Other than 3D toys, the use of two-dimensional (2D) touchscreen media (e.g., iPads®) by young children has been on the rise (e.g., Rideout, 2013). Technology has become part of children's daily activities and a tool to promote language learning (e.g., Penuel et al., 2009). However, there is a dearth of research specifically investigating the nature of parent-child interactions and children's spatial learning using digital mobile devices. Therefore, the present study examined the frequency and variation of parental linguistic input elicited during play using an iPad® (a 2D touchscreen device) and using 3D spatial toys.

In addition to the types of spatial learning (3D versus 2D), factors such as parents' spatial anxiety and attitudes towards math can also influence their spatial language production. Research suggests that one's attitude or anxiety towards mathematics can influence the amount of numeracy talk in which individuals engage (e.g., Gunderson et al., 2013). However, no studies have examined the relationship between spatial anxiety and spatial talk. The present study examined whether the amount of parental spatial talk was influenced by their attitudes towards math, spatial anxiety.

The present exploratory study has three objectives: (i) to examine the frequency and variation of parental spatial language during 3D spatial toys versus 2D iPad® visual-spatial applications interactions with their preschoolers, (ii) to investigate whether parental spatial input (i.e., language and activities) predicts children's spatial knowledge, and (iii) to explore the role of parental spatial anxiety and attitude towards mathematics on their spatial language input. Thirty-four 3- to 5-year-old children and their parents participated in interaction with 3D and 2D spatial learning media at two home visit sessions. Math and spatial activities engaged by the dyads at home, parental level of spatial anxiety, and attitude towards math were assessed. Children were tested with the Woodcock Johnson III Tests (Woodcock et al., 2001) for spatial, math, language competencies, and working memory capacity. Their spatial abilities were also assessed via 3D Mega Blocks© Test of Spatial Assembly (TOSA; Verdine et al., 2014). The sessions were videotaped, transcribed, and coded for the frequency and variation of spatial talk produced by parent-child dyads. Results revealed that parents used more spatial talk with regards to spatial dimensions in 3D interaction and more orientations and transformations during 2D interaction, yet the total frequency and variation of parental spatial talk did not differ between 3D and 2D interaction. As parents engaged in a relatively infrequent spatial talk (6% in 3D talk and 5% in 2D talk), the frequency of parental spatial input was not predictive of preschoolers' spatial language production, which led to a minimal effect on their spatial competence. Furthermore, parental levels of spatial anxiety and attitudes toward math were not related to the amount of parental spatial input produced during parent-child interactions.

The present study underscores the importance of supporting parents with pointers on how to instill spatial talk and activities with their preschoolers. Implications on the use of 3D and 2D learning media are discussed.

Keywords: 2D versus 3D learning, block and puzzle play, early spatial development, mobile technology, parent-child play interactions, preschoolers, spatial input, spatial language

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Spatial abilities, such as the ability to locate objects or navigate space, are fundamental for individuals to function in the physical world. People who lack spatial abilities may have difficulty directing and locating things, are worse at reading and interpreting graphic representations such as bar graphs, and struggle to visualize the relationships between different physical objects in the surrounding environment (Basham & Kotrlik, 2008; Newcombe, 2010; Newcomer, Raudebaugh, McKell, & Kelley, 1999; Strong & Smith, 2001). On the other hand, individuals who exhibit a higher level of spatial proficiency have been found to perform better than those with lower spatial skills in many academic domains and career fields (e.g., Shea, Lubinski, & Benbow, 2001).

According to the National Council of Teachers of Mathematics (NCTM, 2000; 2006), geometry and spatial sense is one of the mathematical domains that is essential for children to acquire before entering formal schooling. Geometry refers to the ability to describe the physical world with geometric elements such as shapes, sizes, direction, and position of objects. Spatial sense builds up geometric knowledge and is comprised of one's awareness and ability to process non-linguistic information (Kersh, Casey, & Young, 2008) about spatial orientation, spatial relation, as well as visualization. Specifically, spatial orientation is considered the ability to locate objects in the world, spatial relation is the ability to determine relationships between objects, and visualization is the ability to manipulate objects mentally (Linn & Peterson, 1985). In the present study, the term spatial ability was used interchangeably with spatial skills, spatial sense, spatial cognition, spatial reasoning, and spatial thinking.

Proficiency in geometry and spatial ability has important implications for children's academic achievement. For instance, better spatial skills are predictive of higher IQ scores (Smith, 1964), better cognitive capacity (e.g., Kaufman, 2006), achievement in many aspects of mathematical abilities (Clements & Sarama, 2007; Newcombe, 2010; Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2014), later academic performance, and are linked to future success in science, technology, engineering, and mathematics (STEM) fields (Newcombe, 2010; Shea et al., 2001; Wai, Lubinski, & Benbow, 2009; Wolfgang, Stannard, & Jones, 2001). Finding from a hierarchical structure analyses, spatial abilities have been found to strongly relate to intelligence, particularly fluid ability (Colom, Contreras, Botella, & Santacreu, 2002). Spatial factors, such as spatial visualization and spatial orientation, also load heavily on general intelligence (Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001; Smith, 1984).

Evidence of the relationship between one's working memory and spatial ability also suggests that a limited working memory capacity is predictive of lower levels of accuracy in a spatial folding task (Salthouse, Mitchell, Skovronek, & Babcock, 1989).Also, both the storage and processing components of working memory are related to one's performance on spatial visualization and mental rotation tasks (Kaufman, 2006; Shah & Miyake, 1996). Further, spatial knowledge, spatial cognition, as well as mental rotation skills have been shown to correlate with performance on arithmetic, geometry, and word problems in both high school and university students (Delgado & Prieto, 2004; Geary, Saults, Liu, & Hoard, 2000). These skills are also correlated with individuals' performance on a chemistry course, especially for students majoring in science and engineering (Carter, LaRussa, & Bodner, 1987). Overall, a higher level of spatial ability during early adulthood leads to engagement and achievement in occupational fields involving STEM in later adulthood (Shea et al., 2001). Therefore, it is evident that fostering one's spatial ability during the early years has important implications for one's future success in many ways.

During the early years, experiences such as hearing spatial language and engaging in spatial activities have both been found to facilitate spatial learning and performance on spatial tasks in young children (Casey et al., 2008; Levine, Ratliff, Huttenlocher, & Cannon, 2012). For instance, hearing spatial language, such as "The shovel is *underneath* the flower pot *by* the dresser," was found to be beneficial for children between ages of three to four years, especially when they were asked to look for an object in an unfamiliar room (Plumert & Nichols-Whitehead, 1996). Certainly, talking about spatial concepts, such as spatial features, relations, and orientations, is useful for children to acquire spatial ideas (Levinson, Kita, Haun, & Rasch, 2002; Munnich, Landau, & Dosher, 2001). Pruden, Levine, and Huttenlocher (2011) conducted a study to examine the relations between parental spatial language input, children's spatial language production, and children's later spatial abilities. Their findings suggest that the amount of spatial language produced by young children is associated with parents' spatial input. Further, children's spatial language production is predictive of non-verbal spatial tasks involving spatial transformation and block design (Pruden et al., 2011).

Other than spatial language, engaging in spatial activities involving blocks and puzzles is also suggested to be beneficial for children's spatial learning. Casey and colleagues (2008) suggest that block play for children between four- to six-years-old is predictive of their subsequent spatial skills. Levine and colleagues (2012) also suggest that children's engagement in puzzle play has a significant influence on their early development of spatial abilities, even at as young as two years of age (Levine et al., 2012; Verdine et al., 2014; Wolfgang, Stannard, & Jones, 2003). Other spatial activities, such as making a map of children's surroundings and incorporating landmarks around the room (e.g., desks, posters), help them to apply their understanding from a two-dimensional map onto an area in the real world (Pollman, 2010).

In addition to its significant impact on children's spatial learning, construction play involving blocks and puzzles was found to be related to parents' spatial language input. Previous research has shown that engaging in spatial activities such as block play especially stimulates the production of spatial language in both the parent and the child compared to other non-spatial activities (e.g., reading story books, having lunch) engaged at home, as spatial language occurs simultaneously and can be naturally elicited during block play (Ferrara et al., 2011). Further, integrating spatial-related talk into daily activities, such as explaining the spatial relationship between two objects during storybook reading, is also linked to higher performance on spatial-representation tasks (Szechter & Liben, 2004).

Spatial activities engaged in by parent-child dyads involving blocks and puzzles occur in a three-dimensional (3D) context. Specifically, these toys are three-dimensional, which can be physically touched, rotated, and transformed. Research suggests that through playing with 3D toys, children are essentially provided with two types of stimuli (i.e., physical and visual) as they are allowed to physically manipulate and visually observe the toys (Siegal & White, 1975). It is also suggested that 3D spatial activities naturally elicit more spatial language from parents (e.g., Ferrara et al., 2011; Hengeveld et al., 2009; Raffle, 2008). Additionally, a number of studies indicate that 3D learning experience could potentially be more beneficial for children to understand and further apply their spatial learning to real life scenarios (e.g., Lehnung et al., 2003; McComas, Pivik, & Laflamme, 1998; Waller, 2000). This is because they are allowed to explore and move around their surrounding environment and make inferences about real world objects through what they see and experience. In addition, they are more likely to understand the spatial representation and relation of objects, and further develop a systematic spatial scheme for the three-dimensional world (e.g., Lehnung et al., 2003).

Other than the use of 3D toys, children's exposure to two-dimensional (2D) screen media, namely televisions, smartphones, and touchpad devices has become more prevalent among young children (DeLoache & Chiong, 2009; Zimmerman, Christakus, & Meltzoff, 2007a). Rideout (2013) conducted a nation-wide survey in the United States suggesting that 40% of children under the age of eight have access to these 2D devices including iPads® and smartphones. Given the increase in the use of these 2D devices, it is suggested that there could be a possible shift for parents and their young children to spend more time interacting with two-dimensional (2D) touchpads such as iPads® rather than three-dimensional tangible toys such as blocks (e.g., Sigman, 2012). Thus, researchers have begun to investigate whether these 2D learning platforms could effectively facilitate children's development and learning (e.g., Sutton, 2006), especially in the spatial domain. Touchpad devices are considered two-dimensional because information is presented on a screen and children cannot directly touch or manipulate the object presented. Previous studies indicate that during 2D learning, children are only provided with visual stimuli (e.g., Silverman, 2002) and the parents may also engage in less spatial language input (e.g., Beschorner & Hutchison, 2013). Therefore, it may be more challenging for children to apply their learning from a 2D source to a real environment, which is 3D. Parental input, such as the use of spatial language, is vital during children's spatial learning (Verdine et al., 2014). A few studies have investigated whether playing with 2D toys elicits a similar amount, or more spatial language in parents than playing with 3D tangible toys. Therefore, one of the objectives in the present study examined and compared the nature of spatial language elicited during 3D and 2D learning experience to determine whether one type of experience is more conducive to children's spatial learning than the other.

As early spatial ability is heavily related to one's future success in a variety of ways (e.g., Shea et al., 2011) and has been found to remain stable throughout adulthood (e.g., Delgado & Prieto, 2004; Poltrock & Brown, 1984), it is important to explore and examine factors that influence parental spatial input during interactions with their young children. In addition to the two types of spatial learning experiences (3D and 2D), parental factors such as socio-economic status (SES), parental level of spatial anxiety, and their attitudes towards mathematics could possibly be contributing to the amount of spatial input, especially spatial language, during parent-child interactions (e.g., Farrant & Zubrick, 2013; Ferrara et al., 2011; Verdine et al., 2014; Thompson & Williams, 2006). Familial SES is often determined by maternal levels of education, a proxy of SES, as a number of studies have shown that it is a good predictor of children's learning and achievement throughout school years (e.g., Catts, Fey, Zhang, & Tomblin, 2001; Hess, Hollway, Dickson, & Price, 1984; Magnuson, 2007). Mothers who have a lower education attainment were found to use fewer communicative cues, lower levels of joint attention, produce less spatial language, and engage in less spatial activities when interacting with their children, and this is seen in children as young as three years of age (Dearing et al., 2012; Farrant & Zubrick, 2013; Ferrara et al., 2011; Thompson & Williams, 2006; Verdine et al., 2014). It is important to introduce children to spatially-rich environments involving more exposure to spatial language and activities, in order to minimize the effect of SES (Verdine et al., 2013).

It is widely acknowledged that individuals' performance on one academic subject is highly related to their attitudes toward that particular subject. For example, individuals who have higher levels of math anxiety in high school and university perform worse on math tests (Eccles

& Wigfield, 2002; Meece, Wigfield, & Eccles, 1990). Further, parents' perceptions on mathematics are linked to their children's subsequent mathematical achievement (Yee & Eccles, 1988). Parents who are more anxious about doing math or who have a relatively negative attitude towards math tend to avoid speaking about or integrating it into daily activities at home with their children, which often leads to children's poorer performance on math related subjects (Eccles & Jacobs, 1986; Gunderson, Ramirez, Levine, & Beilock, 2012, Genderson, Ramirez, Beilock, & Levine, 2013). Indeed, the link between anxiety and performance in mathematics is well established, and a number of studies (e.g., Schmitz, 1997) that looked at the relationship between spatial anxiety and one's spatial ability have found similar results. Schmitz (1997) suggests that low levels of spatial anxiety are correlated with more directional descriptions when describing and walking through a maze, and this result was especially prevalent for males. Strategies such as using landmarks and directional elements to orientate oneself were also found to only be efficient for individuals with lower levels of spatial anxiety (Coluccia & Louse, 2004; Lawton, 1994). A piece that is missing from previous work regarding parental level of anxiety is to examine whether it is reflective of how they talk about spatial concepts (i.e., spatial features, properties, orientations) with their young children. This missing piece was examined in the present study.

Geometric Knowledge and Spatial Ability

It is suggested that geometric knowledge and spatial sense are used extensively in everyday situations (e.g., Casey et al., 2008; Graumann, 1987; Newcombe, Uttal, & Sauter, 2013). For instance, geometry and spatial skills are essential when trying to draw a map, to locate a car in a parking lot, and to orientate oneself in an unfamiliar environment. Geometry is the visual study of shapes (i.e., two- or three- dimensional shapes), sizes, transformations (i.e., composition, decomposition), positions, directions, and movements that describe and represent the physical world. Spatial sense is the intuitive awareness of one's surrounding such as locations or the relations with other objects/people within the same space. Having geometric knowledge, understanding and appreciating the shapes, sizes, and the inter-relationships between objects enables one to map and navigate, as well as mentally visualize and imagine the location of objects in various environments (Clements 1998; Clements, 2004).

Spatial ability is a cognitive ability which requires the translation of one's geometric knowledge. It generally refers to one's ability to generate, transform, and represent information to make sense of the world in a practical way. Spatial skill encompasses three main components: spatial orientation, spatial relation, and spatial visualization (Linn & Peterson, 1985; Newcombe, 2010). These three components are equally important and cannot be treated separately. Spatial orientation may be considered as one's ability to anticipate the appearance of objects, to identify the location of an object in relation to the physical world, and to further map and navigate, especially in unfamiliar environments (Golledge, 1999; Linn & Peterson, 1985; Newcombe, 2010; Newcombe et al., 2013). In fact, navigating in surrounding environments is highly dependt on one's representation of the position of different objects, the environmental features in the surrounding world, and spatial relation between these objects (Newcombe et al., 2012; Souman, Frissen, Sreenivasa, & Ernst, 2009). Spatial relation refers to the understanding of object relationships with respect to each other (i.e., the chair is *beside* the table). Lastly, spatial visualization is concerned with the ability to mentally imagine, transform, and manipulate spatially presented information, such as two- and three-dimensional objects (Casey et al., 2008). Often, spatial visualization ability allows individuals to perform well in mental rotation tasks, because it also involves the ability to recognize the rotated version of one stimulus compared to another. In order to successfully perform spatial visualization tasks, individuals also require the ability to distinguish different spatial characteristics (i.e., shapes, sizes of the object; Casey et al., 2008; Newcombe, 2010).

Geometry and spatial skills in young children. Geometry and spatial sense are important for young children. They provide a way for them to describe, interpret, and explore the physical world. Through continual construction of geometry and spatial ideas, young children learn how to make sense of the physical surroundings based on their experiences with the environment as well as the interactions with other individuals, such as their parents and peers (Copley, 2000).

One’s geometric and spatial ability often improve with age. Over the years, research has been conducted to investigate when children acquire geometry and spatial skills, such as their understanding of object relations. Piaget (1952; 1971) believed that infants have no conceptual ideas of other objects’ existence and their relationship to them until the second year of their lives. For example, block play during infancy helps mainly to develop motor and reflex skills thus has limited value to cognitive development (Piaget, 1977). By 12 months old, young children start to recognize the relationship between themselves and the surrounding environment and to understand object permanence. Around this time, they start to view blocks as symbols and representations of the physical world, which allow them to visually observe spatial features and relations of different objects. For example, when building a farm, they can use shorter cubical blocks to represent animals, and tall cubical blocks as farmers. Playing with blocks provides children with challenges, visual stimulation, and hands-on experience in manipulating objects. Eventually, block play promotes their abstract thinking, which is essential for logical reasoning skills in various subjects such as algebra and science (Piaget, 1977; Stroud, 1995).

However, contrary to Piaget's view, a study investigating whether six- and 16-month-old infants can track the movements of their parents found that even at 16 months old, infants have already exhibited conscious awareness towards the changes of others' positions in relation to the correct location (Acredolo, 1978). Contradictory results can also be found in map-related tasks involving locating landmarks and identifying objects. Studies show that children as young as three years old already demonstrate basic map-reading proficiency and are able to build a simple map with landscape toys such as animals, cars, and trees (e.g., Blaut & Stea, 1974). Furthermore, they are able to describe the position of each item, with respect to other landmarks effectively (e.g., Blaut & Stea, 1974). However, others suggest that children who are younger than four years old are unable to interpret maps from different perspectives (i.e., aerial view, downward looking) and to perceive location through images of landscape (e.g., Blades et al., 1998).

Other aspects of children's spatial abilities such as mental rotation and visualization skills also improve with age. For example, in a task in which children were asked to find a hidden object, nine-year-old children outperformed three-year-olds. They were able to track the movements of the hidden object covered by a cup and use various landmarks to infer that a 180 degree rotation had occurred (Okamoto-Barth, & Call, 2008). In fact, evidence suggests that children start to demonstrate these skills at an early age. Previous research suggested that infants as young as four months of age can identify the rotated versions of 3D objects, even though the objects were constantly moving (Kellman, 1984; Kellman & Short, 1987). Other studies also showed that at five months old, infants are able to perform spatial tasks involving mental rotation and transformation (e.g., Moore & Johnson, 2008).

Other than mental rotation and visualization skills, infants at a very young age are able to use a variety of spatial cues to locate and orientate themselves (e.g., Landau & Spelke, 1988).

Before reaching 12 months of age, infants are capable of tracking one's position even when the person is actively moving (Landau & Spelke, 1988). At 18 months old, children have already exhibited the ability to use features of different landmarks (i.e., height) to locate objects. Lew, Foster, and Fremner (2006) employed a "Peekaboo" paradigm, in which 12 – 18 months old infants learned to anticipate the appearance of an experimenter. They were placed in a circular room with their parents, and presented with three different landmarks around the room. In the practice trial, the experimenter showed up between two random landmarks, so the infants were habituated with the experimenter's location. The results revealed that infants were able to successfully anticipate the experimenter's location using landmarks as spatial cues, indicating that the ability to locate and orientate objects/people spatially emerges at a young age. Further, by six years of age, children are able to utilize their spatial knowledge sufficiently to understand the physical environment around them (Lai, Penna, & Stara, 2006), as well as to successfully recall locations using spatial memory. A study was conducted to investigate children's ability to locate an object after disorientation (Nardini, Thomas, Knowland, Braddick, & Atkinson, 2009). In this study, children between four and eight years old watched the experimenter hide an object in a box. The experimenter then changed the orientation of the children by asking them to move across the room to the opposite side. Their results revealed that even after the change in orientation, children older than six years old were able to recall the location of the box based on proximal landmarks from a novel viewpoint, whereas younger children relied mostly on directions relative to the self (i.e., the box was on my *left*). This finding is consistent with Piaget's (1971) theory suggesting that young children learn about the concept of self before they understand their relationships with respect of other objects in the surrounding environments.

Importance of geometric knowledge and spatial abilities. Before entering formal schooling, children already possess their own understanding of shape and space and engage in activities including identifying, sorting, comparing, and constructing two-dimensional (2D) shapes and three-dimensional (3D) objects. According to the National Council of Teachers of Mathematics (NCTM, 2000; 2006), learning about geometry and spatial sense is one of the mathematical standards a child should meet prior to entering formal schooling. Further, the geometry standards in the United States for pre-kindergarten to grade two suggest that children should be able to recognize and name a variety of 2D and 3D shapes, describe basic spatial features (i.e., number of sides and angles), mentally transform and manipulate objects, as well as spatially visualize and put together shapes.

Casey and colleagues (2008) suggest that spatial thinking and reasoning skills, such as the ability to describe spatial relationship, create mental images, and visualize transformed shapes, are essential for future success because they provide an alternate route to solving problems, in addition to the use of logical and deductive reasoning skills. Therefore, one of the reasons why these skills are emphasized in educational settings during early childhood is that geometric and spatial thinking are integral to solving many tasks in everyday life involving the understanding of locations, directions, and object relationships (Ontario Ministry of Education, 2014).

School achievement. Geometric knowledge and spatial ability form the foundation of many academic disciplines. It is particularly important for mathematical learning, performance on areas related to science, geometry, and problem solving ability (Battista, 1990; Bishop, 1980; Clements, 1998; Mix & Cheng, 2012). Over the years, positive correlations between spatial skills and math achievement have been established across different ages and tasks, even in areas which seem to be unrelated to spatial knowledge, such as counting, comparing magnitudes, and ordering numbers. For instance, children's spatial skills at age five contribute to their number line knowledge at age six, which further predicts their performance on a symbolic calculation task two years later. Spatial ability helps them to visualize the linear numerical representation, such as the idea that two comes *after* one and it is to the *right* of the number one on a linear line (Gunderson, Ramirez, Levine, & Beilock, 2012). By understanding the spatial representation of each number, children can better comprehend the concept of quantity. Furthermore, the understanding of spatial representation of numbers is universal, as it exists not only in North American populations, but also across other cultures such as in Chinese children (Yang et al., 2014).

Children's performance in mathematics is also related to early block play, a medium for children's spatial learning and reasoning (e.g., Tepylo, Moss, & Stephenson, 2015). Evidence shows that engaging in block play has long-term effect on children's spatial ability. For example, Peterson and Levine (2014) visited children and their parents every four months in their home when the children were between 26- and 46- months and videotaped their daily routines for 90 minutes. They found that children who engaged in more block play performed better on a mathematical and geometry task at grade three compared to those who did not. Further, a study (Verdine, Irwin, Golinkoff, & Hirsh-Pasek, 2014) examining children's block constructing ability suggests that skills in being able to perform spatial assembly tasks are related to general mathematics competence one year later. In the study, children were assessed at three years old with the Test of Spatial Assembly task (TOSA; Verdine et al., 2014), a task that requires children to re-construct three-dimensional Mega Block structures. Children were then tested on a math achievement problem solving task at four years of age. Results revealed that even after removing the effects of other variables, such as one's overt number knowledge, executive function, and maternal SES, spatial skills still served as an important predictor of children's general mathematical performance. Furthermore, preschoolers who constructed more complex block structures (e.g., enclosed buildings, constructions with roofs and doors) with their parents were found to show better numeracy competence a year later (Lee, Zambrzycka, & Kotsopoulos, under review).

Other aspects of spatial ability such as visuo-motor skills (i.e., copying geometry figures such as horizontal lines and overlapping three-dimensional representations) in preschoolers were also found to uniquely predict their later math achievement in fourth grade (Kurdek & Sinclair, 2001; Lachance & Mazzocco, 2006). In addition, preschoolers' choice of strategy for solving arithmetic questions is also related to spatial skills, especially in the area of geometric design and spatial scanning (Geary & Burlingham-Dubree, 1989). These findings suggest that engaging in block play is not only beneficial for children's mathematical achievement longitudinally, the short-term benefits of engaging in such an activity also has important implication for children before they enter formal school system.

Spatial and geometry skills are not only related to mathematical achievement, but are likely to be essential for improving mathematical skills (Clements & Sarama, 2007; Mix, Moore, & Holcomb, 2011; Newcombe, 2010). For example, engaging in activities that are spatially related has been found to facilitate children's mathematical learning. For instance, playing with number board games, especially ones involving the use of visuospatial skills such as snakes and ladder was found to enhance children's numerical knowledge (Ramani & Siegler, 2008). Engaging in sensori-motor spatial activities on number representation, where children were required to physically move left or right in relation to the magnitude of each number, contributes to five- and six-year-old children's general arithmetic achievement (Fisher, Moeller, Bientzle, Cress, & Nurek, 2010). A recent study (Cheng & Mix, 2014) also found that practicing mental rotation skills, such as mentally putting two rotated pieces of a shape and identifying the complete shape, was found to promote performance on a calculation, mental rotation, and spatial relation test in children aged from six to eight years old. Spatial activities involving block and puzzle play are linked to improvement in mathematics (Wolfgang et al., 2001; Sarama & Clements, 2004; Levine et al., 2012). Furthermore, it is evident that children's spatial skills are positively correlated with their mathematical achievement. Through appropriate spatial activities involving the use of spatial skills, children can achieve better understanding and improvement in mathematics (e.g., Cheng & Mix, 2014).

Surprisingly, geometric and spatial knowledge are also linked to subjects that may appear to be less directly related, such as music, arts, and certain sports. A positive relationship was found between spatial-temporal reasoning (i.e., a cognitive ability to recognize spatial patterns and how each item fit into its space) and the ability to create sheet music (Hetland, & Winner, 2001; Rauscher, Shaw, & Ky, 1995; Raucher et al., 1997). Geometric and spatial knowledge are also frequently linked to creativity, which is a vital component for creative and visual arts (Pollman, 2010). For example, the use of geometric elements, such as lines, is essential for expressing one's emotion and creativity. Specifically, vertical lines represent a sense of power whereas horizontal ones express a feeling of comfort, while curvy and diagonal lines can represent dynamic actions such as sea waves (Gohm, Humphreys, & Yao, 1998; Humphreys, Lubinski, & Yao, 1993; Lohman, 1996; Park, Lubinski, & Benbow, 2007; Pollman, 2010). Further, the connection between spatial ability and arts has been demonstrated in preschoolers. Engaging in art-related activities, such as playing with crayons, is predictive of preschoolers' performance on visual-spatial tasks, as they pay attention to spatial patterns and perform eye-hand coordination efficiently during these activities (Caldera et al., 1999). Spatial orientation skills also enhance individuals' performance in dancing related sports like ballet and gymnastics, as individuals develop the ability to orient themselves in the surrounding space and maintain specific positions among different body parts while being aware of the relationship between the environment and the body (Corsi-Carbera, & Gutierrez, 1991; Tarampi, Geuss, Stefanucci, & Creem-Regehr, 2014).

Spatial ability has also been found to be related to children's literacy development, especially in the context of block play. Block play is a spatial activity known to be related to the development of geometric and spatial knowledge (Caldera et al., 1999; Ferrara et al., 2011; Park, Chae, & Boyd, 2008), which also enhances children's reading and writing skills (Stroud, 1995). Preschoolers who had higher scores in block play are more capable of creating more sophisticated constructions. For example, they used more horizontal and vertical constructions, built constructions with enclosures, and used complex configurations that include landmarks, routes, and interior space (Hanline, Milton, & Phelps, 2010). These children performed better on the Test of Reading Ability (TERA) test at age eight, as well as demonstrated a faster growth rate in TERA scores in early elementary grades. A possible explanation for this finding is that when building a more complicated structure, children require more developed and sophisticated language skills such as a greater amount of vocabulary to convey what she/he is building. Therefore, engaging in block play stimulates children's language skills (Stroud, 1995). Indeed, construction activities play an important role in children's spatial learning, which further enhances better achievement in education settings. The effects and benefits of block and puzzle play will be discussed in more detail in the following sections.

Spatial abilities and geometric knowledge, such as mental rotation, spatial visualization, and orientation skills, are also found to be related to university students' success in science. For example, proficiency in mental rotation skills has been linked to better understanding of molecular structures in chemistry courses, as well as body structures in anatomy-related courses (Guillot, Champely, Batier, Thiriet, & Collet, 2007; Stieff, 2007). At the same time, Tally (1973) suggests that college science students perform better on a general chemistry test when three-dimensional molecular models are used during lectures. Specifically, the molecular models provide students with a medium to mentally visualize the structure and make sense of it. Next, using spatial visualization skills, such as drawing, understanding the relationship between lines, angles, planes, points, and solid figures, also promotes students' performance in a geometry course (Brickmann, 1966). Further, spatial orientation skills can also be used to understand and excel in engineering courses (Poole & Stanley, 1972). For example, mechanical engineering students are required to visualize the interaction of different machine parts, in order to operate them accordingly. Similar to mathematics, spatial training is indeed beneficial for students' understanding on science-related subjects, even for those who are in the arts program. A study conducted by Pallrand and Seeber (1984) found that students' visual-spatial abilities increased after being introduced to spatial activities involving locating objects, drawing diagrams, and learning about geometric transformation. Results revealed that not only did the students in physics program perform better on a physics course, students in liberal arts program also demonstrated improvements (Pallrand & Seeber, 1984). Certainly, these studies posit a notion that spatial abilities contribute to individuals' achievements in science, mathematics and engineering field. It is evident that geometric knowledge and spatial abilities are integral to many school disciplines. Being able to mentally imagine, put together, and decompose objects, as well as visualize and understand their relationship is essential for higher educational and occupational achievement (e.g., Shea et al., 2011).

Occupation. Various studies indicate that spatial skills play a unique role in STEM-related careers. In a nationally representative sample (*n* = 400,000), spatial skills assessed in high school were found to be a strong predictor of one's STEM occupation 11 years later, even after controlling for verbal and cognitive skills (Wai et al., 2009). Recently, spatial ability has become a diagnostic and screening tool to uncover and identify talented individuals for the STEM occupation. When measuring the spatial visualization skills among a group of youth, researchers found that spatial ability, such as spatial reasoning skill, is linked to one's potential in math-science careers (Lubinski, 2010; Webb, Lubinski, & Benbow, 2009). Spatial reasoning skill is associated with individual's ability to use spatial representations to solve problems. For instance, an expert chemist who is knowledgeable of the structure and behaviour of a particular molecule may be able to mentally imagine the representation of the molecule model to make decisions or draw conclusions about it (Uttal & Cohen, 2012). Over the years, a number of studies have indicated that geometry and spatial knowledge are essential parts in children's performance at school, which predict their success in future education and career. Proficiency in spatial ability has been linked to achievement in university majors such as sciences and engineering, as well as occupations like surgeons, engineers, dentists, architects, and physicians (Hegarty, Keehner, Khooshabeh, & Montello, 2009; Shea, Lubinski, & Benbow, 2011; Smith, 1964; Uttal & Cohen, 2012; Uttal, Miller, & Newcombe, 2013; Wai, Lubinski, & Benbow, 2009). For instance, engineers must be able to visualize the interactions of different machine parts to operate them properly, and medical surgeons must understand the anatomical structures to operate surgeries.

In addition, one's spatial ability is also considered to be a factor that determines their educational outcomes and career choices. In a longitudinal study conducted by Shea, Lubinski, and Benbow (2011), a group of 13-year-old adolescences completed tasks regarding their spatial abilities. At age 18, 23, and 33, their favorite and least favorite high school class, undergraduate degree major, graduate degree major, and occupation were assessed, respectively. The results suggest that better spatial abilities during adolescence significantly predicted their achievement in school majors. Moreover, it is suggested that these individuals are more likely to choose and succeed in occupation such as science, engineering, computer science and mathematics.

Individual differences. It is evident that better spatial ability leads to greater achievement at school, which further results in advanced educational credentials and occupational outcomes in STEM fields. However, there are individual differences in age, gender, and socio-economic status (SES) that may contribute to variation in spatial ability.

Age differences. Similar to other cognitive, mental, and physical capacities, spatial ability develops during the course of one's life. According to Piaget (1953), the development of spatial ability consists of three periods of sensori-motor development starting from birth. By 12 months, having acquired object permanence, most babies start to perceive the existence of solid objects in the surrounding environment as well as understand the consistency of objects' shapes and sizes, and realize that physical objects will continue to exist even when they are removed or hidden from their view, which in fact, initiates their learning of geometric knowledge and spatial ability (Piaget & Inhelder, 1967). Children often start to systematically acquire spatial ability in the second half of their second year. Furthermore, Joshi, MacLean, and Carter (1999) suggest that seven- to 12-year-old children who were allowed to explore more freely were found to have better knowledge of the surrounding environment. Through movements and exploration as well as touching and manipulating objects, young children gradually make efficient observations and representations of the physical world, which help them with the understanding of object relations and orientations.

An increasing number of studies have been investigating when children acquire certain spatial abilities such as spatial transformation and mental rotation skills. However, the inconclusive results suggest that researchers have not been able to pinpoint a developmental trajectory of these abilities. Some researchers suggest that infants who are younger than five months of age already demonstrate mental rotation skills (e.g., Moore & Johnson, 2008; Quinn & Liben, 2008). In contrast, others may argue that mental rotation skills are not established systematically until four to five years of age (e.g., Frick, Ferrara, & Newcombe, 2013; Harris, Newcombe, & Hirsh-Pasek, 2013; Marmor, 1975). Specifically, one study found that six-year-olds outperformed four-year-olds on a mental rotation task and their performance was comparable to adults. Overall, they produced less rotation errors and required shorter reaction time (Estes, 1998). Harris and colleagues (2013) assessed children between four to seven years of age and suggested that mental folding-a skill involving mental rotation, which is particularly important to spatial thinking, appears at approximately five years of age. Other spatial abilities such as spatial relation skills in young children were also found to be positively related to age (Jansen, Lange, & Heli, 2011; Lehmann, Quaiser-Pohl, & Jansen, 2014; Piaget, & Inhelder, 1967). For example, Davol and Hastings (1967) suggest that children’s ability to distinguish spatial relations increases with age, despite differences in gender, reading ability and SES. This notion is not only applicable for young children, as other studies indicate that older adults perform better on spatial tasks and are better at scanning and rotating objects than younger adults

(Berg, Hertzog, & Hunt, 1982; Childs, & Polich, 1979; Kosslyn, Margolis, Barrett, Goldknopf, & Daly, 1990).

Gender differences. Generally, studies on gender differences in spatial abilities provide a more consistent result. A substantial body of research suggests visual-spatial ability has the most significant gender difference among all the spatial skills, specifically in performance on mental rotation tasks (Jansen, Schmelter, Quaiser-Pohl, Neuburger, & Heil, 2013; Linn, & Peterson, 1985; Richardson, 1994; Voyer, Voyer, & Bryden, 1995). According to Maccoby and Jacklin (1974), gender differences in spatial transformation tasks remain constant through adulthood and often occur during early childhood, as boys often outperform girls on various spatial tasks. During the preschool years, boys as young as three years of age already exhibit a higher level of spatial abilities in simple mental rotation tasks (Ehrlich, Levine, Goldin-Meadow, 2006). By four years old, boys display a faster speed in building more complex three-dimensional constructions (McGuinness & Morley, 1991) and show better performance on a simplified two-dimensional mental transformation task (Levine, Huttenlocher, Taylor, & Langrock, 1999). Gender differences in mental rotation tasks can be seen in infants as young as three to five months old (Moore & Johnson, 2008; Quinn & Liben, 2008). Quinn and Liben (2008) administered three- to four-month-old female and male infants a two-dimensional mental rotation task. These infants were habituated to the number “1” and its mirrored image in different rotations between 0 to 360 degrees. Their findings revealed that male infants preferred and looked at the mirror stimulus more than the rotated version indicating that they recognized the novelty of a mirrored image. On the other hand, females infants divided their attentions between the two stimuli (i.e., mirrored image, rotated image), suggesting that they were unable to recognize the familiar objects after being habituated to them. Similarly, Moore and Johnson (2008) found supporting results indicating that five-month-old male infants were able to further recognize three-dimensional objects even when the objects were presented in different angles compared to the female infants.

It is widely acknowledged that early preference in play behaviour is likely to lead to the development of gender differences in cognitive abilities. Correlational studies have suggested a link between spatial activities and preschoolers' visual-spatial skills (Caldera et al., 1999; Caldera, Huston, & O'Brien, 1989; Connor & Serbin, 1977; Serbin & Connor, 1979; Sherman, 1967). Connor and Serbin (1977) measured a group of three- to eight-year-old children's spatial abilities via a block design task and observed their play activities over a 12-week span, in order to determine their play preference in a naturalistic setting. Activities such as playing with blocks, LEGOs®, and Lincoln logs were categorized as masculine preferences, whereas playing with dolls and crayons were considered as more feminine activities (e.g., Casey et al., 2008; Connor & Serbin, 1977). The result revealed a positive relationship between the block design scores and preference for masculine activities for boys. In contrast, activity choices were not related to girl's performance on the block design task (Connor & Serbin. 1977).

Engaging in constructional play is seen to facilitate a greater outcome on visual-spatial skills in boys. However, research has found that boys and girls do not differ significantly in terms of their building competency, such as the use of building strategies, the complexity of the constructions, as well as the time spent in block play (Caldera et al., 1999; Casey et al., 2008; Hanline, Milton, & Phelps, 2001; Kersh et al., 2008). In fact, Doyle, Voyer, and Cherney (2012) suggested that engaging in spatial activities during childhood significantly predicts an individual's spatial ability in adulthood and the outcome is above and beyond the effect of gender differences. Previous studies have also suggested that appropriate spatial training programs involving spatial activities are beneficial for both genders; they also mediate gender differences (Feng, Spence, & Pratt, 2007; Kass, Ahler, & Dugger, 1998; de Acedo Lizarraga & Ganuza, 2003; Uttal et al., 2013). Often, these training sessions consist of mental rotation task practices (de Acedo Lizarraga & Ganuza, 2003; Stericker & LeVesconte, 1982), visual-spatial video games (Feng et al., 2007; Okagaki & Frensch, 1994), or block building activities (e.g., Casey et al., 2008). For instance, Tzuriel and Egozi (2011) found reduced gender effects on a visual-spatial task after introducing a group of first-grade children to a *Spatial Sense* intervention program, which mainly focused on presenting the children with stimuli as a whole from different angles and conceptualizing them as representations of different objects. Further, primary school children improved on a mental rotation task two weeks after receiving a motor training session, involving memorizing orientations of objects and bouncing balls around obstacles. In this study, gender differences were found to be non-significant after implementing the intervention session (Bluchel, Lehmann, Kellner, & Jansen, 2013). These findings suggest that although gender differences emerge at a young age, they can be minimized and mediated by interventions involving spatial activities and instructional strategies used to process visual-spatial information (e.g., Tzuriel & Egozi, 2011). In the present study, consistent with previous studies, gender differences were analyzed and being accounted for as a covariant (e.g., Jansen et al., 2013; Linn, & Peterson, 1985; Voyer et al., 1995).

Socio-economic status. Many factors contribute to children's overall spatial skills. Age and gender differences are often considered as biological factors, and socio-economic status (SES) is usually viewed as an environmental factor. For instance, a group of second- and third-graders were followed longitudinally for a two-year period and was assessed on their spatial abilities with a mental rotation task and an aerial-mapping task (Levine, Vasilyeva, Lourenco, Newcombe, & Huttenlocher, 2005). After controlling for their overall cognitive functions, researchers found that boys from a middle- and high-SES background outperformed girls. On the other hand, children's performance on both spatial tasks did not differ between boys and girls in low-SES households. Overall, children from low-SES homes performed less well than their middle- and high-SES peers (Levine et al., 2005). Another study conducted by Pruden and colleagues (2011) found similar results that children from low-SES families exhibited a slower rate of development in terms of spatial language production compared to middle- and high-SES children.

These findings illustrate the Matthew effect, also known as the 'rich-get-richer' effect. The concept of Matthew effect springs from the findings by Stanovich (1986) that children who start off with better reading skills would continue to perform better on reading-related tasks, such as reading comprehension, than those who start out with poorer reading skills. Specifically, children who have better reading skills would be more likely to read more, learn about more vocabulary, and thus read even better, compared to those who start off with poorer reading skills. Thus, the gap between their reading competences widens over time. The Matthew effect can also be seen in individuals' cognitive capacity (Shaywitz et al., 1995), vocabulary acquisition (Penno, Wilkinson, & Moore, 2002), reading development (Stanovich, 1986), and performance in science-related subjects (Merton, 1968/1988). It is also important to note that an individual's environment can either promote or hinder one's learning and development. 2For instance, advantageous environments (e.g., high SES) and better early education experiences (e.g., having parents that are involved in the child's reading) may help facilitate children's reading skills. Conversely, less resourceful environments (e.g., lower SES) may hinder children's reading skills, as the parents may not be able to afford expensive books and materials. The Matthew effect can also be potentially seen in area such as children's mathematical and spatial development. Overall, children who start off with better cognitive abilities and advantageous environments would continue to perform better on mathematically and spatially-related tasks than those who start out with poorer cognitive abilities and less resourceful environments.

SES can also have an impact on the amount of spatial speech parents produce during every day interactions with their young children, which may potentially influence children’s spatial ability. Studies provide evidence that in general, children from lower-SES households are exposed to less spatial language during block play and puzzle play (e.g., Pruden et al., 2011; Verdine et al., 2014). For example, a recent study on spatial language indicates that when comparing parents’ spatial language input among families with different SES, the linear rate of growth on spatial word production is much slower in lower SES households, even when their initial rate was similar to the middle- and high-SES families (Pruden et al., 2011).

One of the ways to reduce and mediate these individual differences is to provide children with spatially-rich environments. It is suggested that integrating spatial concepts into children’s daily activities facilitates their spatial learning (e.g., Newcombe & Frick, 2010). Past studies show that children’s spatial ability often remains stable over time (e.g., Poltrock & Brown, 1984). For example, those who have a better spatial orientation skill during the early years tend to perform well on activities that require direction and orientation skills in adulthood (e.g., DeSilva, 1931; Warren, 1908). It is still unclear what factors contribute to these individual differences. However, it is more likely that the interaction between biological factors and environmental inputs both allow the differences in children’s spatial abilities to remain constant throughout adolescence and adulthood. This finding highlights the importance of spatially-rich environment parents provide for their children during the early years. By engaging in these environments and participating in spatially-related activities, parents are able to foster and scaffold children’s spatial learning at a young age. Without spatially-related experiences, it is assumed that children who perform poorer on spatial tasks and have worse spatial skills will continue to have disadvantages in the future. While different factors that contribute to individual differences in spatial skills are still in need of future investigations, there are different ways a child's spatial ability can be fostered and improve accordingly.

Factors that Foster and Improve Children's Spatial Skills

Spatial language. By definition, language is one of the ways for humans to communicate, convey ideas, express feelings, stress concerns, and influence thoughts (Jakobson & Halle, 2002; Shatz, 2006). For young children, language is a powerful tool they use to make sense of the physical world, as language provides a unique way for them to perceive space, time, causations, and other fundamental concepts (Whorf, Lee, Levinson, & Carroll, 2012). Children cognitively map abstract concepts onto objects in the surrounding environment in order to understand meanings, relations, and representations of objects and conceptual ideas (Booth & Waxman, 2003; Bowerman & Levinson, 2001; Smith, Kirby, & Brighton, 2003). During the course of development, it is essential for parents or caregivers to elaborate on each word, to extend its meaning for the child, and most importantly to use each word in its corresponding context (Tyler, 1978). By doing so, the child can acquire a way to interpret meanings through their experiences (Bowerman & Choi, 2001; Whorf, 1956).

Research has shown that language input from parents is especially important during parent-child interactions (Hoff & Naigles, 2002; Hoff-Ginsberg, 1991; Rowe, 2012). It is known that children's language development such as vocabulary growth is reflective of parental speech input during daily interactions (Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991). Evidence has shown that parental language input in an area provides children with more exposure to that specific domain, which is likely to result in their greater interest, better knowledge, and expectantly, higher level of performance in related fields. For example, spatial language used by parents has been found to relate to the amount of children's spatial language, which ultimately leads to their development of spatial skills (Hermer-Vazquez, Moffet, & Munkholm, 2001; Landau & Jackendoff, 1993; Loewenstein & Gentner, 2005; Pruden et al., 2011).

It is suggested that at three years of age, children are able to hear and use geometric information to make reference to different landmarks in order to locate a hidden object (Hermer-Vazquez et al., 2001). Children, as young as two years of age, have already exhibited understanding of simple location such as *in* and *on*; and by three years of age, they can already distinguish the differences between complex spatial locatives like *in front of* and *behind* (Internicola & Weist, 2003). Given that young children can understand spatial concepts at such an early age, parents should be made aware that their input helps to foster children's spatial learning.

It is important to recognize that children's language development is not strictly due to more language input but also the quality of language (Rowe, 2012). Thus, studies on spatial language focus on both the frequency of spatial talk and the variation (i.e., types) of such language exposure. Spatial language encompasses different categories (Cannon, Levine, & Huttenlocher, 2007) such as spatial dimensions (i.e., full, short, wide, size), spatial features and properties (i.e., side, corner), and spatial locations (i.e. here, there). Indeed, parental spatial input is strongly related to children's understanding of spatial words. Foster and Hund (2012) found that four- and five-year-old children would only understand and use *between* and *middle* proficiently if they heard these two words directly from their parents.

In addition, the use of the spatial language by parents on a daily basis is linked to children's performance on tasks involving spatial thinking and reasoning skills. In a longitudinal study conducted by Pruden, Levine, and Huttenlocher (2011), parent-child interactions were videotaped in a naturalistic home setting every four months when the child was between 14 – 46 months old. At 54 months of age, children's spatial abilities were assessed through a spatial transformation (i.e., a test where children were asked to select a complete shape based on the two separate pieces presented), a block design, and a spatial analogy test (i.e., a test to assess children's ability to perceive the relation between two spatial figures). Utterances spoken in a spatial context were coded. Researchers found some variation in parental spatial language input, in which the most common spatial terms were describing and talking about spatial features (i.e., side, corner), dimension terms (i.e., small, big, size), and two- or three-dimensional shapes (i.e., circle, cube). One primary finding of this study is that parental spatial language input is highly correlated with children's spatial language output ($r = .70$), even when parents' overall speech production was being controlled for. This result suggests that children's spatial language output is not simply a by-product of hearing more language in general, but specifically due to spatial-related language. The researchers also found that the amount of spatial input the children received was significantly related to their scores on the spatial tasks, even after the impact of all the non-spatial talk was removed. After controlling for parents' overall language production, the researchers found a positive link between parental spatial language input and children's overall scores on spatial transformation and spatial analogy tasks. Thus, this study posits an important message that parents' spatial language input is essential for children's spatial learning and development and should be integrated into daily activities (Pruden et al., 2011).

Multiple experiments using different spatial tasks have been conducted to illustrate the importance of spatial language in the child's spatial learning at different ages. Certainly, spatial language input in a specific domain (e.g., talking about spatial relations) is likely to lead to children's performance on a related spatial task. For example, a study conducted by Loewenstein and Gentner (2005) to examine children's understanding in spatial relational language, and whether the spatial relational language facilitated their performance on a mapping task. A group of preschool-aged children watched the experimenter place an object on, in, or under a hiding box. The experimenter then said to the children, "I am putting the object *right here*" or "I am putting the object *on top/ in the middle/ at the bottom* of the box." Children who heard the latter relational statements were better at finding the object than those who heard the former sentence, even after accounting for children's overall language competence. The researchers were also able to find the lasting effect of the relational language two days later, even after the children were distracted with non-relational language such as "Can you put the object *right here*" (Loewenstein & Gentner, 2005). This suggests that preschoolers are able to understand and process spatial information, then successfully hold and retrieve that piece of information to complete the mapping task days later. Studies on spatial orientation also found similar results indicating that hearing a specific type of spatial language facilitate young children's performance on a related spatial task (e.g., Dessalegn & Landau, 2008). For instance, evidence has shown that four-year-old children exhibited a better understanding on a location task, especially when they were given specific instructions related to the location and direction of the target item. Interestingly, a statement includes both locational and directional messages, such as "the red is *on the left*" was more valuable than a non-directional statement like "the red is *touching* the green" (Dessalegn & Landau, 2008). Further, supporting studies indicate that children who can proficiently comprehend the idea of left and right performed better on an object locating task better than those who cannot (Hermer-Vazquez et al., 2001; Newcombe & Huttenlocher, 1992; Shusterman, 2006).

Exposure to spatial language is indeed beneficial for children's spatial learning. In fact, research on visually-impaired children's spatial learning further strengthens the significance of spatial language (e.g., Landau, 1986). For example, Landau, Spelke, and Gleitman (1984) conducted a study to examine a four-year-old visually impaired child's spatial knowledge. In this study, the experimenter provided the child with an 8.5 x 11 inch piece of cardboard, on which wooden blocks had been glued to represent the locations of the child and different objects in the room (i.e., a tactile map). The experimenter then moved the child's fingers across the cardboard, in order for the child to learn about her location in relation to other objects in the room. The child was then entered into a playroom and told to find the target object according to the tactile map. Without any visual stimuli, the visually-impaired child can successfully move around in the space with a tactile map, and locate landmarks in front, behind, or beside her with no previous map-use experiences when she was provided with directional instructions (Landau, Spelke, & Gleitman, 1984). Previous work on visually-impaired children's spatial ability suggest that these children actually rely more on spatial language, as it helps them to acquire spatial ideas (Landau, 1986). By listening to spatial-relevant instructions such as "A square has four *corners*, and circle is a *round* object," these children are able to go beyond immediate impression and make inferences of objects by their spatial features (Landau, 1991). Thus, these findings demonstrate that spatial language may be essential for the early emerge of children's spatial knowledge.

Spatial language is indeed a useful tool for children to acquire spatial concepts. However, factors such as levels of parental spatial anxiety and attitude towards mathematics may potentially influence their spatial language input. A casual correlation has been found between parents and teachers' own attitudes and beliefs and children's performance on math (Gunderson et al., 2013). For example, adults such as teachers' anxieties and negative attitude about an academic domain can casually impact children's learning in that specific area (Gunderson et al., 2013). Research shows that a higher level of math anxiety indirectly leads to less mathematical related talk in elementary school teachers (Kelly & Tomhave, 1985; Wood, 1988). Similarly, a recent study found that teachers' levels of spatial anxiety significantly predict first- and second-graders' spatial skills, even after controlling for their spatial abilities at the beginning of the school year, due to reasons such as avoiding engaging in spatial activities, as well as talking less about spatial-related topics (Gunderson et al., 2013). Thus far, a limited number of studies have examined whether parents' spatial anxiety and attitude towards math have a direct impact on their spatial speech production, yet this may be a relevant issue in children's spatial learning. Therefore, the present study investigated the link between levels of parental spatial anxiety, attitude towards math, and spatial language input to determine its impact on children's spatial acquisition.

Construction play. For children, geometry and spatial skills emerge through construction play, a common play activity for children (Van Hiele, 1999). Common constructional toys like blocks, LEGOs®, and Lincoln logs are often used to enhance children's cognitive skills (Wolfgang et al., 2001). For instance, block building by young children is suggested to have an important value in education settings as it contributes to many aspects of children's development, such as spatial reasoning, knowledge of geometric shapes, numerical knowledge, problem solving skills, as well as language development (Kamii, Miyakawa, & Kato, 2004; Ramani, Zippert, Schweitzer, & Pan, 2014; Seo & Ginsbug, 2004; Stroud, 1995). During infancy, especially in the first few months of a child's life, he/she has not yet established the conceptual idea of self versus others.

Particularly, engaging in block play or other construction play has been linked to better visual-spatial skills because these types of toys provide children with hands-on experiences, which they can manipulate, transform, as well as visually imagine the objects according to their perception of the physical world. For example, three-year-old children who engaged frequently in playing manipulative toys such as blocks scored higher on the Preschool Embedded Figures Test (PEFT) involving spatial visualization (Fagot & Littman, 1976). Other studies found replicated results with a larger sample revealing that preschoolers performed better on PEFT and the Block Design task if they spent more time with blocks at home (Connor & Serbin, 1977; Serbin & Connor, 1979). Further, researchers also found that children performed better on visual-spatial tasks if they are able to successfully re-construct complex block, or LEGO structures (Caldera et al., 1999; Brosnan, 1998). It is clear that children utilize mental rotation and visualization strategies during block building. For instance, when building blocks, children may rotate the blocks to fit them into a specific space in the structure, to demonstrate part-whole relations by equally separating two shapes, and to match the blocks on both sides to create symmetrical patterns. Furthermore, children learn about geometric concepts such as shapes and sizes and how to transform or categorize them into other configurations. Therefore, block building incorporates children's spatial abilities of both mental rotation and visualization skills (Casey et al., 2008; Park et al., 2008).

Based on previous findings, block play seems to be an important factor for children's spatial learning. However, there is a dearth of research investigating whether building blocks could potentially improve children's early spatial skills. One study mainly focused on interventions involving block building activities and whether they could improve children's spatial ability. Casey and colleagues (2008) introduced an intervention program involving three conditions (i.e., control, block building with storytelling, block building) to three kindergarten classrooms over a 6- to 8-week span. The control classroom only engaged in their daily routines. For the block building with storytelling condition, teachers would tell a story about a castle, and children were told to help build the castle with different shapes and structures. In the building block condition, the children were shown a poster of a house surrounded by landmarks, such as bridges and fences. In both conditions, children experienced block building activities consisting of reconstructing different landmarks with increased complexity. The results revealed that regardless of the storytelling component, children who experienced the block building activities outperformed those who were in the control condition on the Block Design test at post-test. When children were asked to build a "school" with given blocks, those who had participated in the intervention conditions exhibited a higher level of building complexity (e.g., enclosed structures, gates, roofs) and were able to better explain their building strategies. Further, a recent study conducted by Jirout and Newcomb (2015) using a large, representative sample from the United States reveals a more explicit relationship between spatial activities and children's spatial development at home after controlling for children's other cognitive abilities (i.e., working memory) and general intelligence. Researchers assessed children's spatial performance with a block design task and asked the parents to report activities (e.g., playing with blocks and puzzles, riding bikes, playing with dolls) engaged at home. Specifically, their results suggest that spatial play is the only interactive parent-child activity related to children's spatial skills.

Block play is not only related to better visual-spatial skills, it also elicits more spatial language compared to other activities. Ferrara and colleagues (2011) analyzed the transcripts of children between three and five years of age and their parents' utterances during spatial activities (i.e., constructional play) and non-spatial activities such as having lunch, drawing, and reading story books. The transcripts were coded using a Spatial Language Coding Scheme (Cannon et al., 2007). The result revealed that both parents and their child use significantly more spatial words in the block play context compared to other daily routines in all three conditions (i.e., free play, guided play, preassembled play), indicating that integrating blocks into daily activities can potentially elicit more spatial words, which could further result in children's better spatial skills. In addition, the researchers also found that parents and children produced the most spatial words during the guided block play condition, in which their task consisted of following instructions and constructing complex block structures. These findings suggest that block play is beneficial for children's spatial learning due to the variety of geometric and spatial concepts children are exposed to. Furthermore, it promotes children's spatial learning by implicitly eliciting spatial language in both parents and their child in comparison to non-spatial activities. (Ferrara et al., 2011).

Puzzle play. Toys such as jigsaw and tangram puzzles have been used as tools to enhance geometric and spatial learning in toddlers and preschoolers. During puzzle play, children are required to perform transformation skills both physically and mentally. For example, mental transformation skills are necessary for children to visualize a correct spot for puzzle pieces to fit in. In addition, they may have to physically rotate or flip the puzzle pieces to match the corners and sides (Van Hiele, 1999). Most importantly, by fitting the pieces into the right place, children are provided with immediate feedback, which allows them to see whether the transformations made are accurate. Moreover, unlike other spatial activities, puzzle play allows children with a spatial experience that is gender-neutral. Specifically, both boys and girls see puzzle play as a gender appropriate activity, which they can be exposed to and gain spatial skills from this activity (Serbin & Connor, 1979). Parents are more likely to use spatial words (e.g., *corner, side, flip, curve, bottom*) to guide and encourage their children during puzzle play, which may therefore increase children's exposure to a variety of spatial language (Levine et al., 2012).

Research suggests that playing with puzzles is correlated with the development of many spatial abilities, such as mental rotation and visualization skills (Levine et al., 2005; Verdine, Troseth, Hodapp, & Dykens, 2008), and these abilities often emerge prior to kindergarten entry. Levine and colleagues (2012) observed a group of 26-month-old children and their parents during a 90-minute free play session four times until they reached 46 months of age. At 54 months, their spatial ability was assessed using a mental transformation task involving mentally putting two separate two-dimensional pieces together to make a complete shape. The frequency and quality of puzzle play (i.e., puzzle difficulty, parent engagement, the use of spatial language) were coded. Overall, children who engaged in puzzle play more frequently outperformed those who did not, even after parents' socio-economic status (SES) and overall spatial language input were controlled for. The researchers also found that only girls' mental transformation task scores were predicted by the quality of puzzle play among those who played more puzzle, although a high level in puzzle play quality was shown between boys and their parents (Levine et al., 2012).

It is evident that engaging in puzzle play facilitates children's spatial development. Thus, it has been used as a medium to foster children's spatial learning, especially in solving part-whole relations, spatial visualization, and mental rotation problems (Casey, Erkut, Ceder, & Young, 2008). A group of preschoolers were introduced to a puzzle play intervention consisting of learning geometry through part-whole relations. During the intervention, children were encouraged to combine small two-dimensional shapes to make larger configurations. For instance, they began by putting two triangles together to make a larger triangle or a rectangle, then they moved on to use more pieces to make another pattern, in which they learned the part-whole relations of different shapes, such as two triangles put together can make a shape of the square. Additionally, they practiced looking at the larger configurations to discover the hidden original shapes (e.g., a small triangle is hidden within the shape of a dragon). Eventually, they moved to exploring three-dimensional part-whole puzzles using different wooden cubes. Overall, the researchers found that children who experienced the geometry intervention at the end performed better compared to the control group (Casey et al., 2008).

These findings emphasize the importance of puzzle play. Given that puzzle play is a common activity among toddlers and preschoolers and is found to be an effective teaching tool in spatial education (Verdine et al., 2014), a vital message for parents is to utilize this tool to foster children's spatial ability by integrating such activity into their daily lives.

Overall, engaging in spatially related activities, such as construction play and puzzle play, is beneficial for children's spatial learning. Usually, children play with building blocks and puzzles in three-dimensional (3D) context, as the toys are solid, easily manipulated and rotated, and maneuverable. However, as the use of two-dimensional (2D) devices has been on the rise (e.g., Rideout, 2013), more children are being introduced to a greater number of 2D applications on touchscreen technologies. Thus, it was important for the present study to examine children's spatial learning through these two experiences.

Spatial Learning through Three- and Two-Dimensional Play Experiences

It is widely acknowledged that children learn through play, a dominant activity during childhood that is essential for children's development (Vygotsky, 1981; Whitebread, Coltman, Jameson, & Lander, 2009). It promotes children's self-regulation skills, communication skills, and problem-solving skills (Vygotsky, 1981; Whitebread et al., 2009). Play activities often associate with toys, which helps to nurture and enhance communication and cooperation skills between children and their parents. Two ways that children can learn through play are through: 1) three-dimensional toys and 2) two-dimensional toys, as elaborated in the following sections.

It is important for children to develop the ability to learn and express their knowledge across different contexts. For example, it is important for one to apply knowledge of geometry to estimate the square footage of an area, to utilize what was learned about fractions to create fanatical plans, or even to answer questions on an arithmetic test based on what he/she learned in the calculus class. As spatial abilities during childhood have important implications for one's future achievement and performance in both academic and professional setting (e.g., Shea et al., 2001), it is vital to examine the learning outcome. Specifically, it is important to examine how children acquire such skills, express their knowledge, and apply their learning onto spatially-related tasks.

Three-dimensional (3D) learning. For children, three-dimensional learning occurs through play activities with three-dimensional toys or objects in the real-world environment. Three-dimensional objects are often labeled by a combination of three terms (i.e., length, width, depth) and can be physically rotated and transformed. In the present study, the 3D spatial toys used were building blocks and tangram puzzles. These toys are tangible and can be touched and manipulated in the physical world.

Tangible objects provide hands-on stimulation and sensory feedback, as the objects can be seen, touched and discussed (Jacobson, 1998; Marshall, 2007; Quarles, Lampotang, Fischler, Fishwick, & Lok, 2008). Researchers have found that adults who used tactile cues, such as landmarks or an object that vibrates when individuals are moving towards the correct direction, to indicate the locations often chose more shortcuts and were less disoriented on a map reading task (Pielot, Henze, & Boll, 2009). Tactile cues have also been used as a tool to enhance children's language learning by integrating farm animal puppets into storytelling activities (Fontijn & Mendels, 2005). Most importantly, being able to touch and feel an object is an important characteristic for children's spatial learning, especially when they fail to use abstract representations to understand physical objects (O'Malley & Fraser, 2004). For instance, they learn about spatial properties such as corners and sides by not only looking but touching a cube. Being able to visually observe the object as well as physically touching it may potentially benefit the children, because that they have two types of stimuli to aid in encoding and remembering the features and properties of certain objects (i.e., cubes, pyramids).

There is evidence that by actively exploring and moving around in the environment, as well as manipulating objects, children perform better on tests of spatial knowledge than those who just watch (Siegal & White, 1975). In order to investigate how they apply spatial knowledge to real environment, McComas and colleagues (1998) introduced a virtual learning (VR) intervention to a group of children in grade one and two. Half of the group experienced training in a real environment, whereas the other half was in a computer desktop virtual learning condition. Children were told that the final goal was to find ten puzzle pieces which were hidden in 14 randomly placed clowns in the room based on the location of the landmarks. They had three practice trials and one test trial, where all the children were tested in a school room. In the real environment training condition, children were trained in the school room with moveable landmarks such as poster boards and desks. In the VR condition, children used a mouse to control movements in the room on a desktop computer. The result showed that children who experienced the real environment training were able to find the puzzle pieces in a shorter period of time with fewer errors. These findings suggest that spatial learning in children involves not only visual stimulations, but also physical and sensory feedbacks (Kozak, Hancock, Arthur, & Chrysler, 1993), which can potentially explain why children learn better through three-dimensional learning as they explore and observe the environment (e.g., Stanton, Wilson, & Foreman, 1996). Three-dimensional learning may also be more enjoyable for children. In a puzzle solving study (Xie, Antle, & Motamedi, 2008), children who were allowed to play with the Jigsaw puzzles (i.e., rotate, flip) physically reported higher levels of enjoyment compared to those who were playing on a laptop.

Further, tangible spatial toys such as blocks and puzzles are found to be efficient in increasing parents and children's overall and spatial language production (e.g., Hengeveld et al., 2009). For instance, when playing with building blocks, parents may ask their child to explain what he/she is building. They may ask questions such as, "What are you building? What is in your castle? Who lives in the tall building?" Thus, activities involving spatial tangible toys could possibly elicit a greater amount of verbal response from the child, which further promotes vocabulary growth, as well as spatial language production (Hengeveld et al., 2009; Snow & Ferguson, 1977). Spatial learning involving tangible toys is a complicated process as many things happen simultaneously. Spatial learning involving the use of spatial language while playing with tangible spatial toys often occurs due to bodily movements of the child and physical actions of the object (Raffle, 2008). For instance, a child can put two blocks side by side to talk about and compare the size differences in them. In the meantime, they can also observe the different heights and make inferences to actual objects in the surrounding environment. Most importantly, learning with 3D toys allow children to also think in three-dimensional contexts, such as three-dimensional diagrams and molecular structures, which is an essential skill for achievements in mathematics and science (Christou et al., 2008).

Several recent studies suggest that children may perform better on three-dimensional mental rotation tasks compared to the traditional two-dimensional pencil-paper tasks. Frick, Hansen, and Newcombe (2013) conducted a study to assess three- to five-year-old children's spatial mental rotation skills. Children were presented pairs of asymmetrical ghost figures, as either three-dimensional cut-outs or two-dimensional paper versions in seven orientations. Only one ghost would fit into the hole if rotated properly, whereas the other orientations were its mirrored version and they would not fit. The result revealed that children demonstrated slightly higher scores when tangible stimuli were presented. To extend this finding to a wider and older age group, a recent study (Hawes, LeFevre, Xu, & Bruce, 2015) assessed four- to eight-year-old children's spatial skills. They found that children performed better when they were shown block designs and asked to identify the target item on three-dimensional blocks, as opposed to on a piece of paper. These results suggest that tangible objects provide children with extra information (e.g., textures, spatial features), especially for children younger than eight years old. A possible reason why children performed better on mental rotation tasks when given tangible stimuli is that the 2D tasks may actually be cognitively challenging for them. For example, there are more abstractions involved in a two-dimensional paper-pencil measurement, in which the children are required to mentally rotate the objects without being able to visually observe them (Hoyek, Collet, Fargier, & Guillot, 2012; Vandenberg & Kuse, 1978). In addition, studies using two-dimensional stimuli revealed that children do not learn about mentally rotating and transforming objects until around the fifth year of their lives (Frick et al., 2013). The ability to rotate and transform three-dimensional objects seems to emerge at an even much later age (i.e., 7 – 10 years old; Frick et al., 2013). Hence, having tangible stimuli contributes to children's performance especially on three-dimensional spatial mental rotation tasks (Frick et al., 2013).

Overall, three-dimensional learning experience enables children to have both visual and physical stimuli, which can be essential for learning about spatial concepts including spatial features, properties, locations and orientations. For those who learn better through experiencing and manipulating objects, tangible toys are essential (Curzon, McOwan, Cutts, & Bell, 2009). This type of learning experience could potentially be more beneficial for children, as a number of studies suggesting that parents use more spatial language during such interactions with their young children (e.g., Hengeveld et al., 2009; Raffle, 2008) and that children are better able to acquire and apply spatial knowledge when they are allowed to explore physically, study the orientation and location of different landmarks, as well as observe the geometric features of objects (e.g., Lehnung et al., 2003).

Two-dimensional (2D) learning. In the present study, two-dimensional learning was defined as learning through touchpad devices, such as playbooks and iPads®. Touchscreen applications on iPads® are considered two-dimensional because children are unable to physically feel or manipulate the object presented on the screen, though they are able to tap and swipe on the screen with their fingers. Furthermore, other sources of two-dimensional learning not limited to touchpad devices, such as video games, were discussed in the following section.

Video games. According to the Canadian Internet Use Survey (2013), 83% of the Canadian households had access to the internet at home and the devices used to access the internet such as computers, laptops, and touchpad devices (i.e., mobiles, tablets). Over the years, interactions with digital technologies (e.g., computers) have become the new trend, especially in educational settings. Students now not only have access to these devices at home, but also in school, as revealed by the People for Education's 17^{th} annual survey (2013) that 96% of elementary and secondary schools in Ontario have access to technology.

Ever since the last decade, exposure to these screen technologies has extended to an earlier age. In 2007, a market research by NDP group (formerly known as National Purchase Diary) in the United States revealed that children's initial exposure to screen media exhibits a fast declining rate, as more children are being introduce to screen technologies at a much younger age. Research has been conducted to examine the use of these digital technologies, such as video games, in educational settings, especially focusing on children's cognitive development. It is suggested that third-graders' mental rotation skills improve after playing with video games on a computer (DeLisi & Wolford, 2002). Other studies also found that video games promote eye-hand coordination, visual scanning, and auditory discrimination skills in young children (e.g., Greenfield, 2014; Johnson, Christie, & Yawkey, 1999).

Research shows that playing with visual-spatial video games was related to adolescences' reaction time and performance on mental rotation and spatial visualization task (Cherney, 2008; Greenfield, 1993; Okagaki & Frensch, 1994). It can also be useful for younger children. For instance, Greenfield (1993) conducted a study to investigate whether a video game intervention is beneficial for 10- to 11-year-old children. Children's spatial abilities were measured using a computer-based test battery involving mental rotation and visualization skills. After the pre-test, they were separated into either the experimental or control group in which a video game was introduced depending on the condition. Children from the experimental group played a video game involving guiding a marble ball along a three-dimensional grip using a joystick. The game has increasing levels of difficulty and was involved with spatial skills such as tracking, visualizing, as well as judging the speeds and distances of the moving objects. On the other hand, children in the control condition played a world video game, which was not spatially related. The results revealed that children who had spatial video game practice performed significantly better on the post-test than those who were in the control condition.

Similar results were found in grade three students aged eight to nine years (DeLisi & Wolford, 2002). A video game intervention involving playing with Tetris© game was introduced to the children after a pre-test. Tetris© is a type of game that requires individuals to visually pay attention to spatial patterns and details in order to fit puzzle pieces into different spots. The findings showed that children's performance on the mental rotation task was improved only when they participated in the intervention program. Further, the effect was more prevalent in children who started out with relatively poor spatial skills. Most importantly, there was no gender differences on children's performance on the post-test even though boys outperformed the girls at pre-test (DeLisi & Wolford, 2002). An important message from these findings is that computer-based video games do have educational value and can potentially reduce gender differences in spatial abilities.

Previous studies (e.g., Cherney, 2008; DeLisi & Wolford, 2002) have established the relationship between video game playing (i.e., Tetris©) and positive outcomes such as in mental rotation skills for older children. Yet, there is a limited number of studies showing that video games are beneficial for younger children's (i.e., preschoolers, kindergarteners) spatial learning. For example, Jain (2012) conducted an exploratory study and failed to find correlations between kindergarteners' mental rotation skills and the frequency they played with video games on various devices including Wii, Nintendo, PlayStation, and Xbox. Overall, Wii was the most popular gaming device, which was played by boys about 60% of the time and 44% by the girls. The results revealed that children prior to formal schooling may not have gained enough spatial knowledge to establish strong mental rotation skills. Furthermore, it is suggested that the type of games (e.g., focus on movements activities) engaged by the children may alternatively influence their performance on the mental rotation task, as these games are less related to spatial concepts compared to spatial-relevant games such as Tetris© (Jain, 2012).

Touchpad devices. As the technology advances, children have been introduced and exposed to handheld mobile or touchpad devices at an early age, suggesting the usage of these devices is on the rise (DeLoache & Chiong, 2009; Rideout, 2013). A recent survey conducted in the United States found that 75% of the children under eight years of age (N = 1,384) had access to touchpad devices (i.e., smartphones, tablets) at home, which is significantly higher than two years ago (i.e., 52%; Rideout, 2013). Etherington (2013) even pointed out that the number of students who have access to an iPad® in class every day has exceeded 4.5 million in the United States of America.

Various studies have started to examine the educational values of touchpad devices for young children. Indeed, these devices provide children with a more intuitive interface (McManis & Gunnewig, 2012), as immediate feedback is provided to them after each input. Some mobile applications on iPhone® and Andriod® devices were found to be linked to language growth especially in Japanese, French and English for second language learner and for children ages three to five (Chiong & Shuler, 2010; Godwin-Jones, 2011; Kukulska-Hulme & Shield, 2008). Touchpad devices, especially iPads® have also been integrated into classrooms for various learning initiatives including language and mathematics (Hutchison, Beschorner, & Schmidt-Crawford, 2012; Manuguerra & Petocz, 2011). Research also showed that most parents exhibited similar amount of emotional (e.g., providing encouraging words) and physical support (i.e., direct physical contact) during iPad® time compared to other play activities (Petkovski, 2014).

Some studies have shown that the use of screen media technology, such as computers and touchpad devices, supports and increases young children's social, cognitive, language and mathematical skills (e.g., Petkovski, 2014). Even though some past studies (e.g., Hutchison et al., 2012; Penuel et al., 2009) have established the relationship between the use of educational technology and positive outcomes for preschool-aged children, such as in literacy skills, there is still a gap in the use of these devices and whether it facilitates children's spatial learning in particular. McManis and Gunnewig (2012) indicate that these devices provide preschoolers with the visual stimulation as well as immediate response on different stimuli, which promotes spatial learning, as children are provided with instant feedback (e.g., whether they move the puzzle piece to the right spot) from their actions. For instance, Sinclair and Bruce (2014) suggest that playing with spatial applications, such as *Spot the Dots* (i.e., an application that allows children to compare the quantity of two squares and understand that the bottom one is bigger than the top one; Sinclair & Bruce, 2014) on an iPad® allows children as young as four and a half years old to use spatial reasoning skills to examine their decisions after immediate feedback, as well as gestures to strengthen the understanding of fundamental numeracy concepts of quantity, magnitude, and ordinality. Others such as Saylor and Rodriguez-Gil (2012) suggest that young children are only receiving visual and auditory stimuli during their experiences with iPads®. For instance, when playing with a visual-spatial game, the child is only allowed to compare the height of two objects by looking at them. He/she is able to neither physically rotate and observe the object from different orientations, nor learn about the size differences at the same time.

Another study conducted by Sutton (2006) has also found a positive correlation indicating that 2D learning on a touch screen device may facilitate children's learning on the use of landmarks and their understanding of object relations. In this study, the ability of children from two to four years of age to use landmarks for a spatial search task on a touchscreen monitor was examined. They were presented with a touchscreen with indistinct landmarks such as trees, and distinct landmarks like farm animals, and barns. The children were required to find the character “Barney” who was hiding behind certain landmarks. On the practice trial, the children were asked to find Barney after he disappeared behind a landmark. The screen went dark immediately after Barney disappeared, and the experimenter covered the children’s eye for five seconds. During the beacon trials, the children were asked to touch either the distinct beacon, such as barns and animals to find Barney. During the landmark trials, the children were required to touch the trees and searched for Barney. The result showed that children were able to use visual cues (i.e., different landmarks) to find Barney’s location at as young as two years of age (Sutton, 2006). Furthermore, four-year-old children exhibited understanding of locations and orientations of landmarks and were able to pinpoint the location of the target. This finding demonstrates children’s ability to code a location using visual cues as spatial referents such as nearby landmarks and beacons can be learned through a two-dimensional touchscreen device. A question remains is whether children can use visual cues to identify and locate their surrounding 3D environment after their learning via a 2D source.

During children’s interaction with touchpad devices, it is vital for parents to recognize the importance of incorporating parental scaffolding during the use of technology (Radich, 2013; Zack, 2010). Without support such as scaffolding and asking questions from teachers and parents, experiences with technology alone cannot support children’s development and learning (McMains & Gunnewig, 2012; Schugar, Smith, & Schugar, 2013). Studies have suggested that parents are more engaged in the content during story time with their three- and five-year-old children on traditional storybooks compared to an electronic book (e.g., Parish-Morris, Mahajan, Hirsh-Pasek, Golinkoff, & Collins, 2013). Specifically, Parish-Morris et al (2013) found that parents spend more time engaging in story-related conversations rather than behavioural-focused instructions such as how to turn on or off the e-book. Using a repeated-measure methodology, Krcmar and Cingel (2014) presented similar results examining parent-child reading interactions between traditional and iPad® books. In this study, parents were asked to read two books, one in traditional format and one in electronic format. The two books, *Quiet Bunny* and *Quiet Bunny, Noisy Puppy,* were chosen because of the similarity in style, as they were written by the same author from the same series, targeting the same age group. The joint reading interactions were videotaped and later coded for parents' verbal comments. At the end, children's reading comprehension was assessed via 14 questions drawn directly from the storyline (e.g., "At the end of the story, who got bigger?"). They were provided with two-response options (e.g., "Bunny" or "Punny") for these questions. Overall, they found that parents provided more information and instruction related to the technology use such as turning the page in the electronic reading condition. In contrast, in the traditional book reading condition, more evaluative comments (e.g., "This bunny is very cute") and content-related questions (e.g., "Do you know where the bunny is going?") were used by these parents. Furthermore, children showed a higher level of reading comprehension after reading the traditional storybook compared to the electronic storybook. Their findings are particularly significant to note, given that high quality parental input such as evaluative comments, questions, and affirmations (e.g., "That is right! The bunny is going home") are essential features in parent-child joint reading interactions (Haden, Reese, & Fivush, 1996)

As the focus of the present study was on parental spatial input, the question remains whether parents provide a broader variety of spatial talk and a greater amount of spatial language during experiences interacting with 3D spatial toys, in comparison to interaction with 2D learning platform. Certainly, parental input during parent-child interactions while playing with touchpad devices such as the iPad® is in need of further investigation, especially on children's spatial acquisition. It is also important to investigate how children express spatial knowledge from their learning on a two-dimensional stimulus to the real environment. Thus, the present study examined the nature of parental spatial language engaged during parent-child interaction with 3D (i.e., tangible blocks and puzzles) and 2D (i.e., visual-spatial applications on an iPad®) and whether playing with these visual-spatial applications facilitates children's spatial ability as a result of a greater amount of spatial language input by parents.

Comparing 3D versus 2D learning outcomes. It is assumed that what children learn at an early age could impact their interests, knowledge, and achievement in later grades, which contributes to behaviours and study preferences in future academic fields (e.g., Barnett & Ceci, 2002). Therefore, when it comes to learning, one of the goals for parents and educators is to foster children's ability to express their knowledge in new contexts and contents that are beyond the initial learning. Usually, children's knowledge is assessed via a task related to that knowledge, such as using a mental transformation task to measure children's visual-spatial skills (e.g., Catterall, 2002; Macaulay, Cree, & Macaulay, 2000). The ability to express knowledge is involved with one's ability to understand and apply what he/she learned from one source to another (Marini & Genereux, 1995; Macaulay et al., 2000). For example, when reading a book about fire, children are required to understand the content of the book in order to answer questions about it or to narrate the story in their own words. In this case, the learning outcome involves better reading comprehension skill and the ability to answer questions, hence, the ability to express their knowledge regarding the storybook and further apply the knowledge to real-life situations (e.g., do not play with fire because you may get burned). Acquiring the ability to express one's knowledge is a complex process that takes place especially during early school years. However, the ability to express knowledge of what was learned only occurs under certain circumstances (Barnett & Ceci, 2002; Brown, Kane, & Long, 1989). For instance, Brown and colleagues (1989) conducted a series of experiments examining a group of three- to ten-year-old children's ability to perform analogous problems. The result revealed that children performed better on the analogous problems when they developed a fully and deep, rather than superficial, understanding (Brown et al., 1989).

The ability to express learning and apply knowledge onto new sources enables the development of abstract thinking and deductive reasoning skills, which are essential for one's performance in school and career fields (Hayne, 2006). In order to successfully express learning across different content and context, children are required to have a flexible representational system, the ability to retrieve cues, and the cognitive capacity to encode the cues to corresponding referents presented in real life scenario (Barnett & Ceci, 2002; Hayne, 2006). Over the years, researchers have been investigating the nature of learning, the extent to which it occurs, and the nature of its underlying mechanism (e.g., Barnett & Ceci, 2002). Indeed, during the early years of children's lives, they learn and develop the ability to express their knowledge. Often, they learn through play activities, which provide them with opportunities to apply what they learn into the real-world environment (Vygotsky, 1981). For example, when a child learns about building with blocks, he/she needs to understand the symbolic meaning of blocks, as a short block represents a shorter building and a tall block represents a taller building.

Presumably, expressing knowledge within the same dimension (i.e., 3D to 3D) is less challenging compared to understanding and applying information from one dimension of stimuli to another (i.e., from 2D to 3D; Barr, 2010; Zack, Barr, Gerhardstein, Dickerson, & Meltzoff, 2009; Zimmerman, Christakus, & Meltzoff, 2007a). This is because the cues (i.e., understanding 2D stimuli and applying the knowledge in 3D environment) that are presented at encoding are mismatched with the ones that are available at retrieval. Zack and colleagues (2009) conducted a study examining how 15-month-old infants express their knowledge within- or across-dimensions. A group of infants was introduced to the within-dimension condition, in which they were provided with either the 2D (i.e., a touchpad) or 3D (i.e., real animal objects) source. For the 3D source, an experimenter pressed a button on the object, which activated a switch that produced a different sound for each object such as a horn honking bus. For the 2D stimuli, the experimenter pressed a virtual button on the screen, which also activated a different sound for each stimulus. The infants were tested at the end of the study to examine whether they could physically perform the action (i.e., show knowledge of understanding the action) to elicit the response from the 2D or 3D stimuli. In the across-dimension condition, infants experienced the same procedure, yet they were presented with the opposite source (i.e., watched experimenter pressed a 3D object, but had to perform the action on a 2D touchpad device) at final testing in order to determine whether they can apply their learning to a novel stimulus. The results showed that infants were able to perform the desired actions in each condition, but those who were in the within-dimension condition (e.g., 2D to 2D, 3D to 3D) outperformed those who were in the across-dimension condition and exhibited fewer errors (Zack et al., 2009).

Given the increased use of screen media technology, more children are now exposed to television, computers, and touchpad devices at a much younger age (Zimmerman, Christakus, & Meltzoff, 2007a). It is essential to examine whether children can relate information between 2D (i.e., screen media platforms) and 3D (i.e., real-life demonstrations) sources during play. It is also important to investigate whether children learn from these 2D devices and are able to show their knowledge within- or across-dimension. According to a nationally representative United States phone survey conducted by Rideout (2013), among families with children aged eight and under, 40% of them own, or have access to touchpad devices, such as iPads®. The percentage of children with access to both smartphone and tablets has drastically increased from 52% to 75% in two years. The amount of time spent using these touchscreen devices has also tripled to 1.5 hours per day for children under eight years old. Furthermore, 80% of children aged two to four are now using a touchscreen devices on a daily bases among those who use a touchscreen devices in a typical day, compared to 39% two years ago. As a third of children (38%) under two years old have now used touchscreen and mobile devices as part of their daily activities, research examining whether these touchscreen devices facilitate children's learning and development has been mainly focusing on infants and toddlers under three years of age (e.g., Barr, 2010; Brito, Barr, McIntyre, & Simcock, 2012; Dalgarno & Lee, 2010; Sutton, 2006).

Previous work suggests that children who are younger than three years of age generally learn less from 2D sources, including televisions, touchpad devices, and books (e.g., e-books) compared to live demonstrations. This phenomenon is known as the video deficit effect, as children under three cannot proficiently imitate and learn from 2D sources compared to their learning from real-world objects and events (e.g., Barr, 2010; Hayne, 2006; Zack, 2010). For instance, Ganea, Bloom-Pickard, and DeLoache (2008) showed a group of 18- and 24- month-olds novel labels from both 2D (i.e., picture books) and 3D (i.e., real 3D objects in the environment) sources. The young children were able to express their knowledge by identifying objects in the surrounding 3D environment after learning about the same objects in a book and vice versa. However, they were better able to understand and identify the real objects when realistic photographs rather than cartoon representations of the 3D objects were shown (Ganea et al., 2008). Other studies (Roseberry, Hirsh-Pasek, & Golinkoff, 2014; Roseberry, Hirsh-Pasek, Parish-Morris, & Golinkoff, 2009) also provide experimental evidence suggesting that children younger than 35 months of age can only learn novel verbs efficiently through interactions including live (i.e., where experimenters interacted with the child in a real-live situation) and video chat (i.e., where experimenters interacted with the child through a video chat session) demonstrations.

In addition to examining outcomes of learning, such as how young children apply their knowledge onto different contexts and content, researchers are also concerned about whether their learning from 2D sources can persist over time, as children are required to retain a piece of information they learned through 2D stimuli. A group of 18- and 24-month-old toddlers saw an experimenter demonstrating on pre-recorded videos or a picture book about how to make a novel three-step toy rattle (Brito et al., 2012). Their learning was later tested through their ability to imitate the three target steps in a real-life environment after a specific delay (e.g., two or four weeks). Results revealed that children as young as 18 months of age were able to recall and retrieve the information to perform the target actions after a delay of two weeks, and 24-month olds were able to do the same after four weeks of delay, which demonstrates the long-term continuities of children's ability to express their knowledge when they are required to imitate actions (e.g., Brito et al., 2012). Many studies have examined the learning outcome of children's language, mathematical, and spatial learning through a variety of tasks (i.e., Levine et al., 2012). However, there is a scarcity of research investigating how children express their spatial knowledge within- and across-dimension and whether their spatial knowledge persists over a long period of time.

What is the underlying mechanism that explains children's ability to express their spatial knowledge in real-life environments, especially after acquiring that knowledge from 2D sources (i.e., virtual reality)? Often, children's spatial abilities are shown to be related to activities in the environment, including walking to school (Joshi et al., 1999), exploring an unfamiliar area, and assembling toys (e.g., Newcombe, 2010). McComas, Pivik, and Laflamme (1998) investigated how six- and seven-year-old children's apply spatial learning to a real environment and found that those who experienced virtual reality training performed poorer than those who trained in the real environment. This finding suggests that children exhibit a better learning outcome when they are required to learn and express their knowledge within the same domain, compared to learning and expressing knowledge across different domain (i.e., 2D to 3D). Overall, many studies have examined children's ability to apply what they have learned across different contexts (e.g., Zack et al., 2010). However, little is known about how children's express their spatial knowledge via 2D sources, and whether using 2D sources promotes or hinders spatial learning, especially with older children (i.e., preschoolers, kindergarteners).

Present Study

Early spatial ability is predictive of one's future achievement in many academic domains and STEM-related occupations (Shea et al., 2001). Given that parental input plays an important role in fostering children's early spatial abilities, the current study examined three objectives with regards to parental spatial input during play interactions with their young children, provided insights on parental spatial input, and investigated the factors that may influence such input. Further, it provided practical implications for children's early spatial development and education by examining whether children's spatial development can be facilitated and fostered by parental input during play interactions.

Objective one. Evidence shows that a great deal of spatial language occurs during spatial activities compared to non-spatial activities (e.g., Hermer-Vazquez et al., 2001; Landau, & Jackendoff, 1993; Loewenstein & Gentner, 2005; Pruden et al., 2011). Specifically, engaging in three-dimensional (3D) spatial activities using blocks and puzzles elicits a greater amount of spatial language in both parents and their children compared to non-spatial daily activities such as drawing (Ferrara et al., 2011). In turn, children who hear more spatial language and/or engage in more spatial activities often perform better on spatial tasks, possibly due to more spatial language input from the parents. However, research has mainly focused on parental spatial input during activities involving 3D toys. There is very limited research examining the use of two-dimensional (2D) touchpad technologies, such as playbooks and iPads®, as a medium for children's spatial learning. Given the use of 2D devices has been on the rise over the last decade (Rideout, 2013; Zimmerman et al., 2007a), children are introduced and exposed to these devices at much younger ages than in the past. Currently, the majority of research on children's learning through 2D devices has focused on language development, such as literacy skills. It remains unclear whether these devices have an educational value for children's spatial learning. Further, no study has examined whether the amount of spatial language parents produce during interactions with 2D devices is comparable or equivalent to interactions with 3D spatial toys, and whether it hinders or promotes children's spatial learning.

The present study was an exploratory study to examine the frequency and variation of parental spatial language input during different spatial learning media (3D and 2D) with their young children (aged three- to five- years) and its effects on their early spatial competence. Thus, the first objective examined the differences in the frequency and variation of spatial language produced by parents during 3D versus 2D spatial learning experiences with their children. Based on previous research (Pruden et al., 2011), it was expected that parents would engage in more spatial talk with regards to categories such as spatial dimensions (e.g., big, small, size), shapes, and spatial features (e.g., side, line, straight) during the 3D spatial learning experience. During the 2D spatial learning experience, it was anticipated that parents would engage in more spatial talk with regards to spatial orientations and transformation (e.g., turn, rotate). This hypothesis was based on previous studies (e.g., Krcmar & Cingel, 2014) suggesting that parents spend more time on instructional language (e.g., tap once to turn/rotate the shape) rather than the content of the story with the preschoolers during story reading time on an iPad®.

Objective two. It is suggested that children's spatial competence is related to the amount of spatial language they produce, which is linked to how much spatial language they hear from their parents, especially during spatial activities (Ferrara et al., 2011). In line with past research, the second objective had two purposes. First, we aimed to replicate this result to provide supporting evidence on the relationship between parental input (i.e., spatial language and activities) and children's spatial language output. It was anticipated that the frequency of parental spatial language and spatial activities engaged at home would be positively correlated to the frequency children's spatial language produced in both 3D and 2D spatial learning experiences.

Further, this study investigated the development of children's early spatial ability by examining children's performance on the spatial tasks. Given that spatial learning is related to one's ability to orient, navigate oneself, and understand the relationships between objects in the 3D physical world (e.g., Newcombe, 2010), it was essential to investigate whether children can understand and apply spatial learning efficiently from both 2D and 3D learning to real life situations and perform well on the spatial tasks accordingly. Zack and colleagues (2009) suggest that 15-month-old infants already exhibit learning from within (3D to 3D) and across (2D to 3D) domains by performing the target actions (i.e., press a button on real objects). However, no studies have examined children's spatial learning. Specifically, this study investigated whether children can express their spatial knowledge both within (i.e., 2D to 2D, 3D to 3D) and across (i.e., 2D to 3D, 3D to 2D) dimension, with regards to whether their performance on the 3D and 2D spatial tasks was related to the frequency and variation of spatial words they produced, as a result of the types (3D versus 2D) of parental spatial input during 3D and 2D learning experiences.

Objective three. In addition to the different spatial leaning experiences (3D and 2D), other factors such as parents' levels of spatial anxiety and attitudes towards mathematics may also predict the amount of parental spatial language produced during parent-child interactions were examined in the current study. Past studies suggest that teachers' and parents' attitudes toward mathematics are highly related to how much they involve and engage in mathematical-related activities and speech (e.g., Farrant & Zubrick, 2013; Gunderson et al., 2012; Gunderson et al., 2013). A more positive attitude towards mathematics often leads to more numeracy talk (i.e., talking about numbers, quantity) during daily interactions (e.g., Gunderson et al., 2013). Given that spatial ability is viewed as a strand of mathematics (Fennema, & Romberg, 1999), it is assumed that one's level of spatial anxiety, attitude towards mathematics, and spatial language production also exhibits such relationship. Thus, the present study examined whether parents who had a higher level of spatial anxiety and a relatively negative attitude towards math would engage in less spatial talk with their preschoolers during the free play sessions. Parents were given two questionnaires measuring their levels of spatial anxiety and attitudes toward math.

Method

Design

This study was a mixed-method design with the collection of both qualitative and quantitative data. It was a repeated-design study consisting of two home visit sessions and an in-lab component to examine the nature of spatial language produced by parent-child dyads during their interactions with three-dimensional spatial toys such as blocks and two-dimensional visual-spatial applications on an iPad®. The children's spatial abilities were assessed during the second home visit and the in-lab visit on three different tasks. The interactions between parent-child dyads were videotaped, transcribed, and coded for spatial language.

Participants

Thirty-six native English-speaking children and their parents were recruited from Waterloo, Kitchener, and Cambridge area through the following media: online advertisements on Kijiji website, online posts on the Child Language and Math Lab Facebook page, baby database, referrals, as well as flyers to local early year centers and libraries. The final dataset consisted of 34 child (20 girls, 14 boys) participants (M_{age} = 50.97 months, *SD* = 7.58; *Range* = 37 months to 67 months). Two participants were excluded from the final dataset due to the following reasons: one child was formally diagnosed with a learning difficulty, and the one child was non-verbal during the first home visit.

In 26 videotaped home visit observations, the primary parent was the mother. For seven home visit observations, the primary parent was the father. A primary parent refers to the parent who participated in the present study and interacted with the focus child during both home visits. One observation consisted of a primary caregiver, the child's grandmother, as the child's mother is a single parent and she was not able to participate in the home visit sessions.

The SES of a family was determined by the highest maternal education level attained, as using only mother's highest education level is common and maternal education is found to be a good proxy for SES (e.g., Catts et al., 2011). The highest education level attained by mothers was as follows: 3% of mothers completed high-school, 21% with college, 44% had a university degree, and 32% of mothers had a graduate degree or professional training.

The parents signed a consent form at the beginning of the first home visit. Upon the completion of the lab visit, each family received a $10.00 Tim Horton's gift card for participating in this study.

Materials

Three-dimensional (3D) toys. Four types of 3D tangible toys were used in the present study including 80 pieces Mega Blocks©, 100-pieces building foam blocks, a shape sorter, two-dimensional flat shapes, as well as 20 different tangram puzzles. The foam blocks that were brought to the homes consisted of shapes such as 3D squares (i.e., cubes), rectangles, circles (i.e., cylinders), triangles, and bridges. Among the 2D flat shapes, three squares, three rectangles, four circles, and four triangles were brought to the participants' homes. Ten types of shapes (i.e., square, equilateral triangle, acute triangles, rectangles, half circles, circles) in five colours (i.e., a total of 50 pieces) were included in the tangram puzzles. Depending on the different patterns, the number of pieces required to complete the tangram puzzles varied. Toys that were brought to the home visit sessions were sanitized and cleaned after each play session.

Visual-spatial applications. Four visual-spatial applications were pre-loaded and installed on an iPad® involving two block building, 20 tangram puzzles and shape recognition. The visual-spatial applications were selected as they are comparable with the three-dimensional (3D) tangible toys used in the first home visit (i.e., two sets of blocks, tangram puzzles, and a shape sorter). See Appendix A for a screen shot of all the applications.

i. *Two block building applications:* The two applications: “Blocks Rock” created by Zephyr games and “Build with Blocks HD Lite” created by Jocada were selected. These two applications provided children with an opportunity to build constructions such as castles and houses freely on the screen with provided blocks. There were no levels involved in these two applications. In the “Blocks Rock” applications, children could either race against the block to match shapes and colours of a provided construction, or to build freely with five shapes (i.e., a square, two different sized triangles, and two different sized rectangles). In the “Build with Blocks HD Lite” application, they could build any constructions with a bridge shape, a triangle, a square, and two triangles. According to the creators, these two games are age-appropriate and suitable for preschooler. These two applications were selected because of their comparability with the tangible foam blocks and Mega Blocks©.

ii. *Fifteen tangram puzzle applications:* Tangram puzzles (i.e., “Cat”, “Christmas tree”, “Dog”, “House”, “Endless alphabets”, “Birds”, “Sea animals”) created by “Kids Doodle & Discover” were selected. Patterns such as cats, houses, sea animals, houseware, and transportations were presented in each corresponding game to the parent-child dyads during the 2D spatial learning experience. Parent-child dyads were allowed to play with all twelve levels in each game, as long as they were unlocked. The levels did not differ in difficulty, as all of them included seven shapes (i.e., a parallelogram, a square, and five different sized triangles). The tangram puzzles were presented as grey-shaded figures with white lines indicating where the pieces would fit. These tangram puzzles were designed for children between three and five year olds, and were selected because of their comparability with the tangible tangram puzzles. For a detailed list of the games, see Appendix B.

iii. *A Shape recognizing application:* “Shapes Toddler Preschool” created by Toddler Teasers is the application that was used. This application was selected due to the comparability with to the 3D tangible shape sorter. This application was created for toddlers and older children. It requires children to answer flashcard quizzes that appear with four shapes at a time and to fit shapes (i.e., a heart, an oval, a crescent, a square, a triangle, a rectangle, and a half circle) into empty slots provided.

Demographic and Activity Questionnaire. The Demographic and Activity Questionnaire was designed to collect information on children’s gender, date of birth, language spoken, number of siblings, number of hours they spend in daycare/preschool, parents’ highest level of education, whether they play with screen technologies (e.g., playbooks, iPads®, smartphones) at home, and the total number of hours per week they spend on these technologies. An example question would be, “Does your child have access to mobile devices, such as iPods or smartphones? Or touch pad devices, such as playbooks or iPads? If yes, what kind of devices, how many hours/week does the child spend on these devices, and how many of these hours are spent on education applications.” Twenty-four questions were presented on the questionnaire. It took approximately 10 minutes for the parents to complete. Refer to Appendix C for a detailed copy of the questionnaire.

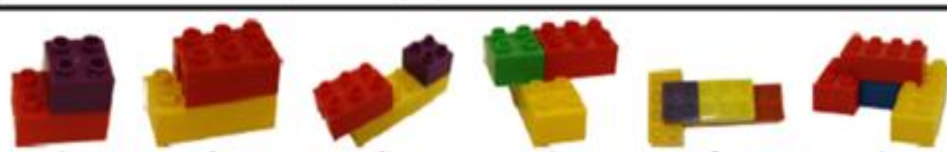
Math and Visual Spatial Activities Questionnaire. The Math and Visual Spatial Activity Questionnaires (Dearing et al., 2012) was adopted and used in the present study to assess the type of math and visual-spatial activities the parent-child dyads engage in at home. Thirty-six questions on two types of activities were presented on the questionnaire: math and spatial (Cronbach's alpha = 0.85). The first sixteen questions were designed to assess children's math activities. Questions such as, "How often does your child play card games that use numbers or counting", "How often does your child add or subtract numbers in his/her head", and "How often does your child use calendar and talk about dates" were asked. Parents were asked to indicate their response on a 5-point Likert scale: Never, Seldom (A few times per year), Occasionally (A couple of times per month), Often (Weekly), and Many times per week.

The second part of the questionnaire consisted of spatially-related activities. Questions such as "How often does your child play with construction toys such as building blocks?" and "How often does your child fold or cut paper to make 3D objects, such as paper airplanes?" were included. In this part, parents were asked to circle their response on a 5-point Likert scale: Never, Seldom (A few times per year), Occasionally (A couple of times per month), Often (Weekly), and Many times per week. The questionnaire took between 10 and 15 minutes to complete this questionnaire (see Appendix D for a detailed copy of the questionnaire).

The Math Attitude and Spatial Anxiety Scale. The Math Attitude and Spatial Anxiety Scale (Cronbach's alpha = 0.98) consisted of a Math Attitude Scale (Fennema & Sherman, 1976; Schackow, 2005) assessing parents' overall attitude towards mathematics, as well as a Spatial Anxiety Scale (Lawton, 1994) assessing parents' level of spatial anxiety. Fifty-five items on the Math Attitude Scale were presented to the parents. Questions such as "Mathematics is a very worthwhile and necessary subject", "I enjoyed studying mathematics in school", and "I did not like being introduced to new mathematical content" were included. Sixteen of the items were reversed scored. Parents were required to check off which best indicates how closely they agree or disagree with the feeling expressed in each statement on a 5-point Likert scale (i.e., Strongly disagree, disagree, neutral, agree, strongly agree). The score for this scale ranged from a minimum of 55 to a maximum of 275; a higher score indicates a more positive attitude towards mathematics.

Eight situations that require the use of spatial and navigation skills were included in the Spatial Anxiety Scale. Statements such as “Finding your way around in an unfamiliar mall” and “locating your car in a very large parking lot or garage” were included. Parents were asked to check off which best indicates their level or anxiety on a 5-point Likert scale (i.e., (1) not at all, (2) not much, (3) neutral, (4) much, and (5) very much). The score for this scale ranged from 8 to 40; a higher score represents higher level of spatial anxiety. Refer to Appendix E for a detailed copy of the Math Attitude and Spatial Anxiety Scale.

The Test of Spatial Assembly. The Test of Spatial Assembly (TOSA; Verdine et al., 2014), a three-dimensional (3D), one-on-one block design test, was used to assess children’s spatial transformation and mental rotation skills. This test was created due to the dearth of spatial tests for younger children. For the present study, six constructions made of interlocking blocks



Design	1	2	3	4	5	6	Total
No. of pieces	2	2	3	3	4	4	18
Block lengths	2, 3	3, 4	2, 3, 6	2, 3, 4	2, 3, 4, 6	2, 3, 4, 6	
Vertical location	1	1	3	3	5	6	19
Rotation	0	1	1	1	2	3	8
Translation	1	1	3	3	5	6	19
Total	2	3	7	7	12	15	46

Figure 1. Six block constructions and dimensional scoring.
Note. Piece rotation will not be scored for component block that are 2 x 2 in dimension because they are symmetrical (Verdine et al., 2014).

(see Figure 1; Verdine et al., 2014) were included and administered to children individually. The researcher glued some of the blocks in advance in order to provide the children with more size options (i.e., 2 pips x 6 pips), given the original Mega Blocks© only have sizes such as 2 x 2, 2 x 3, and 2 x 4 in dimension. There were two levels for each construction. The bottom level always contained a *base* block, which was the biggest block in each model. The top layer had at least one but no more than two blocks for each construction model. The number of blocks in each constructions vary, in which the first two constructions contained two pieces of Mega Blocks©, item 3 and 4 consisted of three Mega Blocks©, and the last two designs were constructed with four pieces of Mega Blocks©. Each subsequent item is more difficult. On average, testing took approximately between 10 and 15 minutes for the children, however, the assessment was not timed. Each child was granted two chances for each construction, and their performance was videotaped for further scoring.

In the present study, the same scoring procedure by Verdine and colleagues (2014) were used. The scoring procedure involved two types of scoring: Match scoring and Dimensional scoring. For match scoring, the researcher gave the child one point if his/her construction matched the original model one hundred percent. The score ranged from 0 to 6, as there the children were required to complete six constructions in total.

There were two steps of dimensional scoring. The first step of dimensional scoring applies to all six constructions items. In this step, the coding was based-related coding, and the researcher would be coding child’s construction in three categories: Vertical location, rotation, and translation. Vertical location was used to assess whether the focus child can successfully place the component block on the correct level compared to the base block. Rotation was scored by determining if the component block is orientated correctly with respect to the base block. The rotation would be either parallel or perpendicular. However, rotation score would only apply when the block was bigger than 2 x 2 in dimension. The rationale was that the 2 x 2 block would appear to be a square, which would be the same regardless of the rotation. A translation point would be given if the component block was placed on the right pipe in comparison to the base block. For instance (Figure 2; Verdine et al., 2014), if the space between two blocks (i.e., one is 3 x 2 and the other one is 2 x 2) was 2 x 2, the child would only be awarded for translation if he/she successfully constructed a model with a 2 x 2 space in between the two blocks. This child would also be awarded for two points when he/she placed the two blocks (3 x 2 and 2 x 2) on the correct sides accordingly.

The second dimensional scoring step focused on the more complicated constructions (Items 3 to 6), as they were consisted of more than two blocks on the top level. In the second set of dimensional scoring, only the relation and orientation between blocks on the top level were considered. Thus, the base level was not coded. This step was applicable for items 3 to 6. The biggest block on the top level would be seen as a *ground* piece. Vertical location were used to assess whether the focus child understand the concepts of "one is on top of the other". Take item four (see Figure 1) for example, in this item, there were two blocks on the top level (i.e., block A,

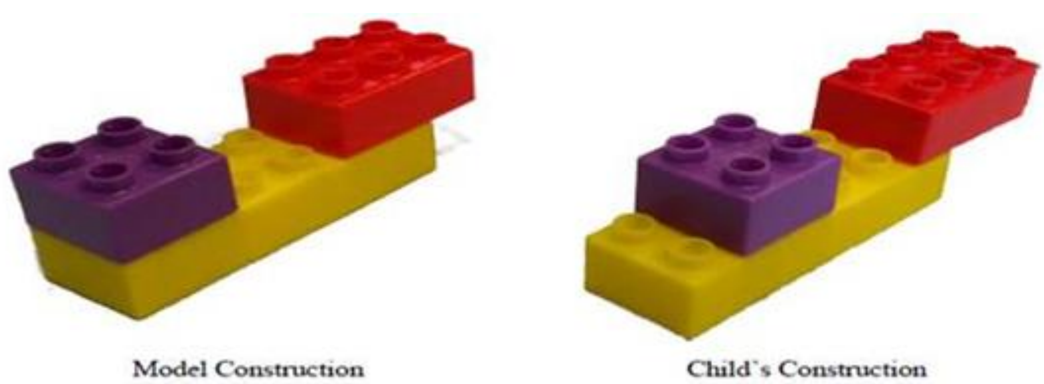


Figure 2. Example for dimensional scoring: translation step one. This child will receive one mark for having a 2 x 2 space between the purple and the red block.

B) and two blocks on the bottom level (i.e., block C, D). The completed item four would follow these criteria, 1) block A would be on top of both block C and D, 2) block B would only be on top of D, and 3) block A and B would be on the same level, and block C and D would be on the same level. A child would be given five vertical location points, if he/she successfully constructed a model that followed all these criteria. Rotation scores were awarded if the focus child placed the component pieces in the correct orientation in relation to the ground piece. Using the item four as an example, a correct construction would meet the following conditions, 1) block B was placed paralleled to block D, and 2) block C was placed perpendicular to block D. If the child placed the blocks appropriately, he/she would be given two points for rotation. Lastly, five translation scores would be given to the child if he/she 1) placed block A in the middle of block C, 2) placed block B right beside block A, leaving a 2 x 2 space at the end on block D, and 3) selected the correct block dimensions for each piece. Overall, dimensional scores ranged from 0 to 46. The final scores were calculated by adding the matching and dimensional scores together, which ranged from 0 to 52. A higher final score indicated a better spatial assembly skill in the child.

The Woodcock Johnson III, the Test of Achievement, and the Test of Cognitive Ability. Woodcock Johnson III, a one-on-one, standardized assessment that is often used by educational psychologists (Woodcock et al., 2001). It is a two-dimensional (2D) paper-pencil task designed for individuals between ages of 2 to 99 years. It has two components: Tests of Achievement and Tests of Cognitive Abilities. A number of subtests are included in the tests, and the reliability was assessed individually by the author for each subtest. In the present study, five subtests were drawn from both components to assess children’s math, language, and spatial ability. One of the tasks had a two-minute time limit, though other tasks were not timed. Testing took approximately 30-35 minutes for the youngest age group. The questions in each subtest were categorized into different entry points depending on the child's age. The tasks selected were as follows:

i. *Calculation (subtest 5):* This task (medium reliability = 85%) was taken from Woodcock Johnson III: Tests of Achievement and measures a child's mathematical computation ability. Forty-five calculation questions involving addition, subtraction, multiplication, and division along with two number drawing questions were presented to the child on a piece of paper. The child was asked to draw the number one and three before he/she started the actual questions. If the child could not perform the initial practice trial, the researcher would not proceed to the actual arithmetic questions. According to Woodcock, McGrew, and Mather (2001), a reversed three should still be counted as a correct response (i.e., "ε" instead of "з"). If they were able to draw the number one and three successfully, the researchers would ask the child to start the calculation questions. Once the child answered six consecutive items incorrectly, the researcher would stop the test.

ii. *Picture Vocabulary (subtest 14):* This subtest (medium reliability = 77%) was taken from Woodcock Johnson III: Tests of Achievement to assess children's oral language and vocabulary by identifying pictured objects. The researcher presented pictures to the child on a stand-up picture book, pointed to different objects on the book, and asked the child "Can you tell me what this is?" Pictured objects included things that a child may see on a daily basis, such as a slide, a cake, and a car, as well as things that a child may have not seen, such as a microscope and a windmill. Each child was presented with the same pictures in the same order. There are 44 pictures in total for the child to name. Once the child answered six consecutive items incorrectly, the researcher would stop the test. The child's score of this test was used as a baseline measure for children's overall language skills.

iii. *Spatial Relations (subtest 3):* This was a task (medium reliability = 81%) obtained from Woodcock Johnson III: Tests of Cognitive Abilities to assess children's visual-spatial thinking by identifying the two or three pieces that from a complete shape. The child was shown different pieces of a puzzle on the stand-up testing book. There were four practice trials for each child to understand the purpose of this task before they moved on to the actual questions. For example, the researcher would point to the two semi-circles on the page and ask the child, "Do you know what shape these are?" If the child correctly identified the two shapes, the researcher would then say, "You are correct! Look, if you put two semi-circles together, you would get a circle." Once the child understood the concept of this task, the researcher would continue with the actual questions. There were 33 items in total, the child was required to finish all the puzzle as the ceiling is dependent on the cut offs.

iv. *Visual Matching (subtest 6):* This was a subtest (medium reliability = 89%) obtained from Woodcock Johnson III: Tests of Cognitive Abilities to assess a child's ability to discriminate and recognize different shapes. There were 26 items in total. This test was timed, and each child was given two minutes to complete all the items. There were four practice trials to help the child understand the purpose of the test. The researcher showed the child four to five different shapes on the testing book, and asked the child to point to the two shapes that appeared to be the same. Because this test was timed, the child was told to point to the two shapes that looked the same as fast as he/she can.

v. *Auditory Working Memory (subtest 9):* This task (medium reliability = 88%) was taken from Woodcock Johnson III: Tests of Cognitive Abilities to measure children's working memory and divided attention. Each child was asked to divide information into two groups and shift attention resources to a new ordered sequence. The researcher said to the child as prescribed in the Woodcock Johnson III test kit, "I am going to tell you some things, like animals and foods. Then, I am going to tell you some numbers. After I said them, I want you to repeat what I just told you, but remember, I want you to always tell me the things first in the same order that I said them, then the numbers in the same order that I said them." Once the researcher ensured that the child fully understood the instruction, two practice trials would be introduced to the child. For instance, researcher would say, "5, Bird". A point was awarded if the child said "Bird, 5." There were a total number of 21 questions, and seven sets of three questions in this subtest. There were one thing and one number in the first set. Starting from the second set, the child would be asked to remember one more thing/number for each subsequent set. The researcher would stop the test when the child failed to answer three consecutive questions in a set correctly.

To score the Woodcock Johnson III, each correct answer was given one point and summed to the child's raw score. Each child would have a raw score for each subtest, resulting in five different scores. Then, using the Woodcock Johnson III Compuscore and Profiles Program (i.e., a computer software program; Schrank & Woodcock, 2001), the raw score for each subtest was entered and computed to a standardized score with a mean of 100 and standard deviation of 15. The percentile rank for each child's standardized score would also be tabulated by the computer program.

Procedure

The present study consisted of two phases: 1) two home visit sessions, and 2) an in-lab component. The procedures (see Figure 3) were the same for both of the home visits, and the children were administered several standardized subtests during the in-lab component. The present study occurred over an eight-week span.

For the first phase of the study, the researcher and a research assistant visited the parent-child dyads at their homes on two separate occasions. Parent-child dyads were provided with different toys to play with depending on the visit. At the first home visit, a set of standardized three-dimensional toys was provided. The toys brought to the homes included 80 pieces Mega Blocks©, 100-pieces foam building blocks, a shape sorter, two-dimensional flat shapes, as well as

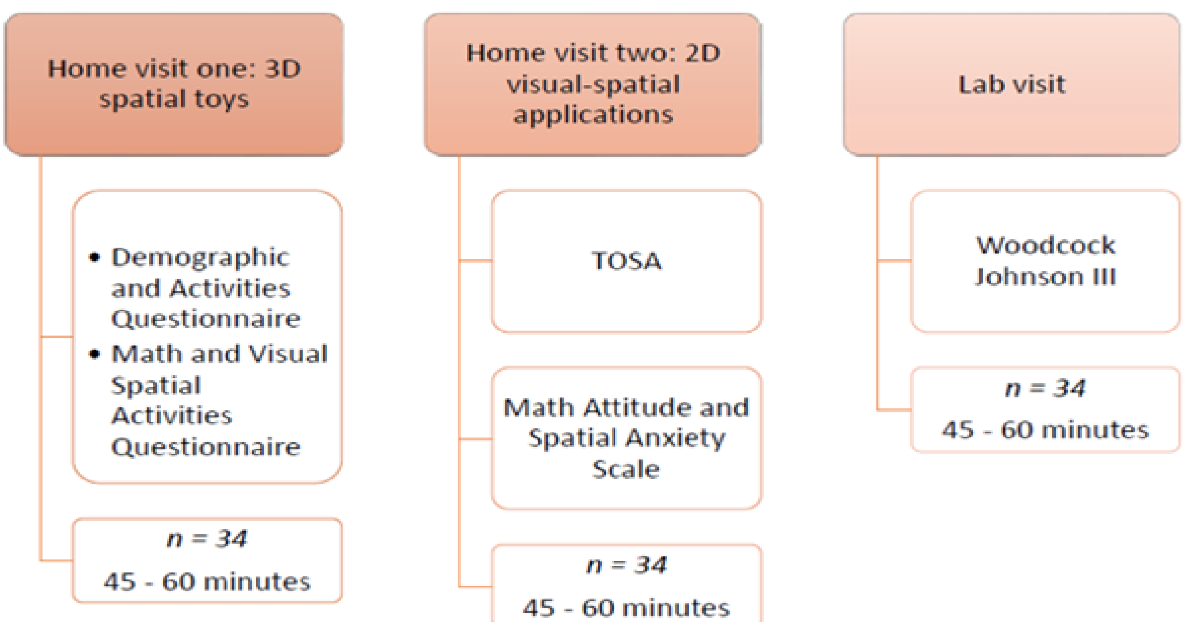


Figure 3. Procedure for each home visit and the lab visit, questionnaires filled out, tasks administered, the number of participants, and the time allocated

20 different tangram puzzles. At the second home visit, the parent-child dyads were provided with an iPad® (approximately 9.5 by 7.5 inches) with a child-friendly case preloaded with three applications focused on visual-spatial activities. These visual-spatial applications included two block building applications, 20 tangram puzzle games, and a shape recognition application. These applications on the iPad® were pre-selected to match with the activities afforded by the three dimensional (3D) tangible toys, in order to have a comparable content across the two types of learning platform (i.e., three-dimensional and two-dimensional).

All of the participants underwent the same procedure, and the order of home visits was not counterbalanced, as the child may lose interest or attention to play with the provided building toys such as Mega Blocks© after they were asked to do a block design task involving Mega Blocks© (i.e., TOSA; Verdine et al., 2014) with the researchers at the beginning of the second home visit.

Each home visit was recorded using a Sony camera on a portable tripod for transcribing and coding purposes. The camera was set up on a portable tripod. At the first home visit, parents were asked to fill out a demographic questionnaire and a questionnaire on math activities they engage in at home with their children prior to the play session after providing consent to participate in the study. The questionnaires took approximately 10 – 15 minutes to complete. After completing the questionnaires, the parent-child dyad was invited to play with the three-dimensional toys for 30 minutes. Siblings, if present, were encouraged to participate in the play session to capture a naturalistic interaction in the home setting. The entire home visit was approximately 45 – 60 minutes in length.

The second home visit, approximately two weeks after the first home visit, was conducted in a similar manner as the first home visit with two variations. First, an iPad® with pre-loaded spatial applications was provided for the parent-child dyads for their play session. Second, the parent was asked to complete a Math Attitude and Spatial Anxiety Scale prior to the play session and the child's spatial skill was assessed by one of the researchers using the Test of Spatial Assembly (TOSA; Verdine et al., 2014), which took around 10 – 15 minutes. The child was presented with a series of block constructions that was put together by one of the researchers prior to the start of the study. The Mega Blocks©, that the child was going to use, were scattered with no particular order in front of the child. The child was asked to provide oral consent to play the game with the researchers prior to the task. In each test trial, the researcher told the child that "we are going to make something with the Mega Blocks©", and he/she was required to copy what the researcher was doing in order to make the blocks to look the same. The child was also told to "feel free to use any colours that they wish," as the blocks were all in different colours. After administering the TOSA test, the parent-child dyads were invited to play with the iPad® together for approximately 30 minutes. At the end of each session, the researchers scheduled a convenient date – usually two to three weeks after this home visit - for the parent-child dyads to come into the lab to complete the second phase of the study.

At the lab visit, five subtests taken from the Test of Achievement and the Test of Cognitive Ability of the Woodcock Johnson III (Woodcock et al., 2001) were administered to the child as fun and interactive games. Oral consent from each child was obtained prior to the assessment. In addition, the child was told to feel free to discontinue the activity and take a break at any time if needed. The parent was with his/her child at all times. The lab visit was approximately 30 – 45 minutes in length.

Transcribing and Coding

A total number of 68 home visit videos were transcribed and coded using the Observer XT Program (Noldus Information Technology, 2008). First, the master student researcher, also served as the primary coder, coded all 68 observations. Then, both of the primary and secondary coders coded two observations (i.e., one from each home visit) together, in order to ensure that both coders understood the coding scheme properly. Out of the 68 observations, 50 percent of each home visit sessions (i.e., 18 for the first visit and 17 for the second visit) were then randomly selected for secondary coding to achieve inter-coder reliability. The 18 first home visit observations had a Cohen's Kappa of 0.85 and a Rho, the population coefficient, of 0.94. The 17 second home visit observations had a Cohen's Kappa of 0.85 and a Rho of 0.95. In situation where discrepancies surfaced, both coders discussed and resolved the discrepancies together to determine, then the most appropriate codes were applied to such situation.

Thirty-four videos recording each child's performance on the Test of Spatial Assembly (TOSA) were also scored independently based on the scoring scheme used by the authors (Verdine et al., 2013). The same procedure used for the home visits coding was also adopted for the TOSA scoring. Specifically, the primary and secondary coders scored two videos together to ensure they understood the coding scheme. The primary coder scored all 34 videos while the secondary coder scored twenty videos that were randomly selected to achieve inter-coder reliability. The inter-coder reliability was 100 percent.

Spatial talk. The video recordings were transcribed using the Observer XT program (Noldus Information Technology, 2008) in order to code the frequency and variation of spatial talk uttered by parents using a 3D (i.e. tangible spatial toys such as blocks) versus 2D (i.e., visual-spatial applications on an iPad®) learning medium.

The coding scheme (see Appendix F) created by Cannon, Levine, and Huttenlocher's (2007): *A System for Analyzing Children and Caregiver's Language about Space in Structured and Unstructured Contexts* was adapted, with authors' permission. This coding scheme was originally developed for and used in two studies by the creators to capture a variety of spatial words. The first study was designed to examine parental spatial language input as they engaged in puzzle play with their children (Cannon et al., 2007). The second study was to investigate parents' spatial speech input and its association with children's growth in spatial language production, and whether the correlation is positively related to children's spatial skills (Ferrara et al., 2011). Given both research studies examined spatial language production during parent-child interaction, this coding scheme was found to be suitable for the purpose of the present study.

The coding scheme developed by Cannon and colleagues (2007) consisted of two analysis levels: a) an utterances-level analysis, and b) a word-type level analysis. In the present study, only the word-type level analysis was used to examine the naturalistic spatial language in terms of amount/frequency and variation produced by the parent–child dyads. This level of analysis would enable us to tabulate the total number of words uttered by parent-child dyads to account for the varying duration of each play session. Therefore, only spatially-relevant words were coded. In this coding scheme, spatial words are categorized into eight domains:

i. *Spatial Dimensions* refers to words that describe the size of objects, people, and spaces, but excluding weight or density. This type of spatial words sometimes occurs when comparing the size of two objects. For instance, "Are the blocks the same *size*? This red one is *bigger* than the blue one."

ii. *Shapes* refers to words that describe the standard or universally recognized form of any two- or three- dimensional objects and spaces. An example is "There is a *circle*, a *semi-circle*, and a *square*."

iii. *Locations and Directions* refers to words that describe the spatial relations between objects, people, and spaces. Spatial words such as *underneath*, *on top*, and *bottom*, would fall under this category.

iv. *Orientations and Transformations* refers to words that describe the spatial orientation of objects or people in a given space. For instance, the parent-child dyad may be talking about *turning* the shape *upside down* in order to fit into the shape sorter.

v. *Continuous Amount* refers to words that describe amount of continuous quantities. Examples include “This is a semi-circle, it is *half* of a circle. This is a *quarter* circle, it is a *part* of a *whole* circle.”

vi. *Deitics* refers to words that are used to describe or identify location in relation to one another, such as *here* and *there*. When coding for this type of spatial word, it is important to rely on the context to understand the referent. For example, “Can you pick up the puzzle that is over *there* by your hand?”, ‘*there*’ would be coded but not in “Is *there* any people in the castle?”, where the context is not spatially-relevant.

vii. *Spatial Features and Properties* refers to words that describe the spatial features of any two- or three- dimensional objects, people or spaces. An example would be “This shape has a *curvy* part and two *straight* lines.”

viii. *Pattern* refers to words that describe a specific order or manner in the context of talking about spatial pattern. For example, “*First*, we will put a big rectangle on the bottom, *next*, we will put a big square on top, and *then*, we will put another big rectangle on top of the square.” The use of *Pattern* in contexts such as numbers (e.g., “What comes next after the numeral one?”) or non-spatial patterns (e.g., “The colour of the wall is blue, yellow, blue, and yellow”) is excluded.

Only spatial words used in a spatial context were coded. For example, when the parent said “I am putting the square to the *left* of the circle”, the word “left” was coded as locations and directions. However, the word “left” was not coded if the parent said “I *left* my lunchbox on the table”.

Toys. Different three-dimensional (3D) tangible toys, such as foam blocks, Mega Blocks©, shape puzzles, a shape sorter, and two-dimensional flat shapes, were provided during the first home visit. Thus, the coding included the types of toys each parent-child dyad played with to determine the time spent on each toy. These codes only applied to situations where the parent-child dyads were using the toys for purposes that are spatially related. For instance, a block play activity would be coded when the dyads are sorting the blocks by their shapes instead of colours. In addition, these codes would not be used when coding the play session at the second home visit because the parent-child dyads were only playing with the applications on an iPad®. The applications that they played with during the home visit were documented and recorded by the researcher at the time of the second home visit. In addition, parents were asked verbally to identify the types of applications they played with on the iPad® after the completion of the second home visit.

Results

An analysis of the frequency distribution of different categories of spatial talk indicated that some of the raw data was partially, positively skewed. Variables that were positively skewed included: a) all eight types of spatial categories produced by parents during 3D spatial learning experience; b) all eight types of spatial categories produced by children during 3D spatial learning experience; c) parents' spatial dimensions, orientations and transformations, continuous amount, and pattern during 2D spatial learning experience; and d) children's spatial dimensions, shapes, continuous amount, and pattern during 2D spatial learning experience.

To ensure the normality of the data, variables that were positively skewed were transformed using a square-root transformation. This type of transformation is often used to transform positively skewed data, as it compresses the upper proportion of a distribution (e.g., 100 would become 10) more than it compresses the lower proportion (e.g., 4 would become 2). Thus, it helps equate group variances across observations, and the distribution of the data becomes more normal (Howell, 2007; Tabachnick & Fidell, 2007). Further, normally distributed variables were also transformed to ensure the consistency of data analyses, and all analyses were conducted using the transformed variables. All the variables were normally distributed after the transformation.

In order to facilitate understanding of the nature (i.e., frequency and variation) of spatial talk, descriptive results are presented using untransformed variables.

Objective One

The first objective of the present study examined the nature of spatial language in which parents engaged with their preschoolers using physical toys and iPad apps. Specifically, the frequency (i.e., how many spatial words in each category were produced) and variation (i.e., how many different types of spatial categories were used) of spatial language were analyzed.

First, the frequency of spatial talk was examined. During interaction with 3D spatial toys, parents produced an average of 92.79 spatial words (*SD* = 47.70, *Range* = 22 to 228), and children produced an average of 41.06 spatial words (*SD* = 26.69, *Range* = 3 to 109). For parents, the most frequently to the least frequently used types of spatial word categories were: locations and directions (31%), shapes (25%), spatial dimensions (23%), deictics (9%), continuous amount

(6%), and spatial features and properties (4%), followed by orientations and transformations (less than 1%), and pattern (less than 1%).

For children, the most frequently to the least frequently used types of spatial word categories were: spatial dimensions (30%), shapes (29%), locations and directions (23%), deictics (11%), continuous amount (3%), and spatial feature and properties (3%), followed by orientations and transformations (less than 1%) and pattern (less than 1%).

Mean, standard deviation, minimum, and maximum number of spatial words parents and their children produced during 3D interaction with spatial toys are shown in Table 1.

For non-spatial talk during interaction with 3D toys, parents produced an average of 1408.44 non-spatial words (SD = 549.829, *Range* = 314 to 2351), and children produced an average of 781.09 non-spatial words (SD = 397.354, *Range* = 217 to 1718). Parents who produced a higher amount of "other" talk were more likely to engage in more spatial talk, r = 0.82, $p < .001$. Overall, during interaction with 3D toys, parental spatial talk occurred approximately 6% (i.e., total spatial words divided by total spatial words + non-spatial words; 92.79 divided by 1501.23) of overall language production, and children spatial talk occurred about 5% (i.e., 41.06 divided by 822.15) of their overall language production.

Correlational analyses were conducted between the frequencies of different spatial categories engaged in by parents during 3D spatial play session (see Table 2). Talk about spatial dimensions was positively correlated with continuous amount (r = 0.71, $p < .001$), locations and directions (r = 0.63, $p < .001$), and spatial features and properties (r = 0.47, p = 0.005). Talk about deictics was positively correlated with shapes (r = 0.74, $p < .001$) and locations and directions (r = 0.49, p = 0.004).

During 2D iPad® play, parents produced an average of 79.35 spatial words (*SD* = 40.20, *Range* = 4 to 155), and children produced an average of 14.85 spatial words (*SD* = 15.36, *Range* = 0 to 71). For parents, the most frequently to the least frequently used spatial word categories were: shapes (29%), locations and directions (24%), deictics (19%), orientations and transformations (15%), spatial dimensions (7%), continuous amount (3%), spatial features and properties (2%), and pattern (less than 1%).

For children, the use of spatial word types from the most to the least frequent was: shapes (46%), deictics (20%), spatial dimension (13%), orientations and transformations (12%), locations and directions (9%), continuous amount (less than 1%), spatial features and properties (less than 1%), and pattern (less than 1%).

Mean, standard deviation, minimum, and maximum number of the spatial words produced by parents and their children during 2D interaction with visual-spatial iPad applications are shown in Table 3.

For non-spatial talk during interaction with 2D applications, parents produced an average of 1301.31 non-spatial words (*SD* = 524.041, *Range* = 61 to 2174), and children produced an average of 276.53 non-spatial words (*SD* = 179.397, *Range* = 1 to 851). Parents who produced more non-spatial talk also produced more spatial talk, $r = 0.81$, $p < .001$. Overall, the frequency of parental spatial talk was 6% (i.e., 79.35 divided by 1380.66) of their overall language production, and the frequency of children spatial talk was 5% (i.e., 14.85 divided by 291.38) of their overall language production of the time.

Correlational analyses were conducted between the frequencies of different spatial categories engaged in by parents during 2D (see Table 4) spatial play session. Spatial talk about shapes was significantly related to talk about spatial dimensions ($r = 0.41$, $p = 0.02$), locations and directions (r = 0.48, p = 0.005), and deictics (r = 0.46, p = 0.006).Talk about orientations and transformation was positively, significantly related to talk about deictics (r = 0.59, p < .001).

A two-way repeated measure MANOVA analysis revealed that there was a significant difference in the amount of spatial talk engaged in by parents at home during 3D and 2D spatial learning media, [F (1, 22) = 2.85, p = 0.03, η^2 = 0.51]. For this MANOVA analysis, the within-subject variables entered were the total frequencies of all eight types of spatial categories and each individual spatial category used by parents for both 3D and 2D spatial learning media. Moreover, the child's age, gender, as well as the parent's SES and total words produced by parents during parent-child interactions were analyzed as covariates.

Parent's total words produced during interactions with his/her child [F (1, 22) = 10.712, p < .001, η^2 = 0.80] was shown to have a significant effect on the frequency of parental spatial talk. This result suggested that parents who produced more words during the parent-child interactions would also engage in a higher frequency of spatial language. Overall, parents who produced more spatial words in total during 3D interaction with spatial toys also produced more spatial words during 2D interaction with visual-spatial applications (r = 0.38, p = 0.03). However, all covariates such as the child's gender [F (1, 22) = 1.84, p = 0.12, η^2 = 0.40], age [F (1, 22) = 1.91, p = 0.11, η^2 = 0.41], and the parent's SES [F (1, 22) = 0.38, p = 0.92, η^2 = 0.12] were non-significant, suggesting that these three variables did not have an effect on the frequency of parental spatial talk.

In order to further examine the differences in the amount of parental input between the eight spatial categories, eight paired sample *t-tests* were performed for each of the learning platforms. To avoid Type I error, a significant p-value of 0.00625 (i.e., the typical p-value used in the social science research was divided by the total number of spatial categories; 0.05 divided by 8; Banerjee, Chitnis, Jadhav, Bhawalker, & Chaudhury, 2009) was used. The paired *t-tests* revealed that three out of eight types of spatial categories were used significantly more by parents during parent-child interaction with 3D toys. The three types of spatial categories were: spatial dimensions [$t(33) = 7.075$, $p < .001$], locations and directions [$t(33) = 3.248$, $p = 0.003$], and continuous amount [$t(33) = 3.937$, $p < .001$].

When interacting with 2D visual-spatial applications on an iPad® with their children, parents produced significantly more spatial words involving orientations and transformations [$t(33) = - 9.03$, $p < .001$] and deictics [$t(33) = - 4.05$, $p < .001$]. This is in contrast to the categories they produced during 3D spatial interactions. Further, the results revealed that the differences in the amount of spatial talk involving shapes [$t(33) = 0.39$, $p = 0.702$], spatial features and properties [$t(33) = 2.39$, $p = 0.023$], and pattern [$t(33) = - 0.52$, $p = 0.605$] between 3D and 2D spatial interactions were non-significant.

Apart from the amount of spatial talk, the variation (i.e., the number of the typs of spatial categories) of spatial talk produced by parent-child dyads during 3D and 2D spatial learning media was examined. The variation of spatial talk from each visit was obtained by the types of spatial talk used divided by the total number of spatial categories, which there are eight in total. For example, if the parent used four types of spatial language during the home visit, the variation score would be four divided by eight, resulting in a variation score of 0.5.

Overall, during interaction with 3D spatial toys, the type of spatial categories used by parents ranged from four to eight. Forty-seven percent of the parents ($n = 16$) produced six types of spatial categories. There was only one parent who used all eight types of spatial categories, and one parent who only used four types of spatial categories. For children, 32% of them ($n = 11$)

used a total number of six types of spatial categories. The variation of spatial categories for children ranged from two to six.

During their interaction with 2D visual-spatial applications, parents used between two and eight spatial categories. Overall, 29% of parents (n = 10) produced six types of spatial talk and 29% of the parents (n = 10) produced seven types of spatial talk. There were two parents who used all eight types of spatial talk, and one parent who used only one type of spatial talk. For children, 26% of them (n = 9) used a total number of four types of spatial talk. The variation of spatial categories for children ranged from zero to six. A detailed distribution of the variation of spatial categories engaged in by parents and their children are shown in Table 5.

In order to investigate whether the variation in parental spatial language differ between 3D versus 2D spatial learning experiences, a paired sample *t-test* was conducted. The result showed that parents did not use more types of spatial language [$t(33) = 0.90$, $p = 0.401$] during parent-child interaction with 3D spatial toys ($M_{3D} = 0.77$, $SD = 0.11$) compared to their interaction with 2D visual-spatial applications ($M_{2D} = 0.74$, $SD = 0.16$).

Objective Two

This objective had two purposes: a) To examine whether the frequency and variation of parental spatial input (i.e., parental spatial language and spatial activities engaged in by parent child dyads) led to the differences observed in the frequency of children's spatial language production; and b) To determine how children express their spatial knowledge through spatial tasks, such that whether their performance on the spatial tasks (i.e., TOSA, Woodcock Johnson III) was related to their specific spatial learning experiences (i.e., 3D versus 2D).

Objective 2a. First, it was expected that the frequency of parental spatial language input during interaction with 3D toys would be related to the frequency of children's 3D spatial talk. During interaction with 3D spatial toys, 30 parent-child dyads engaged in block building activities involving foam blocks and Mega Blocks©. Twenty-seven parent-child dyads only used foam blocks, and 19 dyads only used Mega Blocks©. In addition, 29 dyads played with the shape tangram puzzles, six dyads played with the shape sorter, and 10 dyads played with the two-dimensional flat shapes. Overall, parent-child dyads spent an average of 28.52 minutes (*SD* = 3.25; *Range* = 20.08 to 33.52) playing with 3D spatial toys. Specifically, parent-child dyads spent an average of 9.82 (*SD* = 7.95; *Range* = 0 to 28.19) minutes playing with foam blocks, an average of 6.05 minutes (*SD* = 7.46; *Range* = 0 to 28.16) playing with Mega Blocks©, an average of 8.93 (*SD* = 7.34) minutes playing with tangram puzzles, an average of 0.19 minutes (*SD* = 0.40; *Range* = 0 to 1.34) playing with the shape sorter, and an average of 0.36 minutes (*SD* = 0.96; *Range* = 0 to 5.1) playing with two-dimensional flat shapes, respectively.

A series of correlations was conducted to investigate the relationships among the eight categories of spatial language produced by parents and their children during interaction with 3D toys. The results revealed that parental talk involving spatial dimensions was positively correlated with the amount of such talk engaged in by the child ($r = 0.37$, $p = 0.03$). Other types of talk involving shapes ($r = 0.47$, $p = 0.005$), locations and directions ($r = 0.51$, $p = 0.002$), continuous amount ($r = 0.54$, $p < .001$), and spatial features and properties ($r = 0.44$, $p = 0.009$) engaged by parents were also positively related to how much their children engaged in these particular types of spatial talk. Correlations for all spatial talk categories between parents and their children during interaction with 3D toys are shown in Table 7.

To further examine the relationship between parents and their children on the nature of spatial language use, a regression analysis was conducted with children's overall spatial language production during 3D spatial learning experience as the dependent variable, and parents' frequencies of eight types of spatial categories as the independent variables. In addition, the child's age, gender, overall language competence (assessed via the *Picture Vocabulary* test), and the parent's SES were entered as independent variables. The result showed that the overall model was not significant, F (13, 33) = 1.73, p = 0.13, η^2 = 0.53, suggesting that none of the variables was predictive of children's overall spatial talk production.

Next, it was also expected that the frequency of parental spatial language input during interaction with 2D visual-spatial applications would be related to the frequency of children's 2D spatial talk. The types of visual-spatial applications played by the parents and their children during 2D spatial learning experience were documented by the researcher at the second home visit. All parent-child dyads (n = 34) played with the applications involving tangram puzzles, yet the types of puzzles (e.g., cats, houses, birds) played by the dyads varied. Sixteen parent-child dyads played with the block building applications on an iPad®. However, only five dyads played with the application about recognizing different shapes. On average, parent-child dyads spent approximately 25 minutes (*SD* = 4.47, *Range* = 6.03 to 31.57) playing with visual-spatial applications.

A series of correlations was conducted to investigate the relationship of each spatial talk between parents and their children. Only the frequency of two types of spatial categories: shapes (r = 0.38, p = 0.023) and deictics (r = 0.37, p = 0.03) produced by parents were positively, significantly related to the frequency of these types of spatial words engaged in by their children during parent-child interaction with 2D visual-spatial applications (See Table 8 for correlations between the amount of spatial talk engaged in by the parent-child dyads during 2D spatial learning experience).

Furthermore, a regression analysis was conducted to examine whether the frequency of parental spatial talk in all spatial categories in the 2D spatial learning context was predictive of children's spatial language production within the same context. The amount of parental spatial talk, the child's age, gender, language competence, and the parent's SES were entered as the independent variable. The amount of children's spatial language production was entered as the dependent variable. It was found that the parents' spatial language input during interaction with 2D visual-spatial applications was not predictive of children's spatial language output, F (13, 33) = 2.06, p = 0.07, η^2 = 0.57, however there was a strong trend approaching significance.

Lastly, it was anticipated that children's spatial language output would be related to the frequency of spatial talk they hear from their parents during spatial interaction with 3D and 2D spatial learning media, as well as the amount of spatial activities they engage in at home with their parents (e.g., Ferarra et al., 2011). A descriptive analysis revealed that out of a rating of 4 on average, parents and their children engaged in activities such as colouring and drawing (M = 3.73, SD = 0.51), playing outside (M = 3.71, SD = 0.46), building with construction toys (e.g., blocks; M = 3.41, SD = 0.78), and playing with action figures such as trains (M = 3.44, SD = 0.86) on a weekly basis (i.e., often). Overall, 26 parent-child dyads engaged in colouring and drawing many times per week. Twenty-four of parent-child dyads played outside many times per week when the weather permits. Twenty of them played with construction toys such as Legos many times per week, and 21 of them played with action figures such as cars many times per week (see Table 6).

A number of correlations was conducted to examine the relationship between children's spatial language output and the amount of spatial activities they engaged in at home with their parents. The amount of spatial activities was calculated by adding the sum of the frequency of each activity together. For example, if the parents indicated that their children have never participated in a certain type of spatial activity, a score of zero would be given to that type of spatial activity. If the parents indicated that their children engage in a spatial activity a few times a year, a score of one would be assigned. Moreover, depending on how frequently the parent-child dyads engage in certain spatial activities, a score of 2 would be given for a couple of times per month, a score of 3 would be given if they engage in the activity often (weekly), and a score of 4 would be given to frequently (many times per week). Overall, a higher score indicated that the parent-child dyads engage in a greater amount of spatial activities at home.

The results showed that the amount of spatial activities engaged in by parent-child dyads was not related to children's spatial talk production while playing with 3D spatial toys (r = - 0.08, p = 0.66). It was also not related to children's spatial talk during interaction with 2D visual-spatial applications (r = - 0.14, p = 0.42). Moreover, the amount of spatial activities engaged in at home was not correlated to any categories of spatial language produced by children in particular (see Table 9 for correlations between the amount of spatial activities and children's production of spatial language in 3D and 2D spatial learning experiences).

In order to further examine whether spatial activities and spatial language input were good predictors for children's spatial talk production during both 3D and 2D spatial learning experiences, a regression analysis was performed. The total amount of spatial talk produced by parents (*M* = 172.75, *SD* = 70.67; *Range* = 26 to 323) was computed by adding the amount of 3D and 2D spatial talk together, and the same procedure was performed to get the total amount of spatial language output by children (*M* = 55.91, *SD* = 33.11; *Range* = 17 to 130). This regression analysis was conducted with the dependent variable being the child's overall spatial language output, and the independent variables being the overall parental spatial talk along with the amount of spatial activities engaged in at home. The child's language competence, age, gender, the parent's SES, and overall language production were also being controlled for as independent variables. It was found that the amount of parental spatial talk and spatial activities engaged in at home were non-significant, *F* (6, 33) = 0.15, *p* = 0.99, η^2 = 0.03, and none of the variables in the model was significantly related to children's overall spatial production.

To further examine whether a specific type of spatial activity was related to children's spatial language production during 3D and/or 2D spatial learning media, a series of correlations was conducted among the 20 individual spatial activities, children's spatial talk during 3D interaction, spatial talk during 2D interaction, and their total spatial talk (3D + 2D). The result revealed that engaging in paper folding or cutting to make 3D objects (such as paper airplanes) was negatively, significantly related to the amount of children's 2D spatial talk, *r* = -0.38, *p* = 0.03. Engaging in puzzle play, such as tangrams and picture puzzles, was positively, significantly related to the amount of children's 2D spatial talk, *r* = 0.37, *p* = 0.03. Other activities such as block play were not related to children's spatial language production during 3D, 2D, or 3D + 2D interaction.

Next, a regression analysis was conducted to examine whether the frequency of spatial talk and the types of spatial activities were related to children's overall spatial language production. The frequency of these two types of spatial activities (i.e., making 3D objects, puzzle play) was entered as independent variables along with the parent's total spatial words, SES, the child's age, gender, and language competence were predictive of the dependent variable, children's overall spatial language production. The result showed that no specific spatial activities was predictive of children's overall spatial language production, *F* (6, 33) = 0.971, *p* = 0.56, η^2 = 0.75.

Objective 2b. This objective explored whether children's performance on a specific spatial task (e.g., TOSA; 3D block constructing task) was related to the frequency of spatial talk they produced during a specific spatial learning experience (e.g., playing with 3D spatial toys), as a result of the spatial language input they received from their parents. It was expected that children are able to demonstrate their spatial knowledge both within (e.g., from 3D to 3D) and across (e.g., from 3D to 2D) dimension. Children's spatial competence was assessed via the 3D Test of Spatial assembly task (TOSA; Verdine et al., 2014) involving re-construction of six Mega Blocks© structures and 2D Woodcock Johnson III Test of Achievement and Cognitive Abilities (Woodcock et al., 2001)

Children's Mega Blocks© constructions were videotaped and scored for the matching component (i.e., determine whether the constructions were identical to the model structures) and the dimensional component (i.e., determine whether the constructions were built with the correct orientation as the model structures). For the matching component, three children scored zero ($M = 2.47$, $SD = 1.71$; *Range* = 0 to 6), and three children received a perfect score. For the dimensional component ($M = 29. 91$, $SD = 12.07$; *Range* = 2 to 46), three children received a perfect score. For each child, the scores for the matching and dimensional component were summed to obtain a final score ($M = 32.38$, $SD = 13.486$; *Range* = 2 to 52). Overall, three children received a perfect score of 52, and they were 62, 67, and 62 months old at the time of testing, respectively. Correlational analyses were conducted to examine the relationship among the child's TOSA score, age, and gender. The results revealed that the child's age was positively, significantly correlated with his/her TOSA score ($r = 0.59$, $p < .001$), indicating that older children had a higher score compared to the younger age group. The child's gender was non-significant.

Children's cognitive (assessed via the *Calculation* and *Auditory Working Memory*), vocabulary (assessed via the *Picture Vocabulary*) and spatial ability (assessed via the *Spatial*

Relation and *Visual* Matching) assessment data were collected through the Woodcock Johnson III Test (Woodcock et al., 2001) and standardized using the Compuscore and Profiles Software Program (Schrank & Woodcock, 2001). Children's performance on the *Calculation* (Woodcock Johnson Tests of Achievement subtest 5) and *Auditory Working Memory* (Woodcock Johnson Tests of Cognitive Abilities subtest 9) cannot be converted to a standardized score due to their young age. Therefore, scores for these two tests were excluded from the final analyses. In addition, children's *Picture Vocabulary* score was used as a variable to control for their overall language competence, as the present study focused on the nature of parental spatial language and its effect on children's spatial language output and spatial development (e.g., Loewenstein & Gentner, 2005).

Overall, standardized scores on the *Picture Vocabulary* test ranged from 96 to 145 (M = 125.26, SD = 11.616), and 21 children performed better than the average of all the scores. Standardized scores on the *Spatial Relation* test had a mean of 113.15 (SD = 6.89), and the scores ranged from 98 to 124. Sixteen children had a higher score than the average of all children. Standardized scores on the *Visual Matching* test had a mean of 135.79 (SD = 13.37), and the scores ranged from 88 to 150. Twenty-three children had a higher score than the average of all children.

A number of correlations was also conducted to determine which variables (i.e., the child's age and gender) were related to children's performance on the Woodcock Johnson III Test (Woodcock et al., 2001). The child's gender was positively, moderately correlated (r = 0.39, p = 0.02) with their *Picture Vocabulary* score (M = 125.26, SD = 11.616; *Range* = 96 to 145), indicating that boys (M = 130.57, SD = 9.16) performed better on this test compared to girls (M = 121.55, SD = 11.901), and the difference was significant, $t(32) = -2.38$, p = 0.02. For the subtest regarding *Spatial Relations*, boys (*M* = 114.36, *SD* = 5.786) had a higher score than girls (*M* = 112.30, *SD* = 7.603), though the difference was not statistically significant, $t(32) = -0.85$, $p = 0.40$). Similarly, there were no significant differences between children's *Visual Matching* score, $t(32) = -0.33$, $p = 0.74$, though boys (*M* = 136.71, *SD* = 10.586) had a higher score compared to girls (*M* = 135.15, *SD* = 15.25). Based on these findings, gender differences in children's spatial tasks performance were non-significant. Overall, the child's age and gender were not correlated with children's performance on the Woodcock Johnson III spatial tasks.

In order to examine how children express their spatial learning and knowledge from both within- and across-dimension, further analyses were conducted. Three types of within-dimension learning were examined: a) the frequencies of children's spatial categories during 3D spatial play session and their score on the TOSA task (from 3D to 3D); b) the frequencies of children' spatial categories during 2D spatial play session and their score on the *Spatial Relation* task (from 2D to 2D); and c) the frequencies of children's spatial categories during 2D spatial play session and their score on the *Visual Matching* task (from 2D to 2D).

First, a series of correlations was performed to examine the relationship between children's TOSA scores and the frequency of spatial language produced by them. The results revealed the children's TOSA score were significantly related to the frequency of 3D spatial talk with regards to continuous amount, $r = 0.39$, $p = 0.03$, which was used 3% of the time out of all the spatial talk.

Further, a regression analyses was conducted with children's TOSA (Verdine et al., 2014) score as the dependent variable, and their spatial language production during interaction with 3D spatial toys as the independent variable. In addition, the child's language competence (assessed via the *Picture Vocabulary* subtest), age, and gender were included as independent variables. The result revealed that the overall model was significant, F (11, 22) = 3.48, p = 0.006, η^2 = 0.64, yet the effect was solely a result of the child's age [β= 0.85, p = 0.02] and their level of language competency [β = 0.49, p = 0.04]. This result suggested that in the present study, older children performed better on the TOSA task compared to the younger age group. Also, children who performed better on the *Picture Vocabulary* test were more likely to perform better on the TOSA task than children who performed poorer on the *Picture Vocabulary* test.

Next, a series of correlations was performed to examine the relationship between children's spatial talk and their Woodcock Johnson III *Spatial Relation* score. The results showed that none of the spatial categories produced by children during interaction with 2D applications was significantly related to their *Spatial Relation* score (see Table 11).

A second regression analysis was then conducted. Children's Woodcock Johnson (Woodcock et al., 2001) *Spatial Relation* score was entered as the dependent variable, and children's overall spatial language output during interaction with 2D visual-spatial applications was entered as the independent variable, along with the child's age, gender, and language competence. The result was non-significant [F (11, 22) = 0.85, p = 0.60, η^2 = 0.30].

Lastly, a series of correlations was conducted to investigate the relationship of the frequency of children's spatial talk with their score on the *Visual Matching* task. The results showed that none of the spatial categories produced by children during interaction with 2D applications was significantly related to their *Visual Matching* scores (see Table 11).

A final regression analysis was conducted. Children's Woodcock Johnson (Woodcock et al., 2001) *Visual Matching* score was entered as the dependent variable, and children's overall spatial language output during interaction with 2D applications was entered as the independent variable, along with the child's age, gender, and language competence. It was found that children's spatial talk with regards to deictics (β = -6.51, p = 0.01) and their *Picture Vocabulary* score (β = 0.51, p = 0.03) were predictive of children's *Visual Matching* score [F (11, 22) = 2.42, p = 0.04, η^2 = 0.51]. However, a negative beta value (i.e., β = -6.51) indicated that if the child engaged in less spatial talk with regards to deictics, he/she would have a higher *Visual Matching* score.

Three types of across-dimension learning were examined: a) the frequency of children's spatial categories during 2D spatial play session and their scores on the TOSA task (from 2D to 3D); b) the frequency of children' spatial categories during 3D spatial play session and their scores on the *Spatial Relation* task (from 3D to 2D); and c) the frequency of children's spatial categories during 3D spatial play session and their scores on the *Visual Matching* task (from 3D to 2D).

First, a series of correlations was performed to examine the relationship between children's TOSA scores and the frequency of spatial language produced by them during 2D spatial play session. The results revealed the children's TOSA score were not related to any of the frequencies of spatial categories produced by children during interaction with 2D spatial applications.

Further, a regression analyses was conducted with children's TOSA (Verdine et al., 2014) score as the dependent variable, and their spatial language production during interaction with 2D applications, age, gender, and language competence as the independent variables. The result suggested that the child's age [β = 0.95, p = 0.007] was predictive of their performance on the TOSA task, which contributed to the overall significance of the model, F (11, 22) = 3.10, p = 0.01, η^2 = 0.61. However, none of the other variables was significant.

Next, a series of correlations was conducted to examine the relationship between the frequency of spatial talk by children during interaction with 3D toys and their score on the Woodcock Johnson III (Woodcock et al., 2011) *Spatial Relation* task. The results revealed that none of the frequencies of spatial categories was correlated with their *Spatial Relation* score (see Table 11).

A second regression analysis was performed. The dependent variable entered was children's *Spatial Relation* task score, and children's spatial language production during interaction with 3D toys, age, gender, and language competence as the independent variables. The results revealed that the overall model, F (11, 22) = 1.40, p = 0.24, η^2 = 0.41, was not significant.

Lastly, a series of correlations was conducted to examine the relationship between the frequencies of spatial categories by children during 3D spatial play session and their *Visual Matching* score. The results showed that spatial talk with regards to spatial features and properties (r = 0.38, p = 0.03) was significantly related to children's *Visual Matching* score. Spatial features and properties was used only 3% of the time out of all spatial talk by children during interaction with 3D toys.

A final regression was conducted. The dependent variable entered was children's *Visual Matching* task score, and children's spatial language production during interaction with 3D toys, age, gender, and language competence as the independent variables. The overall model was significant, F (11, 22) = 2.356, p = 0.042, η^2 = 0.54. The results revealed that children's talk about spatial features and properties [β = 6.98, p = 0.02] significantly contributed to their *Visual Matching* score.

Correlations between each spatial category by children during 3D and 2D spatial learning experiences and their TOSA score are shown in table 10. Correlations between children's spatial language production and their performance on Woodcock Johnson III tests, see Table 11.

Objective Three

The third objective of the present study examined whether different parental factors, such as their levels of spatial anxiety and attitudes towards math, were predictive of their spatial language production during interactions with their children. Parent's overall language input with regards to the eight categories from the two spatial learning experiences (3D and 2D) were summed (3D spatial talk + 2D spatial talk) and total scores were generated.

Parental levels of spatial anxiety and attitudes toward math were measured via the Math Attitude and Spatial Anxiety Scale (Fennema & Sherman, 1976; Schackow, 2005). For the Math Attitude Scale, parents scored an average of 176.44 (SD = 32.63), and their scores ranged from 128 to 241. In addition, three parents scored lower than 137.5, which is the average score on the Math Attitude Scale (i.e., total score of 275 divided by 2).

For the Spatial Anxiety Scale, parents in the present study had an average score of 16.82 (SD = 6.13), and their scores ranged from 8 to 30. Overall, three parents scored 8 on the scale, and two parents scored 30 on the scale. Further, nine parents (26%) scored above 20 on the scale, which is the average score of the Spatial Anxiety Scale (i.e., a total score of 40 divided by 2).

In order to examine the relationships between parental level of spatial anxiety, attitude towards math, and spatial words in each category, correlational analyses were conducted. The results showed that the parent's level of spatial anxiety was significantly, negatively correlated with talk about deictics, $r = 0.36$, $p = 0.04$, indicating parents who had a relatively low level of spatial anxiety produced more talk with regards to deictics during 3D spatial learning experience. On the other hand, parents' talk about shapes ($r = -0.35$, $p = 0.05$) and deictics ($r = -0.42$, $p =$

0.01) were negatively correlated with their attitudes toward math, suggesting parents produced more talk about shapes and deictics if they had a less positive attitude towards math. During 2D interaction, parents who had a lower level of spatial anxiety would produce more shapes talk (r = -0.39, p = 0.21). Those who had a less positive attitude towards math would engage in more talk about deictics (r = -0.36, p = 0.39). The correlations of each spatial category with parental level of spatial anxiety and attitude towards math are shown in Table 12.

A series of correlations was also conducted to examine the relationship among the parent's level of spatial anxiety, attitude towards math, and variables as the child's age, gender, and the parent's SES. The results were non-significant. In addition, the parent's level of spatial anxiety was not related to his/her attitude towards math (r = -0.18, p = 0.92).

Further, two regression analyses were conducted. The parent's overall spatial language production during 3D and 2D spatial interactions with his/her child was entered as dependent variables, and the parent's level of spatial anxiety and attitude towards math were entered as independent variable, respectively. Furthermore, the parent's SES was also entered as independent variables to examine whether the effect of parent's spatial anxiety and attitude towards math are above and beyond these additional variables. Overall, analyses revealed that none of the predictors was predictive of the frequency of parental 3D spatial talk, F (3, 30) = 0.51, p = 0.68. In addition, none of the predictors was predictive of the frequency of parental 2D spatial talk, F (3, 30) = 1.33, p = 0.28.

Discussion

The present study was an exploratory study that examined the nature of parental spatial language input during parent-child interaction with three-dimensional (3D) tangible toys such as blocks and puzzles, as well as two-dimensional (2D) visual-spatial applications on an iPad®.

There were three objectives: (i) to examine the frequency and variation of spatial language that parents naturally engage in during different spatial play (3D and 2D) sessions with their preschoolers; (ii) to investigate whether parental spatial language is predictive of children's spatial language production, which further leads to their performance on spatial tasks (i.e., Woodcock Johnson III *Spatial Relations* and *Visual Matching*, TOSA); and (iii) to investigate whether parental factors such as the levels of spatial anxiety and attitudes toward math (assessed via *The Math Attitude and Spatial Anxiety Scale*) are related to the amount of spatial talk parents engaged in during interaction with their young children.

Our results showed that overall, parents engaged in a similar frequency of spatial talk during the two spatial interactions (i.e., 6% for 3D play session and 5% for 2D play session). Yet, the nature of spatial language provided was significantly different between the 3D versus 2D spatial interactions. During interaction with 3D toys, the most frequently used and discussed spatial talk were: locations and directions, shapes, and spatial dimensions. The least amount of talk occurred in the areas of orientations and transformations and spatial pattern. During interaction with 2D visual-spatial applications, parents produced more spatial talk with regards to shapes, locations and directions, deictics, as well as orientations and transformations. Moreover, the amount of parental spatial input (i.e., spatial language and spatial activity) was not related to preschoolers' spatial language output, though during the 3D spatial learning experience, the frequency of talk regarding shapes was related to children's overall spatial talk. In turn, children's language output was not related to their performance on spatial tasks. Finally, parental levels of spatial anxiety and attitudes toward math were not significantly related to the amount of spatial talk they produced during the two play sessions (3D and 2D).

Although there was no difference in the overall frequency of spatial words spoken by parents between 3D versus 2D interaction, some spatial categories, such as spatial dimensions, were used more by the parents during interaction with 3D spatial toys compared to 2D interaction. Other spatial categories, such as orientations and transformations, were used more by the parents during interaction with 2D visual-spatial applications compared to interaction with 3D toys. These findings provide important insight on the nature of spatial input by parents through interactions with different spatial learning media (i.e., 3D tangible toys and 2D visual-spatial applications) in home environments, especially since no study thus far has specifically investigated spatial learning via 2D learning platforms. Given that there was no difference in overall frequency of spatial talk, yet some spatial categories were used more than the others during different spatial interactions, it is important to further examine the differences in the types of spatial language input provided by parents during 3D versus 2D spatial interactions. Moreover, it is essential to examine whether different types of spatial language is related to three- to five-year-old children's spatial development.

Parental Spatial Input at Home

This study examined the nature of parental spatial input at home during 3D and 2D spatial learning experiences. Overall, the difference of parental overall frequency of spatial talk between 3D versus 2D interaction was not significant. However, the types of spatial talk produced by parents between these two spatial learning experiences varied.

First, the difference of the frequency of total spatial talk was non-significant between 3D versus 2D interaction. However, when comparing the spatial categories individually, the results show that parents produced more talk with regards to spatial dimensions, locations and directions, and continuous amount during interaction with 3D toys compared to 2D interaction. Further, they produced significantly more spatial words in the area of deictics and orientations and transformations during 2D interaction, in comparison to 3D interaction.

Consistent with previous studies on block play and puzzle play, the frequency of spatial talk produced by parents during interaction with 3D toys was about 6% of the total language production (i.e., spatial words + non-spatial words). This finding is similar to Ferarra and colleagues' (2011) finding – 6% of overall parental talk was spent in spatial talk – in a block play study they conducted. It is slightly higher than Levine and colleagues' (2012) finding of 4% overall talk spent engaging in spatial talk in their study focused on puzzle play between parent-child dyads. The observation that 6% overall spatial talk by parents during the entire home visit may reflect a general concern in the early mathematical development in children and that parents may lack an understanding of how to provide spatially-related talk to foster children's spatial development. This global observation reinforced in the present study suggests that parents need to be aware of the kinds of input that are essential to building strong spatial skills in young children. For instance, Pruden and colleagues (2011) suggest that parents can nurture a child's spatial skill by doing simple tasks such as engaging in spatial activities and using spatial language to integrate spatial concepts into that child's routine life.

Even though 6% of the time appears to indicate a small proportion of spatial talk, many implicit spatial words uttered were not coded for during parent-child interaction with 3D toys. For example, if a parent said, "Can you bring me the block *over there*?", the words "over" and "there" are both spatial words, but are presented in an ambiguous manner. Specifically, it is difficult to determine if the parent was referring to "over there" as a specific location. Thus, spatial words such as "over" and "there" were only coded when parents were explicitly referring to a location by pointing to a specific spot in the room and/or describing the location further (e.g., “Can you bring me the block *over there* that is *by* the bookshelf?”).

Our findings that parents produced significantly more spatial dimensions, locations and directions, and continuous amount during interaction with 3D spatial toys are consistent with previous research by Ferarra and colleagues (2011). Ferarra and colleagues (2011) suggest that when playing with 3D toys such as blocks, parents engage mostly in spatial talk with regards to categories about spatial dimensions (e.g., “My castle is *bigger* than yours”), deictics, as well as locations and directions (e.g., “This red block is *on top* of the yellow block”). On the other hand, categories such as spatial features (e.g., the square has four *sides*), orientations and transformations (e.g., “You can *turn* the block sideways”), and spatial pattern are used less frequently by parents with their preschoolers.

It is not a surprise that spatial talk with regards to locations and directions (31% of overall spatial talk) was engaged the most by parents, in comparison to other spatial categories. Ferarra and colleagues (2011) acknowledge that a number of different spatial categories are elicited simultaneously during block play activities, as parents and their children spend the most time talking about constructing complex block structures and describing structures that they made. As a result, spatial talk with regards to locations and directions, such as “I am putting this block right here, *beside* the tall tower”, is used the most in conjunction with spatial dimensions (e.g., tall). Specifically, spatial talk about locations and directions is used to describe the relationship between structures; the category “spatial dimensions” is used to further describe the differences in size, length, and height in each structure.

According to Newcombe (2010), spatial abilities are often linked to one’s ability to locate objects, read maps, and follow directions. In fact, it is suggested that navigating in surrounding environments and understanding locations of objects are used every day in individuals' lives. Thus, talking about locations and directions of objects/people in the space is intuitive to most individuals when it comes to spatial concepts (Newcombe, 2010). Also, when interacting with 3D toys, parents are allowed to use real-world referents to help solidify children's understanding of spatial relations, which enables children to develop a way to memorize, encode, and retrieve spatial cues in the future (Barnett & Ceci, 2002).

Overall, spatial categories such as spatial dimensions, locations and directions, and continuous amount were used significantly more during interaction with 3D spatial toys compared to interaction with 2D visual-spatial applications. A possible reason may be due to the fact that playing with tangible toys provides children an opportunity to be creative and open-minded, as they are not limited by the bounds (e.g., the size of the screen on the touchpad devices) presented by the hardware or the limited input presented by the software (e.g., tap once to turn the shape and two times to move it). They are allowed to build complex structures (i.e., that can be as tall as the child or as wide as the room) with the block pieces, to learn about part-whole relations as they physically put one block next to/on top/underneath one another, and to freely combine puzzle pieces to produce new patterns (e.g., Casey et al., 2008). By doing so, they are constantly describing spatial dimensions of objects (e.g., "The long pieces are the pillars, and the short pieces are the windows"), learning about spatial relationships (i.e., using the words such as inside, outside, top, and bottom), and creating new designs (i.e., combining two half pieces to make a whole) as they play (Casey et al., 2008; NCTM, 2000).

The findings that the frequency of overall spatial talk engaged by parents did not differ between 3D (6%) and 2D (5%) spatial interaction are consistent with previous study conducted by Parish-Morris and colleagues (2013). According to Parish-Morris and colleagues (2013), parents do not necessarily engage in a higher frequency or amount of language input during storybook reading time on e-books compared to on traditional books. The differences in parental language input lie in the types of language (i.e., story-related, behavioural-focused) they provide. The two studies are comparable because they both examined children's learning via live (3D) versus technology based (2D) medium.

Overall, spatial talk with regards to deictics (e. g., "Where does the triangle go?"), as well as orientations and transformations (e.g., "You need to turn the shape the other way") was produced significantly more by parents during 2D spatial learning medium compared to 3D interaction. On the other hand, spatial talk about spatial features and properties as well as spatial dimensions was used less frequently. As the present study was the first to examine spatial input, it is not feasible to make comparison with previous research on whether certain types of spatial talk are generally elicited more during 2D interaction, compared to other categories of spatial talk.

A possible reason that deictics as well as orientations and transformations were used the most by parents may be due to the type of visual-spatial applications parent-child dyads engaged in. During interaction with 2D applications on an iPad®, the most frequently used application was the tangram puzzles. Even the types of puzzles (e.g., cats, dogs, sea animals) varied, all 34 parent-child dyads engaged in puzzle play on the iPad®. According to Levine and colleagues (2012), parents produced the most spatial talk in the area of shapes, locations and directions, deictics, as well as orientations and transformations during puzzle play with their children. Our findings are consistent with these findings, as deictics as well as orientations and transformations were used the most during 2D interaction in the present study. A possible explanation is that puzzle play in general is more likely to elicit these categories (i.e., deictics, orientations and transformations) of spatial talk, regardless the use of spatial learning medium (3D versus 2D). For instance, when playing with tangram puzzles, a parent may ask the child "*Where* does the triangle go?" or "Can you *turn* the shape this way so it would fit?", as they guide and encourage their children to complete the puzzles (Levine et al., 2012). Further, these questions are applicable when completing a puzzle game on an iPad®, which are not limited to only tangible (3D) puzzle play.

Research on parental input and preschoolers' reading development suggests that book sharing between parent-child dyads is critical. During story book reading using traditional paper books, parents engage in and focus more on the context of the book and are more likely to extend story-related conversations to real life situations (e.g., Bus & Neuman, 2010; Parish-Morris et al., 2013). Further, parents provide more evaluative comments such as "The princess is very beautiful. She lives in a big, fancy castle" and content-related questions (e.g., Do you know where the princess is going?) when reading traditional books (Krcmar & Cingel, 2014). On the other hand, it is suggested that more behavioural focus instructions are engaged by parents during story reading with electronic books (Parish-Morris et al., 2013). Questions such as "What are you going to do next?" and instructions such as "You can tap once to turn this page" are used more often in e-book reading compared to reading on traditional books. Thus, based on these findings (e.g., Parish Morris et al., 2013), it is expected that parents would also produce more instructional language during spatial activities involving the use of touchpad devices (e.g., an iPad®) with their children, compared to spatial activities with 3D tangible toys.

In fact, most of the children in the present study have not yet had the experience of interacting with visual-spatial applications such as tangram puzzles. These applications require fine motor skills, such as rotating the shape with one finger, that a child may not have developed at a young age (i.e., preschool). Therefore, the parents in the present study were using instructions such as "Use your finger to *turn* the shape" and "Move the shape *here*, *here* beside the triangle" repeatedly during interaction with 2D spatial applications, resulting in a high amount of spatial language input in the area of deictics (e.g., here) and orientations and transformations (e.g., turn). Thus, it is important to note that the amount of spatial talk with regards to deictics as well as orientations and transformations may be partially due to the repeated instructional language. This suggests that conducting a longitudinal study may be essential to understanding the nature of parental spatial language during interaction with 2D applications. The researchers can potentially rule out the effect of instructional language once the parent-child dyads are familiar with how to navigate through these applications.

Overall, our results show that the amount of spatial talk with regards to shapes did not differ between the two spatial learning interactions (3D versus 2D). During 3D interaction with spatial toys, spatial talk about shapes occurred roughly 25% of the time when spatial language was elicited. During interaction with 2D visual-spatial applications, spatial talk about shapes occurred around 46% of the time. Given the popularity and accessibility of shapes in children's early environments (i.e., toys), it is expected that parents would engage in more spatial talk with regards to shapes. According to the Ontario Ministry of Education (2005b), understanding the characteristics of two- and three-dimensional shapes and figures is one of the important aspects of children's spatial competence. By the time children enter school, most of them can already distinguish and accurately identify basic shapes such as circles, squares, and triangles (e.g., Hannibal, 1999). As the present study focuses on preschoolers' spatial learning, it is essential for children to be exposed to spatial concepts regarding shapes in home settings, in order to prepare them for spatially-related education in formal schooling.

The findings of the present study also reveal that parents only spent 9% of spatial talk with regards to spatial features and properties, in comparison to all the other spatial categories during 3D spatial learning experience. Further, parents engaged in 2% of this type of spatial talk during 2D spatial learning experience. Spatial features and properties is important to children's spatial learning because it builds on their knowledge of different shapes and further helps classify shapes based on their attributes and features. It is important that children are introduced to various examples of typical and atypical shapes, along with explanations on the distinctiveness of them (e.g., an isoceles triangle versus an equilateral triangle). Parents should also be made aware that spatial features and properties is an important aspect of spatial concepts, especially because the National Council of Teachers of Mathematics (NCTM, 2000; 2006) also addresses that children should not be solely focusing on defining or memorizing the terminology of different shapes. Parents and educators should explain and help the children to explore the features by using manipulatives and referents in the surrounding environments, in order to foster children's understanding of spatial features and properties of different objects. Further, findings of the present study could also be useful for software companies, especially when designing spatially-related applications. For example, a shape recognizing application could potentially incorporate features that allow parent-child dyads to explore the surrounding environments together, learn about shapes of different objects, and further compare the spatial features of the shapes of real objects and shapes presented on the 2D screen.

Apart from the similarity of the frequency of overall spatial language input by parents during 3D and 2D spatial learning media, we also noted a small variability in the number of types of spatial talk engaged in by parents. Overall, 47% of the parents engaged in a total of six types of spatial categories during 3D interaction. During 2D interaction, 29% of the parents used a total of six types of spatial categories, and 29% of the parents used a total of seven types of spatial categories. It appears that just under half of the parents produced six types of spatial categories during 3D interaction, and just over half of the parents produced at least six types of spatial categories during 2D interaction. A possible reason may be due to the nature of spatial activities. For both 3D and 2D spatial learning experiences, parent-child dyads were provided with spatial toys and applications that are comparable in nature, such as 3D tangible blocks and 2D block building application. Parental spatial language may be elicited naturally due to the activities involving spatially-related materials, regardless of how the materials were presented (i.e., 3D versus 2D).

Children's Spatial Learning

It is suggested that parental spatial language input is related to the amount of children's spatial language output and is predictive of children's spatial competency (Ferarra et al., 2011). During parent-child interaction with 3D spatial toys, although many spatial categories produced by parents were correlated with children's spatial talk, there was still a low portion of spatial talk engaged in by parents overall. As such, it is unsurprising that the first part of our second objective – the amount of parental spatial language input would be related to the amount of preschoolers' spatial language production – was not supported. During 3D interaction, parental spatial talk involving spatial dimensions, shapes, locations and directions, continuous amount, spatial features and properties were all positively related to how much spatial talk their children produced in these spatial categories. However, when it comes to examining whether parental spatial talk was predictive of the children's overall spatial language output, only spatial talk related to shapes was significant. A reason that spatial talk with regards of shapes was predictive of the frequency of children's overall spatial language may due to the fact that block and puzzle play provide a shared goal (i.e., building structures, completing puzzles) that is more likely to elicit shape words (e.g., Parent: "What kind of *shapes* are you using for your castle?", Child: "I am going to use *squares, cubes,* and *triangles.*") and spatial relation language (e.g., "The *triangle* goes *on top* of the *square* for me castle", "The *square* is beside the *triangle* on the puzzle.") between parent-child dyads (Verdine et al., 2014).

Further, the finding that overall spatial talk did not predict children's overall spatial words production is contrary to Pruden and colleagues' (2011) finding that the amount of parental spatial talk is related to children's overall spatial production. One possible explanation could be that the present study was conducted over the span of eight weeks with two 30-minute play sessions at home. Pruden and colleagues' (2011) study was conducted over a period of three years with nine 90-minute play sessions at home. Our finding demonstrates that a longitudinal study may be essential to further examine the relationship between parents' and children's spatial language, as Purden and colleagues' (2011) study allowed for more and longer play sessions.

During 2D spatial interaction, parental spatial language was not predictive of children's overall spatial words. This may be due to the low portion of overall spatial talk engaged in by children during 2D interaction. However, parental spatial input in the area of shapes and deictics were found to be related to the amount of such spatial categories engaged in by their children. A possible reason may be due to the nature of parent-child conversation during interaction with 2D spatial learning medium. As mentioned earlier, all 34 parent-child dyads played with the tangram puzzle applications on the iPad®. During puzzle play, children are constantly using their spatial knowledge to identify shapes, to consider the relationship between each piece, as well as to mentally and physically perform transformation skills in order to fit the puzzle pieces into the correct spot (e.g., Casey et al., 2008). In fact parents are also constantly asking questions such as "*Where* does the *triangle* go?", "Do you know what *shape* this is?", and "What *shape* goes here?"

to elicit verbal response from their children. Thus, spatial categories such as shapes and deictics (e.g., here, where) by children may be potentially elicited the most.

Research suggests that engagement in spatial activities such as block and puzzle play naturally elicits spatial language from both parents and their children (Ferarra et al., 2011). Thus, it was expected that the amount of spatial activities engaged in by parent-child dyads would be related to the amount of spatial language produced by children. Surprisingly, our results did not support this finding. A possible reason why the amount of spatial activities was not related to the children's may be because of the lower level of parental engagement they receive during these activities. Given that a lot of the spatial activities mentioned on the Spatial Activity Questionnaire (Dearing et al., 2012) does not necessarily involve parental engagement (e.g., "Playing with toy soldiers, action figures, cars/trucks, planes or trains" and "Playing in the parks or green spaces when the weather permits"), a lack of parental spatial language input may be expected. Further, the Spatial Activity Questionnaire (Dearing et al., 2012) was designed for a slightly older age group (i.e., first grade children), activities such as "drawing map" and "drawing building layouts" may not yet be familiar activities for preschoolers in the present study. Therefore, a low score on the amount of spatial activities engaged by parent-child dyads was expected.

Parental input is indeed an important part of children's learning. Psychologists and educators are interested in understanding whether children are learning from input that they receive from their parents at home. As the present study focuses on children's spatial development, it is essential to investigate whether children are able to demonstrate their spatial knowledge on spatially-related tasks. Specifically, the present study examined whether children can demonstrate their spatial ability within (i.e., from 3D interaction to 3D tasks, from 2D interaction to 2D tasks) and across dimensions (i.e., from 3D interaction to 2D tasks, from 2D interaction to 3D tasks), especially because previous studies suggest that children may learn less from 2D sources compared to live demonstrations (e.g., Roseberry et al., 2014).

Our findings reveal that children's ability to demonstrate spatial knowledge within dimension (from 3D spatial talk to 3D TOSA task) was not established. Although correlational analyses suggest that children's TOSA score was positively correlated with the amount of spatial talk about continuous amount (e.g., half, whole, match) they produced during 3D spatial interaction with their parents, none of the other spatial categories produced was related to preschoolers' spatial knowledge. Given that the TOSA task focuses on children's ability to re-create and match Mega Blocks® constructions, which requires children's understanding of whether two shapes are the *same* and that one block is *half* the size of the other one (i.e., continuous amount), it is possible that children's continuous amount spatial talk actually contributed to their performance on the TOSA task.

However, it is also possible that differences in children's performance on the TOSA task are due to other individual factors, such as the child's age, and not just the amount of spatial talk. This is evident by the finding that children's age was highly predictive of their performance on the block reconstruction task, which revealed that a large portion of the variance in children's TOSA scores was due to the differences between individuals. Future research can possibly examine children's spatial learning using TOSA task within a specific age group (i.e., three year olds), in order to rule out the possibility of age differences.

Similarly, our findings suggest that children's performance on the 2D Woodcock Johnson III tasks was not related to the amount of spatial talk they produced during 2D interaction. Even though correlational analyses revealed that children's 2D spatial talk with regards to spatial dimensions correlated with their performance on the *Spatial Relation* scores, when examining the effect of children's overall spatial talk, none of the spatial talk categories was predictive of their performance on the task. A possible reason is that children on average produced significantly fewer spatial words during 2D interaction with their parents compared to how many spatial words they produced during 3D interaction, thus it is difficult to determine the degree of the effect of children's spatial language output on their spatial competence.

Our findings suggest that children were unable to demonstrate their spatial knowledge of 2D spatial talk through their performance on the 3D TOSA tasks. This is contradictory to Zack and colleagues' (2009) findings that even 15-month-old infants can demonstrate across-dimensional (i.e., from 3D to 2D and vice versa) learning. A possible reason may be due to differences in the tasks. The present study examined children's spatial learning by assessing their performance on specific spatial tasks. On the other hand, Zack and colleagues (2009) examined whether infants can copy a target action performed by the experimenters on a touchscreen device, in order to elicit a specific response (i.e., animal sounds). The infants were simply required to imitate an action, which could be less difficult than performing a 3D re-construction task (i.e., TOSA; Verdine et al., 2014).

Additionally, our findings reveal that children were able to acquire spatial knowledge from 3D spatial talk and apply that knowledge to 2D spatial tasks. However, the ability to express knowledge across-dimension was limited to only one spatial category: spatial features and properties. Correlational analyses suggest that a greater amount of spatial talk with regards to spatial features and properties by children during 3D interaction was correlated with their performance on both of the *Spatial Relation* and *Visual Matching* tasks. For the *Spatial Relation* task, children were required to perform mental transformations to find the pieces that fit into different puzzles. Understanding concepts about spatial features and properties such as corner, curve, and straight may be beneficial when working on a spatial task that requires them to recognize spatially-related information (i.e., would this curvy part on the piece fit into the puzzle). On the other hand, the timed *Visual Matching* task requires children to look at the features of both typical (e.g., squares) and atypical (e.g., stars) shapes within a 2-minute period, in order to identify the shapes that are the same. Understanding spatial features and properties such as “squares have four sides and four corners” may help children classify shapes based on their attributes (Clements, 2004a).

Parenting Factors and Parental Spatial Language

It is suggested that parenting factors such as parents’ levels of spatial anxiety, their attitudes toward math, SES, and their overall language production are all related to the amount of spatial language they produce during interaction with their preschoolers. It has also been found that there is a lack of spatial input that children receive from teachers with a higher level of spatial anxiety. For instance, teachers of first and second grade children who have a relatively higher spatial anxiety level would avoid engaging in spatial activities and talking about spatially-related concepts in class (e.g., Gunderson et al., 2013). Even though there is a limited number of studies examining whether parents’ spatial anxiety is predictive of their spatial language production, it is expected that the relationship would exhibit a similar trend, where a higher level of parental anxiety is related to less spatial language input. However, our results revealed that the parent’s level of spatial anxiety was not related to the amount of parental spatial language produced during both 3D and 2D parent-child interactions.

In addition, it is suggested that parents’ attitudes toward mathematics may potentially influence the amount of math talk in which they engage with their young children during daily interactions (e.g., Gunderson et al., 2012). Given that spatial ability is considered an important aspect in mathematics education (Fennema & Romberg, 1999; NCTM, 2000), it was assumed that parents' attitudes toward mathematics may have an impact on the amount of spatial language they produced during interactions with their children. However, our results showed that on the parent's attitude towards mathematics was not related to the amount of parental spatial language produced during both 3D and 2D parent-child interactions. A follow-up study could include an exploratory factorial analysis on the Math Attitude Scale to measure and tease apart whether a specific domain, such as the usefulness of mathematics (e.g., "Mathematics is a very worthwhile and necessary subject") loads highly on the frequency of spatial words produced by parents. A similar factorial analysis could be conducted to examine the specific aspects related to parental anxiety towards doing mathematics (e.g., "My mind goes blank and I am unable to think clearly when working with mathematics").

In the present study, the amount of parental spatial input did not differ as a function of their levels of spatial anxiety and attitudes toward math, which is contrary to previous studies on adults' levels of anxiety and the amount of relevant talk produced (e.g., Gunderson et al., 2013). A possible explanation can be due to the small variability of parental level of spatial anxiety and attitude towards math in the current sample. Specifically, parents in general had a relatively lower level of spatial anxiety, as only 26% (n = 9) of them scored above the mean (i.e., 20; higher scores indicate higher anxiety) of the Spatial Anxiety Scale (Lawton, 1994). Similarly, parents in the present study exhibited a relatively positive attitude towards math, given that only three parents scored lower than the mean (i.e., 137.5; lower scores indicate negative attitude) on the Math Attitude Scale (Fennem & Sherman, 1976; Schackow, 2005). In addition, parents in the present study may consider spatial anxiety as a fear of getting lost rather than the anxiety of performing spatial tasks (Ramirez, Gunderson, Levine, & Beilock, 2012), as statements on the

Spatial Anxiety Scale are involved with one's ability to navigate and map. Thus, the level of spatial anxiety reflected by the Spatial Anxiety Scale may not affect the amount of spatially-related talk with regards to shapes and spatial features (e.g., "What *shape* is this? It is a *triangle* because it has three *sides*,"), spatial dimensions (e.g., "My castle is *taller* than yours. It has a *big* door and a *small* window") or locations and directions (e.g., "Can you bring me the block that is *beside* the bookshelf the bookshelf *by* the other toys").

When it comes to examining the correlation between spatial anxiety, attitude towards math, and the types of spatial categories, our findings reveal that parents who had a lower level of spatial anxiety and less positive attitude towards math both produced more talk about shapes and deictics. A possible reason for these findings may be due to the fact that parents in the present study did not view spatial ability as a strand of mathematics, as the parent's level of spatial anxiety was not related to his/her attitude towards math. Given that the present study is of an exploratory nature, a comparison with previous studies is not feasible.

Parental SES can potentially contribute to the amount of parental spatial input they produce during parent-child interactions. Research shows that children of lower SES households receive less spatial input from their parents (e.g., Dearing et al., 2012; Verdine et al., 2014). Specifically, parents of preschoolers and first-graders from lower SES homes report that they produce less spatial words and engage in less spatial activities with their children, in comparison to parents from high income households (Dearing et al., 2012; Verdine et al., 2014). Our result on parental SES and spatial language input did not support this finding, as parents from higher SES homes did not produce more spatial language than parents from low SES homes. A possible reason may be the fact that in the present study, only eight parents were categorized in the lower SES households (i.e., one mother graduated from high school and seven mothers graduated from college). Thus, a comparison between higher versus lower SES families cannot be made in the present study given a limited number of parents.

Consistent with previous studies (e.g., Pruden et al., 2011), parents who produced a lot of “other talk” also produced a greater amount of spatial words during parent-child interactions. This finding further supports the fact that it is important to control for overall language produced by parents when examining the relationship between spatial words in which they engage during parent-child interaction.

Limitations

The present study had a few limitations. First, due to the study design and the time allocated for the study, one 30-minute home visit session was conducted for each type of spatial learning medium (3D, 2D). A one-time 30-minute naturalistic observation for each medium may provide a limited depiction of the frequency and variation of spatial language input that parents produce on a daily basis. Previous studies on parental spatial language input (i.e., Levine et al., 2012; Pruden et al., 2011) ran over a period of three years, allowing for a broader collection of data, as there were nine 90-minute home free play sessions for each parent-child dyad. However, given the commitment the parents had to give to the present study and the time allotted for the study, it was not feasible to add more home visit sessions.

The second limitation was that the word-type-level analysis may not fully provide an accurate depiction of the spatial words produced by parents during parent-child interactions. This type of analysis analyzes and calculates all the spatial and non-spatial words uttered by parents and their children. Words that are being used frequently such as determiners (e.g., a, the) and pronouns (e.g., I, you) may contribute to a higher number of total word spoken. Given that the amount of parental spatial words is highly related to the amount of total words they produced, when calculating the frequency of spatial words (i.e., spatial words divided by spatial words +

non-spatial words), it is expected that parents would have a low level of spatial language production regardless of the level of parental engagement. However, this may merely be the result of the type of analysis used. Future research could use an utterance-level analysis to circumvent this limitation. Specifically, utterances such as "Can you bring me the block *over here* that is *by* the bookshelf?" would be categorized as used in a spatial context. The amount of spatial language input parents engaged in would therefore be determined by whether the utterances were produced in a spatial context instead of by the total number of spatial words they engaged in. This could provide a more appropriate representation of the nature of parental engagement in spatial words during parent-child interactions.

The third limitation was that the 2D visual-spatial applications selected for the present study were difficult to operate and navigate through for most of the children. Children may not have the experience interacting with these applications, whereas they may already have been exposed to toys such as blocks at a young age. At preschool age, these children may not have yet established the more sophisticated fine motor skills required to navigate through these applications. Specifically, these applications require them to perform hand-eye coordination (i.e., rotating a shape with one finger without touching anything else) in order to play the games as smoothly as they would usually engage in 3D play with toys. Further, because of the novelty and difficulty children experienced during play with 2D applications, many children showed frustration and some did not wish to continue with the games. Given that children were unfamiliar with how to operate and navigate through the 2D applications and the frustration they experienced, parents spent a significant amount of time explaining and instructing the children, such as on how to move the shapes or turn the shapes around. It is, therefore, more difficult for interpretation of the frequency of spatial talk for each parent-child dyad and whether the spatial talk produced during 2D interaction was strictly related to spatial concepts. That being said, to circumvent this limitation, the researcher provided all parent-child dyads with explanations and instructions on the purpose and features of the game, prior to the 2D play session.

The forth limitation of the present study is that 75% of the parents were from a higher SES family. Perhaps the results may have differed if there were more families of lower SES in the study. Past research has shown that parents from lower SES families provide less spatial language and engage in less spatial activities with their preschool and first grade children (e.g., Dearing et al., 2012, Verdine et al., 2014). Thus, SES may be a significant factor to control for in terms of the frequency of spatial talk engaged by parents during 3D versus 2D spatial learning medium.

A final limitation is that the Spatial Anxiety Scale (Lawton, 1994) used in the present study did not capture the nature of spatial anxiety a parent might have, as the scale focuses more on one's ability to navigate and map. Therefore, parents may associate spatial anxiety as the fear of getting lost, rather than the anxiety of performing spatially-related tasks, such as mental rotation tasks. As some parents indicated while filling out the Spatial Anxiety Scale (Lawton, 1994) that "I am not anxious about getting lost. Besides, I have my phone with me that I can just use the google map," this scale may not be the most suitable scale for the purpose of the present study. To circumvent this limitation, the researcher could ask the parents to perform a spatially-related task (i.e., mental transformation task) and provide a questionnaire regarding their levels of anxiety when thinking about their performance on the task. This way, the thought of spatial anxiety may be made more salient to the parents, which in turn more accurately provides insight on the amount of parental spatial language input provided to the preschoolers.

Future Research

The present study provides insight on the nature of parental spatial language input during different types of spatial learning media (3D versus 2D). Several questions for future research emerged from the findings of the present study. First, future research should investigate the number of different types of spatial words that are produced by parents during parent-child interactions. For example, spatial words such as “big, small, tall, and narrow” all fall under the spatial dimensions category, yet “narrow” was hardly used by the parent-child dyads in the present study, compared to other three spatial words. Further, parents may be using the same word (i.e., big) repetitively, resulting in a high frequency of spatial word in the given category. However, that does not necessarily mean that the children are exposed to a great variety of spatial words. As a result, the children’s spatial word learning may be limited to only a few types of words. As Rowe (2012) suggests that the frequency of words, types of words and the variation of words produced by parents are all related to children’s language growth, future research should continue to examine the frequency and variation of spatial words and to further evaluate the types of spatial words the parents engage in with their children as they play. It would also be beneficial for future research to develop a list of most useful and frequently used spatial words, similar to Fry’s word list used for teaching reading, writing, and spelling (Fry, 1980). This spatial word list could serve as a possible teaching tool for parents and educators to increase the frequency and variation of spatial talk during interactions with their young children to facilitate children’s spatial competency.

Future research should also investigate the impact of instructional language (e.g., “Tap once to turn the shape”) while parents and children interact with 2D visual-spatial applications in a naturalistic home setting. Parents spend a significant amount of time providing instructional language during story-reading time on e-books (Krcmar & Cingel, 2014), but the effect of instructional language that occurs during spatially-related interactions is still unknown. In order to evaluate the frequency of parental spatial language input during interaction with 2D touchpad devices, future research should code for the occurrence of instructional language within each parent-child interaction. Thus, the influence of instructional language on children's spatial learning via 2D medium should be investigated.

The present study could be complemented by incorporating the use of gestures during parent-child interactions using an experimental approach. Research has shown that the use of gestures could also be a mean to foster children's spatial development (e.g., Cartmill et al., 2012). In the present study, parents sometimes used gesture to assist their verbal input (i.e., spatial language). Future study could examine the effect of spatial language, the effect of spatial language accompanied with gestures, or the effect of gestures along to better pinpoint the factor(s) in which may have an impact on children's spatial competence.

Lastly, in order to further examine the nature of parental spatial language input during spatial activities, a final potential area of investigation could be to focus on a specific type of spatially-related play. For example, when examining parental spatial language input, Levine and colleagues (2012) focused on only puzzle play. Ferarra and colleagues (2011) also only examined parental spatial input during block play. Future research could evaluate the effect of parental spatial language between 3D and 2D spatial media based on one type of play, in order to compare the type of spatial words parents engage in with their children between the two media. Moreover, as block play and puzzle play may elicit different types of spatial language (Ferarra et al., 2011; Levine et al., 2012), this methodology would allow researchers to compare and tease apart the differences in the types of spatial words the parent-child dyads engage in during distinct spatial activities.

Conclusion

Fostering children's spatial abilities has many implications, as their spatial abilities are essential for success in many school subjects (e.g., mathematics; Cheng & Mix, 2014) and future achievement in STEM-related occupations (Shea et al., 2001). Further, the findings that spatial abilities can be fostered (Uttal et al., 2013), and that the differences in spatial abilities often persist over time (Newcombe, 2010) indicate that spatial input from parents is essential, especially during early childhood years. Research suggests that hearing spatial language (Ferarra et al., 2011) and engaging in spatially-related activities (e.g., Casey et al., 2008) are found to facilitate children's spatial learning. Comparing the amount of parental spatial language input, children who hear more spatial words from their parents often produce more spatial words, which leads to better performance on spatially-related tasks (Pruden et al., 2011). These findings further solidify the fact that the development of young children's spatial abilities is heavily dependent on parental input and the spatially-rich environments they are exposed to.

For a long period of time, spatially-rich environments were only involved with tangible 3D spatial toys such as blocks and puzzles. These toys allow children to touch and manipulate them. Most importantly, it is suggested that parents and children engage in more spatially-related talk during interaction with these toys (e.g., Ferarra et al., 2011). Over the last decade, due to a shift in technology, 2D touchpad devices such as iPads® have become more prevalent, and are becoming a part of children's daily activities (Sigman, 2012; Rideout, 2013). When playing with spatially-related applications such as tangram puzzles on these touchpad devices, children are allowed to interact with a 2D interface, which provides them with immediate feedback after each input (e.g., Sinclair & Bruce, 2014). However, the impact of these touchpad devices, specifically if they promote or hinder children's spatial learning and development is not yet known.

The present study was one of the first to investigate the nature of parental spatial input between 3D (e.g., spatial toys such as blocks and puzzles) versus 2D (e.g., visual-spatial applications on an iPad®) spatial learning media in a naturalistic home setting. Findings of the present study reveal important information on the nature of spatial talk children receive during parent-child interactions. Despite the low level of overall parental spatial talk, 2D learning mediums such as iPads® did not necessarily hinder or facilitate parental spatial talk, as the type of spatial categories parents produced between the two media (3D and 2D) was significantly different. Findings of the present study also highlight that the variability of spatial talk is important to foster children's spatial development. This is essential given that children's language learning is highly related to both the frequency and variation of language they hear from parents during daily interactions (Rowe, 2012). Thus, the quality of parent-child interaction is also vital. Parents should be aware of the strengths and shortcomings of the 3D and 2D spatial toys and the importance of incorporating all types of spatial categories during parent-child interactions, regardless of the media they choose to use for the interaction.

The present study was also one of the few to investigate how three- to five-year-olds' demonstrate their learning in a spatial context by assessing the amount of spatial talk produced by children as a result of receiving parental spatial language input. Our results are promising given that some types of spatial categories produced by children were related to their performance on spatial tasks, even though the overall spatial learning within and across dimensions were not achieved. This finding highlights that spatial input at home should be seen as an important part of children's daily routine, as the spatial knowledge children acquire at home prior to formal schooling has an effect on their spatial competence. Also, it is worth noting that individual differences in spatial abilities already exist in children as young as three years old

(Frick & Newcombe, 2009). Therefore, fostering their spatial development as early as possible is vital.

Overall, the findings from the present study shed light on the spatial language input parents are providing to their preschoolers at home. In order to maximize the impact of parental input on children's spatial development, parents should be made aware of the types of spatial language input they engage in during parent-child interactions with different spatial learning media. Furthermore, the findings highlight the practical implications of spatial input that children receive during their early years, as well as the importance of spatially-rich environments. These findings help contribute to the facilitation of children's early acquisition of spatial knowledge required to better prepare them for further education.

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Table 1

Mean, standard deviation, minimum, and maximum of spatial words in spatial category during 3D interaction by parent-child dyads

Types of Spatial Talk	Parent		
	Mean (*SD*)	Minimum	Maximum
Locations and Directions	29.35 (*16.88*)	5	75
Shapes	23.03 (*18.51*)	1	81
Spatial Dimensions	21.68 (*15.49*)	4	67
Deictics	8.71 (*5.39*)	1	27
Continuous Amount	5.44 (*5.18*)	0	20
Spatial Features and Properties	3.88 (*4.88*)	0	20
Orientations and Transformations	0.62 (*0.95*)	0	4
Pattern	0.09 (*0.38*)	0	2
Types of Spatial Talk	**Child**		
	Mean (*SD*)	Minimum	Maximum
Spatial Dimensions	12.50 (*12.32*)	0	45
Shapes	12.06 (*10.79*)	0	42
Locations and Directions	9.47 (*8.76*)	0	35
Deictics	4.32 (*4.18*)	0	20
Continuous Amount	1.38 (*2.00*)	0	9
Spatial Features and Properties	1.29 (*2.21*)	0	10
Pattern	0.03 (*0.17*)	0	1
Orientations and Transformations	0.00 (*0.00*)	0	0

Note. The spatial categories are shown in descending order based on the mean

Table 2

Correlations between spatial categories engaged in by parents during 3D play session

Types of Spatial Talk	1	2	3	4	5	6	7	8
1.Spatial Dimensions	-	.15	.63**	-.37	.71**	.14	.47**	-.04
2. Shapes	-	-	.28	.31	.21	.74**	.34*	.02
3. Locations and Directions	-	-	-	-.20	.57**	.49**	.31	-.09
4. Orientations and Transformations	-	-	-	-	-.20	.28	.14	.04
5. Continuous Amount	-	-	-	-	-	.25	.39*	-.11
6. Deictics	-	-	-	-	-	-	.26	-.07
7. Spatial Features and Properties	-	-	-	-	-	-	-	-.02
8. Pattern	-	-	-	-	-	-	-	-

Note. ** $p<.01$, * $p<.05$

Table 3

Mean, standard deviation, minimum, and maximum of spatial words in each spatial categories during 2D interaction by parent-child dyads

Types of Spatial Talk	Parent		
	Mean (*SD*)	Minimum	Maximum
Shapes	22.88 (*15.96*)	0	61
Locations and Directions	19.09 (*11.08*)	1	42
Deictics	15.18 (*10.30*)	0	48
Orientations and Transformations	12.12 (*11.72*)	0	51
Spatial Dimensions	5.44 (*6.99*)	0	29
Continuous Amount	2.62 (*3.41*)	0	11
Spatial Features and Properties	1.85 (*2.90*)	0	14
Pattern	0.18 (*0.72*)	0	4

Types of Spatial Talk	Child		
	Mean (*SD*)	Minimum	Maximum
Shapes	6.62 (*6.93*)	0	23
Deictics	3.00 (*6.26*)	0	36
Spatial Dimensions	1.97 (*2.89*)	0	12
Orientations and Transformations	1.71 (*3.02*)	0	14
Locations and Directions	1.38 (*2.58*)	0	12
Continuous Amount	0.09 (*0.38*)	0	2
Spatial Features and Properties	0.09 (*0.38*)	0	2
Pattern	0.00 (*0.00*)	0	0

Note. The spatial categories are shown in descending order based on the mean

Table 4

Correlations between spatial categories engaged in by parents during 2D play session

Types of Spatial Talk	1	2	3	4	5	6	7	8
1.Spatial Dimensions	-	.41*	.49**	.16	.27	.37*	.44*	.18
2. Shapes	-	-	.48**	.16	.50**	.47**	.40*	.25
3. Locations and Directions	-	-	-	.29	.59**	.38*	.42*	.19
4. Orientations and Transformations	-	-	-	-	.22	.54**	.22	.28
5. Continuous Amount	-	-	-	-	-	.31	.41*	.28
6. Deictics	-	-	-	-	-	-	.30	.15
7. Spatial Features and Properties	-	-	-	-	-	-	-	.53**
8. Pattern	-	-	-	-	-	-	-	-

Note. ** $p<.01$, * $p<.05$

Table 5

The variation of spatial words used by number and percentage of dyads

	(*N* = 34)	Variation (number of spatial categories used)	Variation score	*n*	Percentage
Home visit one: 3D toys	Parent	4	0.5	1	3%
		5	0.625	6	18%
		6	0.75	16	47%
		7	0.875	10	29%
		8	1	1	3%
	Child	2	0.25	2	6%
		3	0.375	2	6%
		4	0.4	9	27%
		5	0.625	10	29%
		6	0.75	11	32%
Home visit two: 2D visual-spatial applications	Parent	2	0.25	1	3%
		4	0.5	2	6%
		5	0.625	9	27%
		6	0.75	10	29%
		7	0.875	10	29%
		8	1	2	6%
	Child	0	0	4	12%
		1	0.125	3	9%
		2	0.25	3	9%
		3	0.375	8	23%
		4	0.5	9	26%
		5	0.625	6	18%
		6	0.75	1	3%

Note. n refers to the number of participants (parents or children) per variation

Table 6

Mean, standard deviation, and the number of dyads engaged in for each activity

Spatial Activities	Mean (*SD*)	*n**
1. Colour, plaint, or draw free hand (not filling-in outlines)	3.75 (*0.51*)	26
2. Play in parks or green spaces when the weather permits	3.71 (*0.46*)	24
3. Do arts and craft projects (such as making jewelry, straining beads, or using play dough)	3.53 (*0.61*)	20
4. Set up play environment with toy furniture, toy buildings, train tracks or building blocks	3.47 (*0.66*)	19
5. Play with toy soldiers, action figures, cars/trucks, planes or trains?	3.44 (*0.86*)	21
6. Build with construction toys (such as building blocks, Legos, magnet sets, Lincoln logs)	3.42 (*0.78*)	20
7. Explore woods, streams, ponds, or beaches or search for plants, bugs, or animals outdoors when the weather permits	3.29 (*0.72*)	15
8. Play with puzzles (such as picture puzzles, tangrams, slide puzzles, 3D puzzles)	3.21 (*0.77*)	13
9. Race toy animals or cars on the ground or around obstacles	3.01 (*1.11*)	15
10. Play paper and pencil game (such as maze, connect the dots)	2.29 (*1.19*)	6
11. Build dams, forts, tree houses, snow tunnels or other structures outdoors when the weather permits	2.09 (*1.11*)	4
12. Set up obstacle courses, tunnels, or runway for kids or pets	2.06 (*1.07*)	2
13. Fold or cut paper to make 3-d objects (such as paper airplanes)	1.94 (*1.23*)	6
14. Use tools (such as hammers or screwdrivers) to make things or take things apart to see how they work (such as a broken flashlight or toy)	1.76 (*1.18*)	4
15. Use computer or video games to do drawing or painting, or matching and playing with shapes	1.73 (*1.31*)	2
16. Climb trees when the weather permits	1.35 (*1.30*)	1
17. Play with flying toys (such as kites, paper airplanes)	1.32 (*0.73*)	1
18. Draw maps (such as treasures hunt maps)	1.29 (*1.00*)	1
19. Use kits to build models (such as airplanes, animals, dinosaurs, doll houses)	1.09 (*1.08*)	1
20. Draw plans for houses, forts, castles or other buildings or layouts	1.00 (*1.26*)	2

**Note. n refers to the number of parent-child dyads who engaged in the activity frequently (many times per week) and the activities are shown in descending order based on the mean*

Table 7

Correlations between parent-child spatial words during 3D spatial learning experience

Type of Spatial Talk by Child / Type of Spatial Talk by Parent	1	2	3	4	5	6	7	8
1.Spatial Dimension	.39*	-.08	.29	-	.45**	-.01	.17	-.22
2. Shape	.26	.47**	.03	-	.13	.27	.34*	-.01
3. Locations and Directions	.16	-.02	.51**	-	.39*	.26	.19	-.09
4. Orientations and Transformations	-.00	.35*	-.31	-	-.03	-.01	-.12	.15
5. Continuous Amount	.13	-.25	.10	-	.54**	.01	.04	-.33
6. Deictics	.08	.42*	.09	-	.11	.26	.21	.18
7. Spatial Features and Properties	.11	.13	-.03	-	.25	-.03	.44**	-.21
8. Pattern	.01	.10	-.08	-	.05	-.05	.41*	-.04

Note. ** $p<.01$, * $p<.05$

Table 8

Correlations between parent-child spatial words during 2D spatial learning experience

Type of Spatial Talk by Child / Type of Spatial Talk by Parent	1	2	3	4	5	6	7	8
1.Spatial Dimension	.15	.01	.00	.18	-.08	-.21	.23	-
2. Shape	.12	.38*	.15	-.18	-.22	.07	.01	-
3. Locations and Directions	-.13	-.07	-.03	-.09	-.13	-.17	.13	-
4. Orientations and Transformations	-.20	-.23	-.15	-.15	-.02	-.05	.26	-
5. Continuous Amount	-.20	.10	-.26	-.12	-.15	-.16	.03	-
6. Deictics	-.03	.01	.15	.14	.-.12	.37*	.34	-
7. Spatial Features and Properties	-.02	.01	-.11	.08	-0.9	-.06	.15	-
8. Pattern	-.08	.08	.06	.05	-.07	.18	-.07	-

Note. * *p<.05*

Table 9

Correlations between the amount of spatial activities engaged at home and children's spatial language production

Spatial Activities	Child	
	3D	2D
1.Spatial Dimension	-.05	.23
2. Shape	-.14	-.12
3. Locations and Directions	1.5	-.08
4. Orientations and Transformations	-	-.22
5. Continuous Amount	-.12	.01
6. Deictics	.08	-.11
7. Spatial Features and Properties	-.03	-.18
8. Pattern	-.02	-

Table 10

Correlations of the amount of each spatial category by children and their TOSA scores

TOSA	Frequency of Each Spatial Talk by Child	
	3D	2D
1.Spatial Dimension	.33	-.21
2. Shape	.10	-.12
3. Locations and Directions	.34	-.13
4. Orientations and Transformations	-	.02
5. Continuous Amount	.39*	-.03
6. Deictics	.30	-.26
7. Spatial Features and Properties	.24	-.22
8. Pattern	-.08	-

Note. * $p<.05$

Table 11

Correlations of children's spatial talk and Woodcock Johnson III test

Spatial Relation	Types of Spatial Talk by Child	
	3D	2D
1.Spatial Dimension	.21	.25
2. Shape	-.19	-.15
3. Locations and Directions	-.04	-.02
4. Orientations and Transformations	-	.04
5. Continuous Amount	.16	-.08
6. Deictics	-.15	.01
7. Spatial Features and Properties	.29	-.11
8. Pattern	-.00	-
Visual Matching	**Types of Spatial Talk by Child**	
	3D	2D
1.Spatial Dimension	.16	.07
2. Shape	.03	-.12
3. Locations and Directions	.15	-.30
4. Orientations and Transformations	-	.18
5. Continuous Amount	.08	.06
6. Deictics	-.22	-.50**
7. Spatial Features and Properties	.38*	-.08
8. Pattern	.08	-

Note. ** $p<.01$, * $p<.05$

Table 12

Correlations of each spatial category engaged in by parents with the level of spatial anxiety and attitude towards math

Spatial Anxiety	Spatial Talk by Parent	
	3D	2D
1.Spatial Dimension	.08	.11
2. Shape	-.20	-.39*
3. Locations and Directions	-.17	0.10
4. Orientations and Transformations	-.13	-.04
5. Continuous Amount	-.20	-.33
6. Deictics	-.36*	-.23
7. Spatial Features and Properties	-.07	-.15
8. Pattern	-.10	.02
Math Attitude	**Spatial Talk by Parent**	
	3D	2D
1.Spatial Dimension	.15	-.06
2. Shape	-.35*	-.05
3. Locations and Directions	-.05	-.03
4. Orientations and Transformations	-.27	-.14
5. Continuous Amount	.07	.04
6. Deictics	-.42*	-.36*
7. Spatial Features and Properties	.01	.25
8. Pattern	-.13	.04

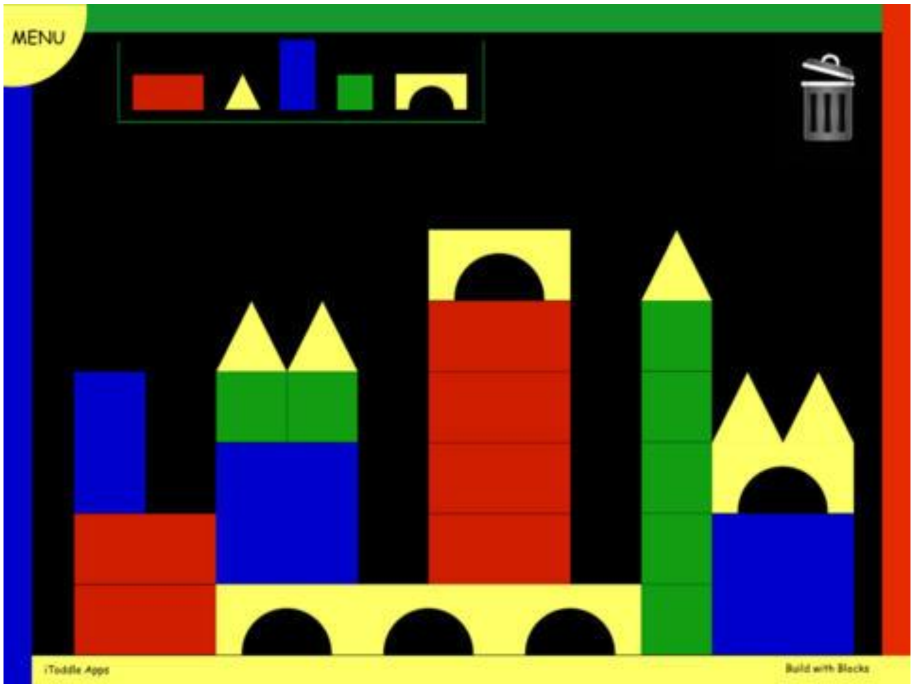
Note. * *p*<

Appendices

Appendix A

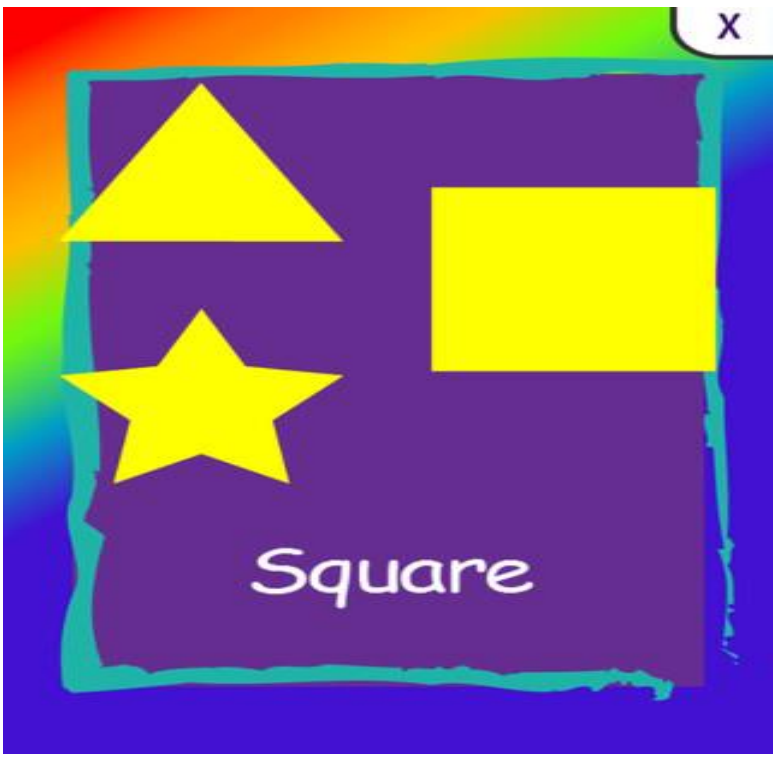
1. Blocks Rock

2. Build with Blocks HD Lite



3. Tangram Puzzle (House)

4. Shapes Toddler School



Appendix B

Names of the tangram puzzles by "Kids Discover and Doodle"

1. Cats
2. House
3. Dogs
4. Sea Animals
5. Endless Alphabets
6. Safari Animals
7. Christmas tree
8. Transportations
9. Birds
10. Portraits
11. Houseware
12. Wild Animals
13. Tools
14. Sports
15. Farm Animals

Appendix C

Demographics and Activities Questionnaire

The parent/guardian who spends the most time at home with the child should answer the questions below. Your answers will be kept confidential and used for research purposes only. You can choose not to answer any question. It will take approximately 5-10 minutes to complete this questionnaire.

DEMOGRAPHICS

PARTICIPATING CHILD

1. Please indicate:
    a. Child's first name: ________________________
    b. Child's birth date: _____________________
    c. Gender: boy____ girl ____

2. How many hours/week is the child in daycare/preschool outside the home?_________
3. How many hours/week was your child in daycare/preschool
   At age 1?____________
   At age 2?___________
   At age 3?___________
4. If your child is 4 years old and older, is he/she attending Junior/Senior Kindergarten?
   Yes________ NO________
   (If *NO*, is your child attending a daycare program? Yes ______ NO______
5. Was your child born in Canada?: Yes______ No_____
6. Number of years you and your child have lived in Canada: _______________ (in years)
7. Is your child LEFT- or RIGHT-handed or UKNOWN. Please circle.

FAMILY INFORMATION AND ACTIVITIES

8. Your relationship to the child: Mother____ Father____ Guardian____
   Other, please specify: ______________________
9. Marital Status: ___ Single
   ___ Committed Relationship (married or common law)
   ___ Divorced/Separated/Widowed
10. What is your (and your spouse's) highest level of education?

    Yourself:
    No formal education
    Completed Some Elementary school (grades 1-8)
    Completed Elementary school (grade 8)
    Completed some High School (grades 9-12)
    High school diploma
    College Diploma
    Undergraduate University Degree
    Graduate Degree: Master's
    Doctorate
    Post-Doctorate

    Spouse:
    No formal education

Completed Some Elementary school (grades 1-8)
Completed Elementary school (grade 8)
Completed some High School (grades 9-12)
High school diploma
College Diploma
Undergraduate University Degree
Graduate Degree: Master's
Doctorate
Post-Doctorate

11. Occupation/Job:
    Yourself: ______________________
    Your spouse (if applicable): _____________________
12. Your age:
    ______ 21-29 _______ 30-39 _______ 40-49 ______ 50-59
13. Your spouse's age (if applicable):
    ______ 21-29 _______ 30-39 _______ 40-49 ______ 50-59
14. Is English your first language? Yes/ No
15. If no, how old were you when you first learned English (in years)? _______________
16. What is your first language? _________________________
17. How many children do you have?
    1 2 3 4 5 6 more than 6

    Number of siblings (brothers and sisters):
    Age: ______ Gender: ________
    ______ ________
    ______ ________
    ______ ________
18. Mother is LEFT-, RIGHT-handed, or unknown (if not birth mother). Please circle.
19. Father is LEFT-, RIGHT-handed, or unknown (if not birth father). Please circle.
20. How many hours per week is the child read to (at home)? ____________
21. How many hours per week does your child currently spend watching TV? ___________
22. How many of these hours are educational TV (e.g., Blue Clues, Dora, PBS, Sesame street)? __________
23. Do you think parents should engage in math activities with their young children at home?

    Yes_________________
    If yes, what kind of activities do you use with your child and why?
    ____
    ____
    No __________
    If no, why? ____

____

24. Does your child have access to mobile devices, such as iPods or smartphones? Or touch pad devices, such as playbooks or iPads?

    Yes __________.
    If yes, what kind of device? ____
    If yes, how many hours/week does the child spend on these devices? ___________
    If yes, how many of these hours are spent on educational applications (literacy apps, math apps)? __________. What are the names of these educational apps?
    ____
    No ___________

25. Does your child play puzzles or blocks using mobile devices (e.g., smartphones or touch pad devices)?

    Yes ______________,
    If yes, which apps? ____
    No _____________

*****Thank you for completing the questionnaire!*****

Appendix D

Math and Visual Spatial Activities Questionnaire

How often does your child:

(Child math activities)

1. Use a calculator?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

2. Use computer or video games to do addition, substraction or other math activities?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

3.Show interest in or talk about time using clocks?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

4. Play card games that use number or couting (such as Go Fish,War)?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

5. Count down using number (10,9,8,7,...)?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

6. Play board games games that uses numbers, counting,or dice (such as Chutes and Ladders, Monopoly Jr.)?

0	1	2	3	4
Never	seldom	occasionally	often	many times

	(a few times per year)	(a couple of times per month)	(weekly)	per week

7. Count out money?

0	1	2	3	4
Never	seldom	occasionally	often	many times
	(a few times per year)	(a couple of times per month)	(weekly)	per week

8. Memorize math facts (such as 2+2)?

0	1	2	3	4
Never	seldom	occasionally	often	many times
	(a few times per year)	(a couple of times per month)	(weekly)	per week

9. Wear and use a watch?

0	1	2	3	4
Never	seldom	occasionally	often	many times
	(a few times per year)	(a couple of times per month)	(weekly)	per week

10. Measure the length and width of things?

0	1	2	3	4
Never	seldom	occasionally	often	many times
	(a few times per year)	(a couple of times per month)	(weekly)	per week

11. Solve problems with numbers bigger than 10?

0	1	2	3	4
Never	seldom	occasionally	often	many times
	(a few times per year)	(a couple of times per month)	(weekly)	per week

12. Guess the number of things (such as pennies in a jar)?

0	1	2	3	4
Never	seldom	occasionally	often	many times
	(a few times per year)	(a couple of times per month)	(weekly)	per week

13. Add or substract numbers in his/her head?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

14. Time how fast an activity can be completed (using a clock or stopwatch)?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

15. Use a calendar and talk about dates?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

16. Compare the sizes of numbers (such as 5 is more than 4)?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

(Child spatial activities)
17. Play with toy soldiers, action figures, cars/trucks,planes or trains?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

18. Fold or cut paper to make 3-d objects (such as origami, paper airplanes)?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

19. Do arts and craft projects (such as making jewelry, stringing beads, or using play dough/clay)?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

20. Color, paint, or draw free hand (not filling-in outlines)?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

21. Use computer or video games to do drawing or painting or matching and palying with shapes?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

22. Use tools (such as hammers or screwdrivers) to make things or take things apart to see how they work (such as a broken flashlight or toy)?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

23. Set up play environment with toy furniture, toy buildings, train tracks or building blocks?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

24. Explore woods, streams, ponds,or beaches or search for plants, bugs, or animals outdoors when the weather permits?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

25. Race toy animals or cars on the ground or around obstacles?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

26. Build with construction toys (such as building blocks, Legos, magnet sets, Lincoln logs)?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

27. Play with puzzles (such as picture puzzles, tangrams, slide puzzles, 3-d puzzles)?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

28. Play paper and pencil games (such as mazes, connect-the-dots)?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

29. Set up obstacle courses, tunnels, or runways for kids or pets?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

30. Draw maps (such as treasures hunt maps)?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

31. Draw plans for houses, forts, castles or other buildings or layouts?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

32. Play in parks or green spaces when the weather permits?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

33. Use kits to build models (such as airplanes, animals, dinosaurs, doll houses)?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

34. Climb trees when the weather permits?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

35. Play with flying toys (such as kites, paper airplanes)?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

36. Build dams, forts, tree houses, snow tunnels or other structures outdoors when the weather permits?

0	1	2	3	4
Never	seldom (a few times per year)	occasionally (a couple of times per month)	often (weekly)	many times per week

*****Thank you for completing the questionnaire!*****

Appendix E

Math Attitude and Spatial Anxiety Scale

*****Math Attitude Scale*****

<u>Directions:</u> This Math attitude Scale (Schackow, 2005; Fennema & Sherman, 1976) consists of 55 statements about your attitude towards mathematics. Please note that there are no correct or incorrect responses. Read each item carefully, and think about the item that best describes your attitude. You will indicate your response on a 5 – point scale, including Strongly Disagree (SD), Disagree (D), Neutral (N), Agree (A), Strongly Agree (SA).

Please check off which best indicates how closely you agree or disagree with the feeling expressed in each statement for each of the 55 items.

Questions	SD	D	N	A	SA
1. Mathematics is very worthwhile and necessary subject.					
2. I want to develop my mathematics skills.					
3. Mathematics helps develop the mind and teaches a person to think.					
4. Mathematics is important in everyday life.					
5. Mathematics is one of the most important subjects for people to study.					
6. I think of many ways that I use math in my daily life.					
7. I think study advanced mathematics is useful.					
8. I believe studying math helps me with problem solving in other areas.					
9. A strong math background could help me in my professional life.					
10. I get a great deal of satisfaction out of solving a mathematics problem.					
11. I enjoyed studying mathematics in school.					
12. I like to solve new problems in mathematics.					
13. I would prefer to do an assignment in math than to write an essay.					
14. I really like mathematics.					
15. I was happier in math class than in any other class.					
16. Mathematics is a very interesting subject.					
17. I am comfortable expressing my own ideas on how to look for solutions to a difficult problem in math.					
18. I was comfortable answering questions in math class.					
19. Mathematics is dull and boring.					
20. Mathematics is one of my dreaded subjects.					
21. When I hear the word mathematics, I have a feeling of dislike.					
22. My mind goes blank and I am unable to think clearly when working with mathematics.					
23. Studying mathematics makes me feel nervous.					

24. Mathematics makes me feel uncomfortable.					
25. I was always under terrible strain in math class.					
26. It makes me nervous to even think about having to do a mathematics problem.					
27. I was always confused in my mathematics class.					
28. I feel a sense of insecurity when attempting mathematics.					
29. Mathematics does not scary me at all.					
30. I have a lot of self-confidence when it comes to mathematics.					
31. I am able to solve mathematics problems without too much difficulty.					
32. I did fairly well in any math class I took.					
33. I learn mathematics easily.					
34. I believe I am good at solving problems.					
35. I am confident that I could learn advanced mathematics.					
36. I took as much mathematics as I could during my education.					
37. The challenge of math appeals to me.					
38. I took more than the required amount of mathematics					
39. I would like to avoid teaching mathematics.					
40. I have usually been at ease during math tests.					
41. I have often helped others with their math homework.					
42. I elected to take part in mathematical competitions.					
43. I usually comprehended math content well and seldom got lost.					
44. I did not like being introduced to new mathematical content.					
45. I get really uptight during math tests.					
46. I have usually been at east during math courses.					
47. I chose a major that did not require too many math courses					
48. I have dropped math courses because they became too difficult.					
49. I usually don't worry about my ability to solve math problems.					
50. Generally I have felt secure about attempting mathematics.					
51. I study mathematics because I know how useful it is.					
52. Girls can do just as well as boys in mathematics.					
53. I would trust a woman just as much as I would trust a man to figure out important calculations.					
54. Taking mathematics is a waste of time.					
55. Knowing mathematics will help me earn a living.					

*****Spatial Anxiety Scale*****

Directions: This Spatial Anxiety Scale (Lawton, 1994) consists of eight situations that require the use of spatial and navigational skills. Please rate these situations based on the your level of anxiety on a 5 – point scale, which the two end points labeled not at all and very much. Please note that there is no correct or incorrect answer.

Please check off which best indicates your level of anxiety for each of the eight items. The five points are very much (5), much (4), neutral (3), not much (2), and not at all (1), respectively.

Statements:	1	2	3	4	5
Leaving a store that you have been to for the first time and deciding which way to turn to get to a destination.					
Finding your way out of a complex arrangement of offices that you have visited for the first time.					
Pointing in the directing of a place outside that someone wants to get to and has asked you for directions, when you are in a windowless room.					
Locating your very large parking lot of parking garage.					
Trying a new route that you think will be a shortcut without the benefit of a map.					
Finding your way back to a familiar area after realizing you have made a wrong turn and become lost while driving.					
Finding your way around in an unfamiliar mall.					
Finding your way to an appointment in an area of a city or town with which you are not familiar.					

*****Thank you for completing this questionnaire*****

Appendix F

Spatial Coding Scheme

(Cannon, Levine, & Huttenlocher, 2007)

- Talk by the both parent and child will be coded
- There are eight spatial domains and sub-categories under each domain. You may have to refer to the context of a certain spatial word to determine if it is spatial or non-spatial, as well as what domain it falls under
- If they are not talking about spatial concepts, DO NOT code for it. For example, when they are doing a pattern of red, yellow, red, yellow (non-spatial dimension)

Summary of Spatial Domains:

A. **Spatial Dimensions:** words that describe the size of objects, people and spaces (not including weight or density because these do not have a tangible presence in the 2D/3D world).
B. **Shapes:** Words that describe the standard or universally recognized form of enclosed two- and three- dimensional objects and spaces (does not include ice cream *cone* or ice *cube* because they are not always the standard form of these shapes- e.g., an ice cube is still an ice cube even if it looks distorted or is melting).
C. **Locations and Directions:** Words that describe the relative position of objects, people, and points in space (Similar words are found in Category G: Spatial Features and Properties- must refer to context).
D. **Orientations and Transformations:** Words that describe the relative orientation or transformation of objects and people in the space.
E. **Continuous Amount:** Words that describe amount (including relative amount) of continuous quantities (including extent of an object, space, liquid, etc.). The word “some” is not included here because it is a discrete quantity. Also, quantities that do not have a spatial dimension (time, temperature, weight, money, etc.) are not included.
F. **Deictics:** Words that are place deictics/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. Words are coded in this category if they refer solely to the features/properties of a single shape or space. If the context is referring to the relation between two or more objects, spaces, or people, then they are coded in category C.
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.). No number patterns (1,3,1,3) or non-spatial dimensions (red, blue, red, blue) are coded here.

Examples of non-spatial usages:

	Examples
1. Homonyms or Endearments ▪ Spatial words that can also have non-spatial meanings, as well as words used	▪ I *left* my sweater on the bus ▪ You got that answer *right* ▪ It is your *turn*

<table>
<tr><td>to denote affection</td><td>Close the drawer
You are my little angel</td></tr>
<tr><td>2. Metaphors/Abstract Phenomena
Anything that has to do with relating to, dimensions, and movements of objects that do not exist in the 2D or 3D world</td><td>You have a big heart
That is a little problem
That took a long time
The back of my mind
He is out of his mind</td></tr>
<tr><td>3. Spatially Ambiguous
Usages where it is difficult to tell whether the speaker is referring to objects that are real in 2D or 3D, or abstract phenomena</td><td>It will only be a short walk
That was a big meal
He’s your little brother
I’m full because I ate too much</td></tr>
<tr><td>4. Nominatives
Spatial words that are used as part of a name or a body part. Also, spatial prepositions preceding verbs, adverbs, or conjunctions</td><td>Big Bird
Little Drummer Boy
My back hurts
Sit on your bottom/behind
Don’t go upstairs</td></tr>
<tr><td>5. Other
Ambiguous phrases</td><td>Turn on the light/television
Let’s play/eat together
He was on/in the bus
I like the boy in the book
Go away
Look into/at my eyes
I want to eat it with milk</td></tr>
<tr><td colspan="2" align="center">Non-Spatial Usages for Prepositions</td></tr>
<tr><td>6. Verb particles
Prepositions that function as part of a phrase/verb or a common expression (e.g., “look up something in the dictionary” together means to investigate, but the words cannot be broken down into a separate verb and preposition)</td><td>I ran into a friend
Turn on/off the light
Get over it
Oh, come on
Fold up the letter
Let’s get out of doors today
Did you go into hiding?
Did he get on board
Do it by yourself
Fill up, fit in</td></tr>
<tr><td>7. Non-spatial Prepositional Relations
Prepositions used to convey relationships between an object and the rest of the sentence</td><td>We are meeting them between 5 and 6 o’clock
The movie has to be returned The movie has to be returned by Friday
I am leaving in five minutes
Your appointment is on Tuesday
Eat with your fork
Play with me
He is in one of those moods
He went by train</td></tr>
</table>

	▪ I'll wear it *with* pride ▪ I'm bad *at* math ▪ The book is *on/about* colours ▪ I was hit *by* a ball ▪ I came *on* foot ▪ Talk *on* the phone ▪ I moved it *to* make some room ▪ The book was written *by* Dr. Seuss ▪ Get the truck *from* the toy store

Spatial Domains

A. SPATIAL DIMENSIONS		
Modifiers	**Code**	**Words**
Unconstrained Spatial Dimensions	[u]	Big (Bigger, Biggest) Little (Littler, Littlest) Small (Smaller, Smallest) Large (Larger, Largest) Tiny (Tinier, Tiniest) Enormous Huge Gigantic Teeny Itsy-bitsy Itty-bitty
Horizontal/Vertical Dimensions	[h]	Long (Longer, Longest) Short (Shorter, Shortest)
Only Vertical	[v]	Tall (Taller, Tallest)
Only Horizontal	[o]	Wide (Wider, Widest) Narrow (Narrower, Narrowest) Thick (Thicker, Thickest) Thin (Thinner, Thinnest) Skinny (Skinnier, Skinniest) Fat (Fatter, Fattest) Chunky
Horizontal/ Vertical Dimensions in 3D	[d]	Deep (Deeper, Deepest) Shallow (Shallower, Shallowest)
Enclosed 3D Object	[b]	Full (Fuller, Fullest) Empty (Emptier, Emptiest)
Overall Spatial Words	[s]	Size Length Height Width Depth Volume

		Capacity Area (as in of a square) Measure (Measurement)
B. SHAPES		
Modifiers	**Code**	**Words**
2D Shapes Without Sides (*Or don't have all straight sides)	[e]	Circle Oval Ellipse Semicircle/half-circle Arch Teardrop/Raindrop
2D Shapes	[t]	Triangle Square Rectangle Diamond Pentagon Hexagon Octagon Parallelogram Quadrilateral Rhombus Polygon
3D Shapes	[P]	Sphere Globe Cone Cylinder Pyramid Cube Rectangular Prism
Overall Shape Words	[S]	Shape
C. LOCATION AND DIRECTION		
Modifiers	**Code**	**Words**
Terms that Follow Nouns	[y]	At To Toward From (as in moving *away* from something)
Resting Along A Surface	[z]	On Onto Upon Off
Within/Outside Boundaries of a Volume	[w]	In Into Inside Within Out

		Out of Outside
Along a Vertical Axis	[a]	Under Underneath Beneath Below Over Above Up Upper Upward Down Downer Downward On top Top Bottom High (Higher, Highest) Low (Lower, Lowest) Column Vertical Vertically
Along a Horizontal Axis	[A]	Left Leftward Right Rightward Front In front Back In back Ahead Behind Sideways Row Horizontal Horizontally
Proximal to Another Point	[p]	By Near (Nearer, Nearest) Nearby Close (Closer, Closest) Next to With Beside Far (Farther, Farthest) Away Beyond

		Further Past Against Together Separate Separated Join Joined Apart
Relationship Between Two Other Points (at least)	[l]	Between Among
Equal Distance from Something	[m]	Middle Center
In Broad Vicinity of Another Point	[V]	About Around Throughout
Length of Object/Person/Point	[L]	Along Lengthwise
Cardinal Direction	[N]	North (Northern) South (Southern) East (Eastern) West (Western)
One Side to Another Side of Object/Person/Point	[f]	Around Through
Other Side of Object/Person/Point	[O]	Across Over Opposite Aside Reverse
Direction of Orientation of Object/Person/Point/Plane	[D]	Around Reverse Reversed Back (verb) Backward Forward Parallel Perpendicular Diagonal Down (as in “down the street”) Up (as in “up the street”)
Overall Location and Direction Words	[r]	Location Position Direction Route Path Head

		Headed Heading Spot Place Distance
D. ORIENTATION AND TRANSFORMATION		
Modifier	**Code**	**Words**
Orientation of Object/Person	[i]	Upside down Right side up Upright
Transformation Around Axis	[B]	Turn (Turned, Turning) Flip (Flipped, Flipping) Rotate (Rotated, Rotating)
Overall Orientation/Transformation Words	[n]	Orientation Rotation
E. CONTINTUOUS AMOUNT		
Modifier	**Code**	**Words**
Entire Amount	[E]	Whole All
Inexact Part of Continuous Object	[x]	Part Piece Section Bit Segment Portion Fragment Fraction Some A lot A little Much Enough Many Most Least
Exact Part of Continuous Object	[X]	Half Third Quarter Fifth Sixth Seventh Eight Ninth Tenth Etc.
Absence of Continuous Amount	[G]	None

Comparison Between Continuous Amounts	[H]	More Less Same Match Even Equal
Standard Measurement Units	[I]	Inch Foot Mile Centimeter (cm) Meter Kilometer (km) Etc.
Overall Continuous Amount Words	[J]	Amount Room Space Area (as in "space")
F. DEITICS		
Modifier		**Words**
Location of Speaker	[K]	Here
Location of Other	[M]	There x. "How many are there?" (it is not specific, we don't know where there is referring to) o. "How many are there in the castle?" (have a specific location)
Question to Identify Location	[Q]	Where
No, Any, Some, or All Locations	[R]	Anywhere Somewhere Nowhere Everywhere Wherever
G. SPATIAL FEATURES AND PROPERTIES		
Modifier		**Words**
Flat Surfaces	[F]	Side Sided Edge Edged Border Bordered Line
Curvature of Object	[c]	Round (Rounder, Roundest, Rounded) Curve (Curved, Curvy, Curvier, Curviest)

		Bump (Bumped, Bumpy, Bumpier, Bumpiest) Bent (Bend, Bended, Bendy) Wave Wavy Lump Lumpy Arc Sector
Lack of Curvature	[C]	Straight (Straighter, Straightest) Flat (Flatter, Flattest)
Two Sides Meeting	[k]	Angle Corner Point (Pointed, Pointy)
Surface of 3D Object	[T]	Plane Surface Face
Standard Shapes	[j]	Circular Rectangular Triangular Conical Spheric Spherical Elliptical Cylindric Cylindrical Shaped (e.g., heart-shaped)
Orientation of 2D or 3D Shape or Space	[q]	Horizontal Vertical Diagonal Axis
Relation Between Elements	[g]	Parallel Perpendicular Symmetry Symmetric Symmetrical
H. PATTERN		
Modifier		**Words**
Consistent Organization	[U]	Pattern Design Sequence Order
Relative Location in Pattern	[W]	Next First Last

		Before After
Type of Organization of Pattern	[Y]	Repeat (Repetition, Repeated, Repeating) Increase (Increased, Increasing) Decrease (Decreased, Decreasing)
Overall Pattern Words	[Z]	Pattern Design Sequence Order