BENEFITS AND CHALLENGES OF TEACHER PROFESSIONAL LEARNING IN A MATHEMATICS INTERVENTION STUDY IN THE EARLY YEARS (JK-GRADE 2)

by

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A thesis submitted in conformity with the requirements for the degree of Master of Arts
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Abstract

Research shows spatial reasoning and an early start to mathematics are key predictors of later school success. This thesis explores educator learning in a professional learning intervention study, focusing on spatial reasoning tasks. A team of JK-Grade 2 teachers, early childhood educators and a math coach spent time implementing a series of playful, research-developed spatial reasoning tasks in mathematics. Educator learning throughout this process was considered, with particular focus on two cases: a kindergarten teacher and a math coach. Results indicate several benefits to educator learning, including learning by observing children, through implementation of research-developed tasks, about mathematics content, and through personal reflection. The co-creation of tasks was highlighted as extremely important for educator learning. It is important for educators to co-create tasks instead of simply implementing existing ones. This intervention study also highlighted some challenges of teacher professional learning, including time, administrator support, educator perceptions and implementation of tasks.
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Chapter One: Introduction

1.1 Introduction

The purpose of this thesis is to explore educator learning in a teacher professional learning intervention study. As part of the Mathematics for Young Children (M4YC) project, this study investigated spatial reasoning with Junior Kindergarten (JK) to Grade 2 educators and their students. My involvement as an M4YC project research assistant for a number of years has led me to develop a great interest in the area of mathematics for young children and the teaching of math through spatial reasoning. My interests have led me to select this professional learning (PL) study for careful analysis in this thesis.

The results of previous M4YC studies show that PL programs focusing on math (particularly through spatial reasoning) help to build teacher’s conceptual mathematics knowledge and pedagogical best practices with students (see http://tmerc.ca). In all M4YC professional learning projects, educators experience a playful pedagogy both in their own learning and in helping their students. Playful pedagogy can be described as an approach to teaching that “integrates the child-centered engagement of play with curricular goals and [that] enabl[es] children to maintain a large degree of control over their learning” (Moss, Bruce & Bobis, 2016, p. 163). This focus on spatial reasoning, playful pedagogy and early years (JK-Grade 2) math are areas of highly promising recent research and it is exciting for me to think that I have been involved in exploring these areas further for my Masters of Arts thesis.

1.2 Research context

The M4YC project is a joint initiative between Trent University (Trent) and the Ontario Institute for Studies in Education (OISE). Since 2011, teams of educators across
Ontario have worked with teams of Trent and OISE researchers in developing awareness of the importance of: a) providing challenging and engaging mathematics education opportunities for students in the early years of school; b) teaching mathematics with a focus on spatial reasoning (an area of mathematics that is often underrepresented and one that is proving to be of lasting benefit); and, c) focusing on playful pedagogy and making mathematics fun and explorative for young children.

The M4YC professional learning sessions take place in school settings where, after an introduction to the research project and background on M4YC (i.e., a discussion of the benefits of a focus on spatial reasoning and early years math), the team of educators and researchers decides on a collective focus for their exploration. They set research questions and goals for their professional learning and work together with the research team as equal players in exploration. During PL cycles, the team spends a great deal of time developing exploratory tasks to try with their students, they often co-teach these tasks with small groups of students where a large emphasis is placed on carefully observing student learning. Educators then spend time debriefing what they have observed and develop a sense of what young children can do (often developing a rising estimate of JK-Grade 2 students’ mathematical capabilities).

The focus on spatial reasoning is of key importance to this professional learning study and to the M4YC project as a whole. Recent research provides many reasons for why such a focus offers invaluable context for this research. We rely on spatial reasoning; we think spatially all the time (e.g., when we read maps or pack the trunk of our car) (Verdine, Golinkoff, Hirsh-Pasek & Newcombe, 2014). Spatial reasoning is malleable and trainable and, therefore, provides a very rich lens through which to explore
the mathematics curriculum (Casey, Andrews, Schindler, Kersh, Samper & Copley, 2008; Newcombe, 2013; Verdine et al., 2014).

This thesis is based on data from a classroom-centered M4YC intervention study that implemented a field test booklet of spatial reasoning tasks as a medium for exploring spatial reasoning and playful pedagogy in five JK-Grade 2 classrooms. The intervention study lasted for four months (from January to April, 2015) and consisted of a team of seven JK-Grade 2 educators (five teachers and two ECEs), a math coach (from the school board), researchers from Trent University and a numeracy consultant from the school board (who co-facilitated the PL with the researchers). A primary focus in meetings was on describing student experiences with the spatial reasoning tasks. These opportunities for exploring JK-Grade 2 student thinking and learning had the purpose of expanding educator conceptual knowledge of mathematics, raising their estimates of what young students are capable of in mathematics, and verifying the importance of teaching mathematics with a focus on spatial reasoning.

1.3 Research questions

I wanted to explore the impact that teaching mathematics through spatial reasoning has on educator learning. I was interested in both the characteristics of the intervention study that were particularly beneficial and the areas that presented challenges. To combine these ideas into one research question was too restrictive, so I decided on two questions. The following have guided my research and have helped shape my investigation, from the literature review, to my selection of methodology and data analysis procedures, and to my discussion and interpretation of the findings:
• What are the benefits and challenges of a JK-Grade 2 educator professional learning intervention study focusing on spatial reasoning in mathematics?
• What are the effects of implementing spatial reasoning tasks on educators’ conceptual understanding of spatial reasoning?

The data I collected through the intervention study and the nature of these questions led me to select qualitative research methods. More specifically, I chose to answer these questions by carrying out an embedded case study (Yin, 2009), where I consider both the school team as a whole and two individual cases to better understand teacher learning in the intervention study.

1.4 Significance of the study

As educators, I believe we have a moral imperative to improve mathematics instruction. Research shows that math is the best predictor of student overall success (Claessens, Duncan & Engel, 2009; Duncan, Dowsett, Claessens, Magnusen, Huston, Klevanov, Japel et al., 2007). Despite these findings, however, it is commonly understood that much less time in the classroom is devoted to math than to other subjects like literacy or social studies. Studies like this current one help to increase attention on mathematics and to foster and inspire exciting mathematics learning and teaching.

I believe this study is significant in a few key ways. Through the lens of one school case study site, it provides insight into the benefits and challenges to intervention studies. By exploring data collected from the intervention study site, and by carefully considering records of teacher learning, the successes and limitations to such learning come to light.
This study maps new terrain in the area of spatial reasoning and its application in early years classrooms (as does the larger M4YC project). The field-testing of tasks in this intervention study is important in disseminating information and ready-made tasks that educators can try in their own classrooms. It, therefore, opens up the possibility for spatial reasoning to be taught in more early years’ classrooms. Since spatial reasoning is a form of reasoning, it can be applied to all areas of mathematics, not just one strand, and helps students access mathematics in a different way. For example, spatial reasoning can be a focus when we think about number, geometry, measurement and proportional reasoning with young children.

Recent research showing that both spatial reasoning and a focus on challenging mathematics in the first years of school are vital to later successes in school and work, makes this work of utmost importance (Newcombe & Frick, 2010; Verdine et al., 2014). The work of the M4YC project and this intervention study are at the forefront of developing exciting and meaningful mathematics programming in JK-Grade 2 classrooms.

1.5 Background of the researcher

I have always known that I want to work in the area of education. I am intrigued by how others learn and have always felt passionate about helping people learn new things. I deeply value and honour the work of teachers and have tremendous respect for the influence they have on society. My decision to go to teachers college was an easy one and my acceptance into a concurrent education program during my undergraduate degree let me experience teaching and learn about effective teaching for all five years of my first degree.
My school placements in the Queen’s-Trent Concurrent Education program and in my Bachelor of Education reinforced my love for learning and further instilled in me the importance of effective education. My placements were in both primary and junior classrooms and, by watching students light up when they learned something new, I furthered my appreciation and love for teaching and the field of education. I have enjoyed learning in all settings, be it primary or secondary school, university or college, as a student and as a teacher. My love for learning has also led me to value research in the area of educator learning. My course work and thesis work in my Masters of Arts at OISE have largely considered teacher learning and ways to foster rich and meaningful learning contexts.

After I completed my Bachelor of Education, I moved to Bristol, England to teach for the year. It was a wonderful and challenging experience that helped shaped me into the educator I am today. As an occasional teacher, I had the opportunity to work with students of many ages and in a range of elementary schools across the city. Upon my return to Canada, I was excited about how I could become involved in education beyond the classroom.

After Bristol, I had the privilege of finding work as a Research Assistant with the Trent Math Education Research Collaborative (TMERC, http://tmerc.ca) in the School of Education and Professional Learning at Trent University. Our research focuses on mathematics education through lesson study and collaborative action research (teachers and researchers working in mutual areas of interest). As a research assistant, I have developed, first-hand, a sense of the merit and importance of pursuing rich mathematics education environments in our schools. The work has been a fantastic opportunity to
collaborate with professors, teachers, students and other research assistants in extremely valuable work. I have had the opportunity to explore educator and student learning and thinking through exploratory lessons and through specifically designed and implemented task-based interviews with students.

I have seen how, when teachers are given the chance to carefully and purposefully observe their students, they develop in their own mathematical content knowledge and become more confident teachers. I have also witnessed the benefits of considering different mathematics topics through a spatial reasoning lens for both teachers and students. Through this work, I have also seen how educators develop a rising estimate for what mathematics young children are capable of doing.

As a research assistant, I have had the privilege of developing my learning in this area. I have attended and co-presented at mathematics education conferences, co-written papers and reports and helped facilitate professional learning programs. The continued learning and research opportunities available in the areas of early years mathematics and spatial reasoning are so broad and I am so honoured to be able to contribute to this area through my own studies and thesis preparation at OISE the past two years.

1.6 Thesis overview

This thesis is divided into five main chapters. Each chapter considers a particular phase of my research and together they provide a comprehensive discussion of what is already known in the area, what I wanted to explore, what I did, and what I found out.

In this current chapter, Chapter One, I have provided an overview of my thesis, context for my research, presented my research questions and presented an argument for
the significance of the study. I have also given background on my own experiences as a researcher and considered what brought me to writing this thesis.

Chapter Two is a literature review. In this chapter, I explore previous research in areas that relate to and guide M4YC research and that lead to further areas for exploration. Two main areas of literature are presented in my literature review: math content and context, and teacher professional learning.

In Chapter Three, I detail the methodology I employed, from background information to data collection and analysis. I explain why I chose to conduct an embedded case study, where the educator team serves as the main case, and two individual educators become units of closer analysis. The research contexts, participants, data collection, data analysis and ethical considerations are all sections of the methodology chapter.

Findings from my data analysis highlight educator learning and are discussed in Chapter Four. I carefully present findings for the team as a whole and for two educators: a kindergarten teacher and a math coach. In this chapter, themes and patterns in the data are considered.

The final chapter, Chapter Five offers a discussion and interpretation of the findings. Beginning with a summary of my work, I then explore the benefits of teacher professional learning (including developing conceptual knowledge of spatial reasoning and changing pedagogy) as well as the challenges of PL (including time restraints, school-level factors and the nature of the learning). I provide interpretations, discuss possible limitations, and conclude with recommendations for future research.
Chapter Two: Literature Review

2.1 Introduction

In this chapter, I explore existing literature on related areas of research to give context to my exploration and analysis of a teacher professional learning intervention study that focused on early years mathematics and spatial reasoning. This literature review is intended to provide appropriate context for my research and focuses on two major areas of literature: (1) mathematics content and context, including mathematics for young children, spatial reasoning and playful pedagogy; and, (2) teacher professional learning, including classroom-based research intervention studies, characteristics of effective teacher professional learning, teacher content learning and the role of the administrator in PL.

2.2 Math content and context

2.2.1 Mathematics for young children

A great deal of recent research outlines the importance of providing enriching mathematics experiences for young children. The National Council of Teachers of Mathematics (NCTM) “argue for the importance of high-quality mathematics education for children ages 3-6” (Claessens, Duncan & Engel, 2009, p. 415). In a review of a large longitudinal data set of over 21,000 kindergarten students, Claessens, Duncan and Engel (2009) found that children’s skills at kindergarten are related to Grade 5 abilities in math and reading. In addition to skills in reading and mathematics, the authors considered a wide range of factors related to school achievement in kindergartners including socioemotional, academic and attention related skills and abilities. Their analysis concluded that:
school-entry math skills were consistently predictive of fifth-grade achievement. Early math skills such as knowing numbers and ordinality were not only highly predictive of later math achievement but of later reading achievement as well. Rudimentary math skills were the single most important set of kindergarten-entry skills. (p. 423)

Similar results were reported by Duncan, Dowsett, Claessens, Magnusen, Huston, Klebanov, Japel et al. (2007), who found that mathematics was the best predictor of later school achievement in a study of 36,000 children: early math and reading “are consistently associated with higher levels of academic performance in later grades” (p. 1444).

Watts, Duncan, Seigler and Davis-Kean (2014), who considered data from the National Institute of Child Health and Human Development and the Study of Early Child Care and Youth Development databases, make further statements on the importance of an early start in rich mathematics education. Like the two previously mentioned studies, “even after adjusting for differences in other academic skills, attention, and personal and family background characteristics, such as the home environment and [a] child’s cognitive ability” (p. 357), pre-kindergarten children’s math abilities were found to be statistically significant predictors of later (i.e., adolescent) math achievement. The authors conclude that there is long-term importance in fostering and developing math skills in young children.

Based on their curriculum development initiative for pre-kindergarten to Grade 2 students, called Building Blocks, Clements and Sarama (2007) discuss their findings and similarly confirm that “focused early mathematics interventions” (p. 158) are beneficial to young children. Their study found that even very young children have the ability to
“directly model different types of [mathematics] problems” (p. 139) using a variety of manipulatives.

Despite these findings, the mathematical capabilities of young children are often underestimated. In a social policy report, Ginsburg, Lee and Boyd (2008) write that “from birth to age 5, young children develop an everyday mathematics—including information ideals of more and less, taking away, shape, size, location, pattern and position—that is surprisingly broad, complex, and sometimes sophisticated” (p. 4). To carefully consider young children’s abilities in mathematics, a team of researchers designed and conducted a professional learning study where they worked with teachers of students aged 3 to 7, conducted task-based interviews, and developed mathematics exploratory tasks, primarily focusing on spatial reasoning (Bruce, Moss & Flynn, 2013).

The authors found that, as a result of their professional learning program, teachers developed an “increased estimation of young students’ mathematical abilities, leading to an asset-oriented ‘no-ceiling’ approach to math programming” (Bruce, Moss & Flynn, 2013, p. 911). In sum, as Ginsburg, Lee and Boyd (2008) write, “learning mathematics is a ‘natural’ and developmentally appropriate activity for young children” (p. 5). The review of literature in this section emphasizes the great role that educators have in stretching the possibilities in math for young children.

2.2.2 Spatial Reasoning

To begin this section on the discussion of spatial reasoning, a major content focus of the intervention study discussed in this thesis, I offer the following definitions and context:
Spatial thinking, or reasoning, involves the location and movement of objects and ourselves, either mentally or physically, in space. It is not a single ability or process but actually refers to a considerable number of concepts, tools and processes (National Research Council, 2006)… Spatial reasoning vitally informs our ability to investigate and solve problems, especially non-routine problems, in mathematics. (Ontario Ministry of Education, 2014, p. 3)

As humans living in and navigating through a spatial, 3D world, an ability to reason spatially is of great importance:

Experiences such as efficiently packing a car trunk, using a mall map to find a store, and cutting equal slices of pizza for a group of children all require spatial ability. (Verdine, Golinkoff, Hirsh-Pasek & Newcombe, 2014, p. 8)

With these definitions and context in mind, it is easy to imagine the benefits of a spatial approach to mathematics. Seeing math through a spatial lens makes it visual, connects it to the real world and draws on a wide range of learner strengths. Math becomes more accessible to many students when it is approached spatially (Ontario Ministry of Education, 2014). In fact, directly related to the topic of fostering early mathematics is the importance of developing spatial reasoning skills in young children. It is positive to introduce “spatial reasoning as an approach to mathematics right at the point at which children are being introduced to mathematics learning” (Casey, Andrews, Schindler, Kersh, Samper & Copley, 2008, p. 269).

Another study recognizes the need for teachers to spend time teaching spatial reasoning skills to their young students (Newcombe & Frick, 2010). The “evolutionary and adaptive importance” (p. 102) of being spatially inclined has caught the attention of education researchers, psychologists and teachers alike. Like the Ontario Ministry of Education (2014) argues, spatial reasoning is an effective approach to solving many mathematics problems—creating diagrams, finding patterns in numerical information and
making graphical representations of data all involve spatial thinking and reasoning (Casey et al., 2008).

Despite the growing awareness for the benefits of teaching through spatial reasoning, it is common for early years teachers to limit their geometry and spatial sense teaching and place a large emphasis on number sense in their mathematics programming. This is not surprising, however, given the lack of attention paid to geometry and spatial sense in both teaching (i.e., it is often left to the end of the year and taught only briefly) and professional learning opportunities (Sinclair & Bruce, 2014). Sinclair and Bruce (2014) refer to a general lack of time spent on geometry and spatial reasoning in early years classrooms, a concerning trend in this area of teaching. In a large-scale survey based in Ontario, it was found that, when compared to other strands in mathematics, the least amount of time was devoted to the teaching of geometry and spatial reasoning (Bruce, Moss & Ross, 2012). But children have more spatial awareness than we give them credit for. As the authors suggest, children from four years of age have the ability to recognize and identify spatial concepts such as parallel relations, shape recognition and other concepts that are not officially in the math curriculum until much later (Sinclair & Bruce, 2014).

The many recent studies discussed in this section help to argue the imperative need for early years educators to broaden their math programming beyond number sense and beyond simply naming shapes and identifying their attributes in geometry and spatial sense. The “no-ceiling” curriculum (Bruce, Moss & Flynn, 2013) connects beautifully to the notion of stretching our ideas of what young children are capable of doing in both mathematics and spatial reasoning. Spatial reasoning is most obviously linked to
geometry and spatial sense and such an emphasis challenges students to experience and experiment with composing and decomposing shapes, taking different perspectives of objects, building complex figures, exploring symmetry, and visualizing, to name only a few (see Ontario Ministry of Education, 2014, p. 4).

Casey et al. (2008) focus on kindergarten students’ block play in their study and they recognize that “there is [often] little systematic teaching of spatial concepts in early childhood classrooms” (p. 304). They conclude “that systematic teaching of block building skills may be an effective way of developing spatial reasoning skills within the early childhood mathematics curriculum” (p. 305). In another paper, Newcombe (2013) argues for the need to “spatialize” the curriculum and purposefully incorporate spatial training into daily school work. Teachers of young children can support the development of spatial reasoning by “doing jigsaw puzzles, promoting guided play with blocks and geometric shapes, and reading books with spatial words in them” (p. 29). Newcombe (2010) describes various ways to support young children with spatial tasks, including “using spatial words, gesturing, reading spatial books, exploring geometric shapes, doing puzzles, using maps and models, etc.” (p. 33).

In addition to our recognition of mathematics being a predictor of overall success and achievement, a focus on developing young children’s spatial skills also links directly to their readiness for and knowledge of skills necessary for application in science, technology, engineering and mathematics (commonly referred to as “STEM”) subjects. Uttal et al. (2013) cite spatial reasoning’s malleability as being particularly positive as they recognize the dramatic links between spatial reasoning and STEM education. Their research suggests that “improving spatial thinking can help provide the skills necessary to
succeed in STEM fields, yet a specific focus on spatial thinking has been lacking in almost all educational programs” (Uttal et al., 2013, p. 372).

In their consideration of school readiness for young children, Verdine et al. (2014) state a convincing connection between combining the development of early mathematics and spatial reasoning skills: “another reason that spatial skills may be vitally important for success in scientific disciplines is their relationship to mathematical skills… There is growing evidence that the relationship between spatial and mathematical abilities emerges quite quickly” (p. 8). Fortunately, given these findings, even in young children, spatial skills are malleable through training. Like Newcombe (2013) and Casey et al. (2008), Verdine et al. (2014) suggest a number of materials that help develop spatial skills, including exploration with puzzles, blocks and shapes. In sum: “increasing access to a preschool ‘spatial education’ constitutes a safe bet for fuelling school readiness and igniting long-term performance gains in STEM-related fields” (p. 12).

Newcombe and Frick (2010) also report on the significant links between spatial reasoning and the STEM disciplines, all of which employ spatial intelligence. By introducing young children, particularly in the first five years of life, to spatial reasoning means that they are more likely to pursue careers and study in STEM disciplines (Verdine et al., 2014). Given this connection, it is encouraging that “it is clear that spatial training works, in a way that generalizes to new stimuli and novel tasks, and [that] is durable over time” (Newcombe & Frick, 2010, p. 104).

To summarize, it is evident that an early focus on spatial reasoning in mathematics education is invaluable to young students, both immediately in their early years schooling and later on in their educational and professional studies. Promoting
success in STEM has gained momentum in the world of education today (Wai, Lubinski, Benbow & Steiger, 2010). As such, this connection between mathematics, spatial reasoning and STEM is an important one to foster: “the existing literature provides a firm basis for concluding that spatial ability and math share cognitive processes beginning early in development” (Cheng & Mix, 2014, p. 3).

### 2.2.3 Playful pedagogy

Literature recognizes play as a powerful way for young children to explore their surroundings in a safe and fun environment; “there is accumulating evidence over the last decade that a middle ground between unguided play and direct instruction may be most effective in supporting young students in learning mathematics” (Moss, Bruce & Bobis, 2016, p. 163). This “middle ground” can be described as playful pedagogy. Newcombe and Frick (2010) comment on play in their article on spatial intelligence in early education: “it is through play and direct physical experience that children gather most of their knowledge about the laws and rules of the world they live in” (p. 108). Docket and Perry (2010) open their paper with: “play has long been regarded as a critical element of early childhood curriculum and pedagogy” (p. 715). In a consideration of early childhood mathematics education, it is, therefore, extremely important to include a discussion of playful pedagogy and best practices.

In their consideration of early childhood education and mathematics learning, deVries, Thomas and Warren (2010) studied indigenous children from Brisbane, Australia and discuss characteristics specific to early mathematics education. Referring to other literature on the topic, deVries, Thomas and Warren (2010) cite both a rising estimate of what math young children are capable of doing and an appreciation for early
mathematics predicting later math skills. The goal of their study was to determine appropriate strategies for play that help children transition from pre-school (i.e., the home environment) to school. They discuss the commonly perceived separation between teaching and playing and report that teachers often distinguish between teaching, which they view as strictly the domain of the teacher, and playing, which they view as strictly led by children. However, as teachers in the study became more involved in children’s playing, they began to add “to their focus on children as active participants in play (and therefore learning) to include a view of themselves also as active participants in children’s play (and therefore learning)” (deVries, Thomas & Warren, 2010, p. 721).

This focus on teachers’ role in guided play is also discussed by Docket and Perry (2010), who worked with teachers of three- and four-year old children. Like deVries, Thomas and Warren (2010), Docket and Perry (2010) found that there is a great deal of teacher action involved in effective play for learning. Key understandings of mathematical concepts and play-based pedagogies is required by teachers in order to structure play that promotes math learning: “educators who are alert to this, and who themselves feel competent and comfortable playing with mathematics can provoke deep understanding” (Docket & Perry, 2010, p. 717).

Play is central to early years education, is a key motivator for learning math concepts, and leads to the development of “important cognitive and social skills” in young children (Caldera, McDonald, O’Brien, Truglio, Alvarez & Huston, 1999, p. 856). In their study, Caldera et al. (1999) worked with preschoolers and examined the differences between structured and unstructured play with blocks. They found a benefit to
encouraging structured play as “the complexity of play of children’s free play with blocks predicted their accuracy in structured block play” (p. 866).

These considerations of structured/guided and unstructured/free play lead nicely into the discussion of best practices in playful pedagogy. The idea of “free play” is often what comes to mind when thinking about young children playing. This type of play is unstructured and involves no adult intervention.

“Guided play”, in contrast, combines adult intervention and child direction. The combination of adult instruction with child direction (as in guided play) has shown to have better learning results for young children, even when compared to direct instruction alone (Weisberg, Kittredge, Hirsh-Pasek, Golinkoff & Klahr, 2015). In their social policy report, Ginsburg, Lee and Boyd (2008) argue that, “although essential for children’s intellectual development generally and for mathematics learning in particular, play is not enough” (p. 5). Teachers must also make time for direct, planned instruction with their students as it provides them with the opportunity to explore rich and meaningful mathematics learning and make explicit connections between their play and more sophisticated math concepts.

In another consideration of playful pedagogy and guided play, Weisberg, Hirsh-Pasek and Golinkoff (2013) examine early mathematics teaching and best practices in terms of both pedagogy and curriculum. Like Ginsburg, Lee and Boyd (2008), Weisberg, Hirsh-Pasek and Golinkoff (2013) recognize the importance of providing context and teacher-directed instruction as well as allowing opportunities for child-directed learning and play. They also discuss the concept of guided play, which falls somewhere in the middle of direct instruction and free play. They state that guided play involves asking
students open-ended, thought-provoking questions and is a happy medium between the 
two, as it is “adult-scaffolded learning but remains child-directed… while adults might initiate the play sequence, children direct their own learning within the play context” (p. 105). Weisberg, Hirsh-Pasek and Golinkoff (2013) also mention an important shift in children’s self-efficacy as a result of their guided play learning opportunities, where they are given the opportunity to self-direct with support through conversation and adult scaffolding. This combination leads to enhanced opportunities for exploration and discovery in mathematics.

Interestingly, guided play has also been linked to the development of spatial skills (Moss, Bruce & Bobis, 2016; Weisberg et al., 2013). Moss, Bruce and Bobis (2016) explore early mathematics curriculum and teaching pedagogy and are finding “promising developments in the areas of play and spatial reasoning” (p. 154). Moss, Bruce and Bobis (2016) discuss best practices for play and also recognize that free, or unguided play is not enough to promote deep mathematical understanding. They support engagement in play that is directed by young children as it is proven to be both enabling and effective: “this middle ground approach integrates the child-centered engagement of play with curricular goals” (p. 163).

To further these calls for guided play in math, Fisher, Hirsh-Pasek, Newcombe and Golinkoff (2013) suggest that play should involve opportunities for scaffolding, inquiry, engagement and child-centered learning. The authors conducted a study that considered and compared the effects of both play and didactic instruction on preschool children’s (ages 4 and 5) exploration of shapes. Results specifically link gains in shape knowledge and understanding to experiences with guided play: “after approximately 15
minutes of shape training, children displayed very different shape knowledge across guided play, free play, and didactic instruction conditions. Children in guided play demonstrated improved definitional learning of shapes” (p. 1877).

The review of studies presented in this section on playful pedagogy highlight the idea that free play is not enough. Children benefit from teacher action and direction and as such, a happy medium between child-centered and adult-directed play provides positive learning experiences in early years mathematics classrooms.

2.3 Teacher professional learning

2.3.1 Classroom-based intervention studies

In an introduction to a special issue of papers on classroom-based interventions, Stylianides and Stylianides (2013) discuss the approach to education research that aims “to improve classroom practice” (p. 333). They recognize the concern amongst mathematics education researchers who feel that so much of the research in the field “has not played a greater role in supporting improvement of classroom practice, especially improvement of students’ learning of mathematics” (p. 333). The authors identify possible reasons for this apparent lack of focus on classroom-centered research within education including: perceived gaps between research (i.e., academia and researchers) and practice (i.e., educators); a focus on research in curriculum instead of research in pedagogy and teaching practices; and, an aim to avoid the ‘messiness’ of the classroom environment as sites for research.

It is only, however, when interventions are based in classrooms and explore identified classroom-level teaching or learning situations, that classroom practice is strengthened and findings can contribute directly “to research knowledge through
deepening theoretical understanding of classroom phenomena and processes that underpin these phenomena” (Stylianides & Stylianides, 2013, p. 335).

Classroom-based intervention studies carefully examine an area of learning that “typical classroom practice has difficulty in supporting” (p. 334). Stylianides and Stylianides (2013) provide a series of inspiring arguments and reasons for conducting classroom-based intervention studies. The authors argue that in order to “support improvement of classroom practice” (p. 334), research should be:

- conducted in the ‘world’ of practitioners (i.e., in actual classrooms)… with close collaboration between researchers and teachers, thus increasing the likelihood that the results of the research will be directly applicable (instead of merely potentially relevant) to practice; … directly address… problems of student learning and how this learning can be better supported by teaching (including teaching resources such as curriculum materials), thus tackling key issues of current mathematics classroom practice; and… seek… to develop empirically tested and theory-based solutions to alleviate problems of student learning in order not only to show that things ‘worked’ (or ‘can work’) but also to explain how/why things ‘worked’, thus shedding light on the mechanisms of success. (Stylianides & Stylianides, 2013, p. 334)

The benefits of classroom-based interventions are multi-fold. In classroom-embedded research environments, researchers and teachers have the opportunity to work together to develop a collaborative relationship that allows for a deep focus on student learning, thinking, teaching and a consideration of best practices. Classroom-based interventions operate in a dynamic environment that provides a rich, real-life context for research (Stylianides & Stylianides, 2013).

2.3.2 Effective teacher professional learning

Effective teacher professional learning (PL) is action-oriented, classroom-embedded, and involves “iterative cycles of goal setting/planning, practicing, and reflecting” (Bruce, Esmonde, Ross, Dookie & Beatty, 2010, p. 1599). Moss, Bruce and
Bobis (2016) also list key characteristics for effective teacher professional learning. Professional learning is particularly beneficial when it involves “classroom-embedded and practice-focused professional learning programs... clearly articulated and specific objectives for professional development... implementation and use of information from child assessments... [and] sustained professional development of sufficient duration” (p. 177). The following discussion of literature on teacher professional learning offers insight into research on effective PL characteristics.

In an article that considers the design of a conceptual framework to measure and conceptualize effective teacher PL, an author writes: “teachers experience a vast range of activities and interactions that may increase their knowledge and skills and improve their teaching practice, as well as contribute to their personal, social, and emotional growth as teachers” (Desimone, 2009, p. 182). Desimone (2009) recommends that PL activities be spread over a few months and involve upwards of 20 hours, especially if teacher “intellectual and pedagogical change” is a goal (p. 184).

In a more recent publication, Desimone (2011) wrote a primer on effective professional development and, again considers the characteristics of effective teacher professional learning programs. Five key features are identified as important: a focus on content; active participation and learning; coherence and consistency with other programs and beliefs; at least 20 hours in duration; and, like-grade/subject groupings to enhance community building. Desimone (2011) writes:

Successful professional development follows these steps: 1) Teachers experience professional development; 2) The professional development increases teachers’ knowledge and skills, changes their attitudes and beliefs, or both; 3) Teachers use their new knowledge, skills, attitudes, and beliefs to improve content of their instruction, their approach to pedagogy, or both, [and]; 4) The instructional
changes that the teachers introduce to the classroom boost their students’ learning. (p. 70)

Similar calls for professional learning of sufficient duration have been made by other researchers, as indicated by reports of professional learning studies that have credibility in the field. Professional learning in these studies was sustained over a number of years (Franke, Carpenter, Levi & Fennema, 2001), occurred weekly in workshops over an entire school year (Borko, Davinroy, Bliem & Cumbo, 2000), or was offered as intensive weeks in summer months (Cohen & Hill, 2000). Grant and Kline (2004) found a minimum of 43 hours of PL is necessary to experience real benefits and changes to practice.

Garet, Porter, Desimone, Birman and Yoon (2001) estimate a model of professional development based on literature and research in the area. The authors recognize that “there is growing interest in ‘reform’ types of professional development, such as study groups, or mentoring and coaching” (p. 920), instead of the traditional workshop format of PL. Like Desimone (2009, 2011), Garet et al. (2001) consider similar factors important to PL, including the type of activity (e.g., an isolated workshop vs. a classroom-embedded program), duration (i.e., the benefits of sustained PL), collective participation (e.g., involving all educators from the same grade in one school), and ample opportunities for communication with others. Again like Desimone (2009, 2011), the authors “view the degree of content focus as a central dimension of high-quality professional development… [as well as] opportunities provided by the professional development activity for teachers to become actively engaged in meaningful discussion, planning, and practice” (Garet et al., 2001, p. 925).
As was discussed by Stylianides and Stylianides (2013), Bruce et al. (2010) consider the benefits of classroom-situated teacher professional learning. In two Ontario school boards, classroom-embedded teacher learning, with an emphasis on quality teaching, was important to the professional learning programs they examined. In the study, researcher facilitators worked with educators in areas of math communication, spent time co-planning and co-teaching and collaboratively discussing student work (Bruce et al., 2010). In their work, they focused on understanding the impact of professional learning on teacher efficacy and related student achievement.

As a result of the PL, Bruce et al. (2010) observed changes in the ways teachers spoke about student work and in the ways they responded to student thinking and questioning. As such, they echo previously discussed studies and call for long-term, sustained professional learning that is embedded in the classroom and focuses on collaborative exploration of mathematics pedagogy. The research indicates the positive effects that classroom-embedded professional learning can have on both teacher efficacy and student achievement in mathematics.

In order for research to examine the links between teacher instructional practices and student learning, professional development needs to be embedded in the classroom (Polly, Neale & Pugalee, 2014). In their study considering the impacts of professional development on teachers, including their beliefs about mathematics and their mathematical knowledge for teaching, 28 elementary teachers in a south-eastern United States’ rural school who experienced classroom-centered PD made statistically significant gains in math knowledge for teaching. They experienced a shift from teacher-centered to student-centered pedagogy and beliefs (Polly et al., 2014).
Classroom-embedded professional learning, therefore, has been found to improve student achievement and teacher efficacy (Bruce et al. 2010) and has also led to gains in math knowledge for teaching (Polly et al., 2014). Gregson and Sturko (2007) argue that, as teachers work in the context of a classroom, it seems only natural that learning embedded in the classroom is important for teacher professional learning to be relevant and transferable: “professional development can support deep changes in teaching if it is situated in classroom practice” (p. 3). Teachers benefit from professional development that is learner-centered (e.g., focused on student learning), active and engaging, and aimed at considering the links between teacher instructional practices and student learning (Polly et al., 2014).

Ross and Bruce (2007) argue that teacher PL should place an emphasis on facilitating teacher growth and promoting changes in teaching practice. They found that teacher self-assessment proved to “strengthen in-service sessions… [and] provide[d] opportunities for teachers to observe one another and talk about classroom attempts to improve teaching” (Ross & Bruce, 2007, p. 155). In addition to classroom-embedded research of sustained duration that involves active participation, fostering student success in mathematics is another key goal of effective teacher professional learning (Ball, Sleep, Boerst & Bass, 2009; Bruce et al., 2010; Hill, 2004).

### 2.3.3 Teacher content learning

Another major focus of professional learning is a focus on content learning. Desimone (2009) describes content focus as perhaps the “most influential feature” of teacher professional learning. By focusing on content, teachers increase their understanding, knowledge and skills, which, in turn, leads to improvements in student
achievement. Lee (2007) argues that effective professional development enhances pedagogical and content knowledge in mathematics. In order to teach and engage young children in mathematics, teachers require sufficient content knowledge, positive attitudes and confidence in teaching mathematics (Moss, Bruce & Bobis, 2016). Moss, Bruce and Bobis (2016) cite many studies that show “the mathematical knowledge and understanding of young children can be enhanced as a result of … teachers’ involvement in high-quality and sustained programs of professional development” (p. 176).

Hill (2004) provides an overview of professional development opportunities in an Eastern U.S. state and examines the standards defined in the literature for what qualifies effective PD. She argues a need for better-defined standards focusing on content knowledge, student math thinking and learning so that it is clear what is going to occur in PD sessions and what is to be taken away by teacher participants. Standards for teacher professional learning should focus on mathematics content and teacher and student learning outcomes: “Professional development should, in theory, produce changes in teacher practice and, ultimately, improvements in student achievement” (Hill, 2004, p. 217). A focus on content knowledge is included in teacher professional development standards and mathematics content was a focus in nearly all of the PD sessions in Hill’s 2004 study.

Borko (2004) reviews research in the area of teacher professional development with a specific focus on what is known about professional development and its impact on teacher learning. Borko concluded that effective PL programs place an emphasis on subject content knowledge by involving teachers in working through specific problems and tasks (i.e., having the teachers do math and explore various problems). Borko (2004)
also identified that effective professional development programs involve careful consideration of student thinking and reasoning (e.g., by drawing upon student work samples) which helps to increase teacher content knowledge. Sessions that focus on student mathematics thinking were shown to enable teachers to become “better at elaborating the details of students’ mathematical reasoning and understanding their problem-solving strategies, and… develop[ing] instructional trajectories for helping students advance their mathematical thinking” (p. 7).

Hill, Rowan and Ball (2005) express concern about teacher content knowledge in mathematics in the United States and refer to “evidence suggesting that U.S. teachers lack essential knowledge for teaching mathematics” (p. 372). More specifically, research identifies the need for a focus on teacher learning in geometry and spatial reasoning. This is an often-underrepresented area of mathematics PL. For example, Sinclair and Bruce (2015) write that “another area of fertile, future work is certainly that of teacher preparation and professional learning” (p. 327) in geometry education in the primary school. Clements and Sarama (2011) research geometry in early childhood teacher education and recognize that teachers are often lacking content knowledge in the area. They suggest that teacher professional learning should focus directly on geometry and spatial reasoning content. Placing an emphasis on “children’s thinking and learning trajectories” (Clements & Sarama, 2011, p. 142) and “weav[ing] specific content knowledge into… professional development on the geometry learning trajectories” (p. 140) are both recommendations made by the researchers.

Gunderson, Ramirez, Beilock and Levine (2013) relate educator anxiety in spatial reasoning directly to student learning in the domain and call for the importance of
reducing teachers’ spatial anxiety. Not only does teacher content knowledge affect and have an impact on student achievement, but a teacher’s level of comfort and possible anxiety towards a subject can be detrimentally transferred to their students. “This study suggests that reducing teachers’ spatial anxiety has the potential to improve children’s spatial skill, which may have the important benefit of improving children’s interest and achievement in mathematics as well as STEM-related fields more broadly” (Gunderson et al., 2013, p. 199).

2.3.4 Role of the administrator in professional learning

The final section of this literature review considers the role of the administrator in professional learning contexts. In professional development that is classroom-embedded, content-focused and composed of same-school groupings, it makes sense that the principal of a school would have a direct impact on educator professional learning experiences. As Spillane, Halverson and Diamond (2004) state: “leadership is thought critical to innovation in schools” (p. 3).

In a discussion of teacher professional learning, it is important to consider the various school-level factors at play. School-level factors such as the leadership role of the administrations seems often overlooked as very few studies take them into consideration (Gumus, 2013). Gumus’ (2013) research looks at teachers in Turkey and their involvement in in-service professional learning activities and the various school-level factors that have an effect on this participation. The study found “that accountability demands that come from principals affect teachers’ participation in professional development activities” (p. 378).
Goldring and Pasternack (1994) consider the role principals have in creating positive, effective school environments. School administrators can set the tone and goals of a school for developing effective programming: “through goal framing principals coordinate instructional programs by creating a clear sense of shared direction and purpose” (p. 242). In another study that considers the role of the administrator, and that specifically focuses on the relationship between principal leadership and student achievement in mathematics, it was reported that the role of the administrator can influence teachers and increase their motivation in school, develop cohesion amongst school staff and contribute to the formulation of shared goals (Shin & Slater, 2010). The relationships between student achievement and administrative leadership and support are thus evident.

Considering the results of these studies on the role of the administrator, it is evident that school principals do indeed offer prominent and valuable support to teacher professional learning programs; their involvement appears to enhance both teacher learning and student achievement.

2.4 Summary

This literature review has touched upon several key areas of focus for this thesis. The first major area of focus was on mathematics content and context. In this section, three key areas of mathematics education were discussed: mathematics for young children, spatial reasoning and playful pedagogy. Mathematics for young children is an exciting area of research as links between early math skills and later school achievement are being discovered in more and more studies. The concept of the “no-ceiling” curriculum (Bruce, Moss & Flynn, 2013) is one that allows for the expansion of the early
years mathematics curriculum in a way that is rich and explorative and promotes the development of solid foundational math skills in young children.

By focusing on spatial reasoning, we can help young learners develop mathematics skills that promote later achievement in STEM education and careers. As we live in a spatial world, it makes sense that ‘spatializing’ the curriculum is beneficial to learners and allows for many real-life applications in mathematics. As well, research on playful pedagogy calls for an emphasis on guided play where teachers and students share in the direction of learning. Guided play provides increased learning opportunities for early mathematics exploration.

The second major area of focus in this literature review was on teacher professional learning and involved the consideration of four key areas directly related to the study presented in this thesis including discussions of: classroom-based interventions, characteristics of effective teacher professional learning, the importance of a focus on content learning in PL and the role of the administrator in PL contexts. Classroom-based intervention studies provide rich, real-life contexts for research. Literature suggests that effective PL is classroom-embedded, sustained and sufficient in duration, and involves active participation and communication between teacher-researcher teams. A focus on mathematics content in PL allows for mathematics learning on the part of the educators as well as the students. Spatial reasoning, in particular, is a rich area of content focus for mathematics education, especially amongst early years’ PL. The administrator should also play a key role to support teacher learning in PL contexts, as they are a large part of determining the school context and setting school-wide PL goals.
The following diagram offers a visual summary of the research discussed in this literature review:

**Figure 1.** A visual summary of literature review findings
Chapter Three: Methodology

3.1 Introduction

In this thesis, I consider educator learning over the course of a classroom-based intervention study. Based in one school, I focus on a team of five JK to Grade 2 teachers, two early childhood educators (ECEs), and a board-level JK-Grade 8 math coach (because of the combination of teachers, ECEs and the math coach, I refer to this group as “educators”), who were facilitated by a team of five researchers and a board-level numeracy consultant. The educator and researcher team embarked on this intervention study together. The study focused on teaching mathematics through spatial reasoning and educators and researchers spent time collaboratively planning, observing and debriefing student learning around a variety of tasks. I pay particular attention to two unique individuals in the team: a kindergarten teacher and a mathematics coach from the school board. I use these two cases as a way to more deeply explore educator learning in the intervention study.

In this chapter, I detail the methodological considerations I made throughout the process. I undertake qualitative research with a focus on the explanation and interpretation of data. As Stake (2010) writes in his assessment of qualitative research and researchers, “we reconceive the world in terms of the concepts and relationships of our experience” (p. 30). In a consideration of case study, Stake (1995) comments on the emphasis on interpretation, and describes it as the “most distinctive characteristic of qualitative inquiry” (p. 8).

Beyond identifying as a qualitative researcher, I identify with the constructivist research paradigm as I relate to the notion that “constructivism assumes that humans
generate knowledge and meaning from experiences” (Slattery, 2013, p. 296). Educators involved in this project generated knowledge and meaning from their experiences with spatial reasoning in mathematics. It is this generated knowledge that I consider educator learning in my analyses.

3.2 Research Context

3.2.1 Research design

In order to better understand teacher learning in this intervention study and in considering my research questions, I have chosen to pursue an embedded case study. I consider both the team context as well as two specific cases. Yin (2009) discusses this type of case study in his book and comments on the fact that a single case study “may involve more than one unit of analysis” (p. 50). The selection of a unique or extreme case is one of the ways to decide on and define cases (Yin, 2009). The two units of analysis I selected were, therefore, chosen for their uniqueness. I believe, as Stake (1995) wrote, that these two cases “do a better job than others” (p. 4) at providing insight into my research questions. I choose to consider the two units (cases) in greater detail than the rest of the team, as a way to provide insight into individual educator learning as a result of this professional learning initiative.

I consider data from the kindergarten teacher (Carey) and the math coach (Patricia) to be informative and to offer the chance to consider teacher learning in a more detailed, isolated nature. In my case study analyses, the educator team operates as the “total system” with the individuals (the two units or cases) embedded within the system. The two cannot be separated, and one offers great insight into the other when analyzed.
3.2.2 The M4YC project

The Math for Young Children (M4YC) project began in 2011. The intervention study of focus for this thesis is a part of the larger M4YC initiative. The project has been occurring across school boards in Ontario and led by teams of researchers from Trent University (the team that I have been a part of since 2013) and the Ontario Institute for Studies in Education (OISE). From its inception, the project has focused particularly on mathematics for JK to Grade 2 teachers, with a particular focus on spatial reasoning.

Since 2011, the M4YC project has been conducting research with teams of educators. Most previous cycles of M4YC have used lesson study as the professional learning model. Lesson study originated in Japan. It is “the most extensive and nationally widespread version of action research by teachers… with its systematic reflection of practitioners on action” (Kieran, Krainer & Shaughnessy, 2013, p. 382). This form of professional development involves teachers and researchers working together through a cycle of goal setting, reflecting, and teaching. As part of the cycle, a research lesson is taught and observed, providing an opportunity for collective observation of student thinking and learning (Lewis, Perry & Murata, 2006). There are four key components in a lesson study cycle: 1) to set goals and study the curriculum; 2) to plan; 3) to conduct research; and 4) to reflect (Lewis, Perry & Murata., 2006).

Instead of pursuing lesson study in this particular cycle of M4YC work, educators and researchers undertook a classroom-based intervention approach. Similar to the cycle of lesson study mentioned above, the classroom-based intervention study (see Stylianides
& Stylianides, 2013 for more on this type of professional learning) incorporated a series of collaborative processes. The main difference between lesson study and this intervention study is that, instead of co-planning and co-constructing lessons, the educators were provided with a field test booklet of pre-designed spatial reasoning tasks (developed based on previous M4YC research lesson study cycles) to try with their JK-Grade 2 students.

There are five main components in the intervention study learning cycle carried out in this 2015 M4YC professional learning program: 1) collaboratively doing the math of the intervention activity; 2) collectively observing small groups children as they engage in the activity; 3) debriefing observations; 4) implementing tasks in educator classrooms and documenting the version of the activity conducted; and 5) spending time as a whole team debriefing, discussing next steps and beginning the cycle again (starting back at number 1):

Figure 2. The classroom-based intervention study learning cycle
The classroom-based intervention study in this thesis also involved a number of key factors of importance to effective professional learning, as discussed in the literature review. Features of this intervention study approach include:

- A high degree of collaboration between teachers and researchers;
- Research that takes place directly in the classroom (research occurred in the classroom both on and between the professional learning meeting days);
- Close attention to student thinking and responses;
- Opportunities to observe student learning;
- Opportunities to co-teach and co-facilitate task implementation; and
- Qualitative and quantitative data collection.

The teacher data collected will be further described in section 3.5, but it is important to briefly discuss student data collected in M4YC projects, to better understand the overall project design. At the beginning and end of each project, one-to-one task-based interviews are conducted with students. These interviews measure students’ performance on a wide variety of tasks related to mathematics in general (i.e., number sense and geometry), spatial reasoning (including 2D and 3D mental rotation tasks) and language (a measure is used to control for language). Often a teacher-generated task that relates specifically to the spatial reasoning research focus of a particular group is included as well. Pre and post scores on these interviews are compared and analyzed to give an indication of student learning over the course of the professional learning (see www.tmerc.ca for more information and specific findings of previous M4YC research projects).
3.2.3 Overview of the 2015 classroom-based intervention study

The educator-researcher team (i.e., the five teachers, 2 ECEs, the math coach and the research team) met a total of five times from January to April in 2015, for a total of approximately 32.5 hours. Over the course of the five days, the team spent time collaboratively discussing and exploring spatial reasoning tasks, carrying out tasks with small groups of students during meeting days, carefully observing student learning when approaching tasks in the classroom, debriefing student learning, thinking and reasoning, and using observations to select further tasks and areas for exploration. The following table indicates the main agenda and activities on each of the five meeting days to provide context for the discussion of data collection and analysis.

Table 1. A brief overview of 2015 meeting activities in the classroom-based intervention study

<table>
<thead>
<tr>
<th>Meeting date</th>
<th>Description of activities</th>
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<tbody>
<tr>
<td>Day 1: January 27, 2015</td>
<td>This meeting introduced educators to the M4YC project and provided background to the research, including why math for young children is an important area of study, the importance of playful pedagogy, and why a focus on spatial reasoning is so valuable. Educators were asked to complete a concept map, where they reflected on and answered the question: “What geometry activities and concepts are your students doing/have they done/are they going to do this academic year? The educators were given the opportunity to do some mathematics – they participated in a series of challenges directly related to spatial reasoning skills (including mental rotation, perspective taking, composition and decomposition of shapes). Teachers were also introduced the concept of visualize, verbalize and verify, a specific communication strategy coined by the M4YC project that emphasizes the importance of each step in thinking and reasoning both spatially and mathematically. The field test booklet was distributed (described in section 3.2.1) and journals were introduced (intended to track the frequency of implementing tasks tried from the booklet and the amount of time spent on the tasks) and the educators selected tasks of interest. The day ended with logistics and planning for the duration of...</td>
</tr>
</tbody>
</table>
Day 2: January 28, 2015
Day 1 and Day 2 were back-to-back meeting days. The second meeting day was an opportunity for the team to continue their initial explorations of the field test booklet and become more familiar with the major tenets of the M4YC project.

The team planned for the observation of their first task, a pattern block symmetry game. Pairs of JK-Grade 2 students tried out the task and were observed by the team. Detailed observations, possible extensions and various student supports were then debriefed collectively.

Planning for the days between meetings involved thinking about which tasks from the field test booklet to try, how to document observations/successes/challenges, and which students to pick to observe more closely, so as to get a real sense of the specific thinking and learning (i.e., closely observing a few students yields much richer findings than generally observing a whole class).

Day 3: March 6, 2015
Educator observations were debriefed by grade (JK, SK, Grade 1, Grade 2) so as to see any continuum in thinking and learning about the spatial tasks across the grades. Ten different tasks were debriefed in this manner.

The team worked to develop an observation guide (including language to listen for, gestures to look for, and key questions to ask) and then used the guide when observing small groups of students carrying out one of the tasks (a barrier game where one student describes an object to another student who cannot see it).

Day 4: April 7, 2015
The team debriefed what tasks they had done between meetings and, based on their observations, developed a learning summary of their thinking about student reasoning and learning, with an emphasis placed on playful pedagogy.

The team also designed their culminating activity, a community math night, where members of the community (e.g., parents) would be able to participate in spatial reasoning tasks, try math activities and learn about the importance of teaching and learning mathematics through spatial reasoning.

Day 5: April 30, 2015
On the final day of the project, the educators revisited their content maps and added to their initial thinking (in a different colour). They were given the following prompt: Describe the spatial reasoning activities and concepts your students have done this academic year. Describe the spatial reasoning activities you plan to do with your students, including additional concepts, ideas and specific tasks.

The researchers then led the team through a focus group interview. The interview questions asked educators to reflect on their key learnings from teaching mathematics tasks that incorporated spatial reasoning, on what areas they found most
powerful and engaging in spatial reasoning, on what was most challenging, on their students’ key learnings, and what they learned about themselves as teachers through the process (see Appendix A for list of focus group questions and content map prompts).

3.3 Participants

3.3.1 School context

The school is located in a Southern Ontario school board. The school is in an under-resourced community with a relatively large population of low socioeconomic status families. The school has a high rate of student transiency (i.e., students moving during and between school years) and a higher population of English language learners when compared to the board (as depicted on EQAO reports for the school). The school also has a record of scoring below provincial means on EQAO, especially in mathematics.

The school was previously involved in M4YC research, but was only used as a control site. In the control year, students were interviewed twice, to match another lesson study site’s pre and post interviews and in order to control for natural maturation and learning over the year, but no teacher professional learning occurred. This is the first time PL in the area of spatial reasoning and math for young children has occurred in the school.

3.3.2 Team composition

The educator team was comprised of a total of seven educators: five JK-Grade 2 teachers (two kindergarten teachers, one Grade 1 teacher, one Grade 2 teacher and one Grade 2/3 teacher) and two early childhood educators (ECEs) who worked with the kindergarten teachers. In terms of my case study analysis, the team represents the “total
system” or the larger case. The team represented all JK-Grade 2 teachers in the school, and each educator was expected to participate in the project by their principal. The research component of the team was comprised of a team from Trent University. The project was co-facilitated by a professor/lead M4YC researcher and her project manager, and supported by three research assistants (I was one of the research assistants), all certified teachers. A board-level numeracy consultant also participated in the study, and took on a co-facilitation role, working closely with the team of researchers in planning and implementing the PL. One JK-Grade 8 board-level math coach also participated through the entire study.

On Day 1 of the project, the educator team reported having received very little mathematics professional learning; they had received some professional learning in number, but none in geometry. This focus on geometry and spatial thinking in early years, therefore, was a novel area of PL for the team.

3.3.3 Carey: The kindergarten teacher

The first embedded case I selected is Carey, a kindergarten teacher who stood out as unique and exemplary in her learning based on the data collected. Carey was selected with the following in mind: her content map showed a great increase in depth and breadth of understanding, her presence in field notes and the focus group stood out and she had the most entries in her journal (that recorded frequency and duration of facilitating tasks from the field test booklet).

3.3.4 Patricia: The math coach

The second embedded case I selected for deeper analysis is Patricia, a JK-Grade 8 board-level math coach. Patricia spent a great deal of time in the classrooms involved in
this project, as an additional observer and co-teacher. Her wide range of experiences and resulting learning provides a unique opportunity to explore the effects of the intervention study.

3.4 Data Collection

Data was collected in four different ways. The team of researchers collected information in the form of educator content maps, field notes, journals and a culminating focus group interview. The data collected over the course of the project is similar to the qualitative data collected by like-mind qualitative case study researchers. For example, as considered in Yazan’s (2015) analysis of case study, reference is made to Robert Stake, who “suggests the use of observation, interview and document review in qualitative case study research” (p. 143). The following sub-sections detail the data collected over the course of the intervention study.

3.4.1 Student tasks

The tasks that educators implemented were in the form of a field test booklet that was provided to the educator team on the first day of the project. The field test booklet consists of 28 tasks designed to enrich the teaching of geometry and spatial sense in the primary grades and to help young children improve their spatial reasoning (see Appendix B for images from the booklet). The tasks are categorized into seven different types of spatial reasoning: 1) visualization, 2) mental rotations, 3) complexities of symmetry, transformation and coordinates, 4) mapping, location, orientation and gestalt (seeing the whole shape of an object and likening it to something else), 5) composing and decomposing 2D and 3D figures, 6) perspective taking and 7) spatializing mathematics across the strands. Each task is written up in an easy-to-follow manner. The write-up
includes a description of the task, the purpose, a list of materials, instructions, possible extensions and any special notes. The tasks are designed based on previous M4YC research, where, over the course of numerous professional learning studies, researcher-educator teams have developed a series of rich, playful tasks that focus on developing this range of spatial skills in JK-Grade 2 students. The tasks have shown to have a positive impact on both student achievement and teacher learning (see http://tmerc.ca).

By having this group of teachers spend time working on the tasks, the M4YC team gained insight into necessary revisions and modifications. Therefore, after field-testing by educator-researcher groups, revisions were made and a book of over 40 tasks is being published (Moss, Bruce, Caswell, Flynn & Hawes, in press – see Appendix B).

3.4.2 Educator content maps

On Day 1 of the project, educators were asked to create a content map where they reflected on and recorded their thinking in response to two different prompts about geometry and spatial reasoning. Revisiting their content maps on Day 5 was intended to help educators reflect on changes in their understanding of spatial reasoning, the playful teaching of geometric and spatial concepts, and the learning of young children as a result of their experience using tasks from the field test booklet.

Decisions on the design and type of mapping (i.e., the graphical representation of concepts) were left up to the individual. Maps were created on a blank piece of 8½ x 11 paper. The mapping instructions asked teachers to reflect on their understanding of spatial reasoning and the geometry curriculum, how they teach geometry, what geometry looks like in their JK-Grade 2 classrooms, and how they incorporate spatial reasoning in their teaching. On Day 1, the team was given the following prompt: Consider what
geometry activities and concepts students are doing/going to/have done over the year. On Day 5, they were asked to: Describe the spatial reasoning activities and concepts your students have done this academic year. Describe the spatial reasoning activities you plan to do with your students, including additional concepts, ideas and specific tasks. The final teacher maps, therefore, consist of a combination of pre- and post-M4YC intervention study understanding.

3.4.3 Field notes

Detailed field notes were taken at each meeting by a research assistant. The field notes were typed and serve as a record of the team’s discussion over the course of the intervention study. There are a total of 27 pages of field notes.

3.4.4 Journals

In a journal, educators recorded the date, task, length of time and observations/comments each time they tried a task from the field-test booklet. Five journals were created and returned to the researchers (they were submitted by educators from four different classrooms and the math coach), with a total of 41 entries.

3.4.5 Focus group interview

On Day 5, educators participated in a focus group interview (approximately 1 hour in length). The focus group was audio recorded. I designed the questions for this focus group interview based on my research questions and interests in teacher learning. The team was asked a series of questions on their key learnings, powerful and engaging take-aways from their exploration with the spatial reasoning tasks, barriers and/or challenges they experienced, their perceptions of student learning, and overall comments on their experiences during the intervention study (see Appendix A for list of questions).
3.5 Data Analysis

3.5.1 Qualitative analysis

Educator data was qualitatively analyzed. In particular, I employed thematic analysis, as I considered “broad themes that emerged from my data… [and considered my] research questions [through] forming an in-depth understanding of the central phenomenon through description and thematic development” (Creswell, 2012, p. 247). I considered both the team as a whole and the case of two educators in my thematic analysis, since I share the major goal of case study research: to “appreciate the uniqueness and complexity of [the case, and]… its embeddedness and interaction with its contexts” (Stake, 1995, p. 16). As I stated in the introduction of this chapter, I identify with constructivist paradigms, where reality is seen as “constructed by individuals interacting with their social worlds” (Merriam, 1998, p. 6).

It is important to detail how the data was analyzed. For this, I draw on a series of key scholars in education research to describe and validate the data analysis I conducted. To begin, I coded all field notes and the focus group transcription. Codes were used to identify prominent themes in the data. I used open coding (Charmaz, 2003; Creswell, 2012). Open coding involves forming “initial categories of information about the phenomenon being studied by segmenting information. The researcher bases categories on all data collected, such as interviews, observations, and researcher’s memos or notes” (Creswell, 2012, p. 424).

The unit of analysis for coding was considered to be one utterance or a complete phrase (Rowe, 2004). All text was read and utterances were described using a few words. These few word descriptors were then counted, frequencies recorded, and grouped by
pattern or common code: “all research is a search for patterns, for consistencies” (Stake, 1995, p. 44). Once the focus group transcript and field notes were coded, the codes (10 in total) were then grouped into four driving, prominent themes (see Creswell, 2012). These prominent themes (based on frequency of the codes) were selected for further discussion and more detailed analysis (e.g., powerful quotes and utterances were pulled to illustrate each of these overarching themes).

The field notes and focus group transcript were considered in their entirety, for the whole team, and also by case (for Carey and Patricia). In the latter, I paid particular attention to the kindergarten teacher and math coach by pulling quotes from each and carefully considering their perspective.

3.5.2 Educator content map analysis

Educator content maps are a relatively unused form of data collection, but one that offers interesting and valuable data on shifts in thinking over time, with an asset-oriented approach in thinking about gains in educator understanding (Bobis, Clarke, Clarke, Thomas, Wright, Young-Loveridge & Gould, 2005). Content maps can reveal a great deal about an individual’s level of conceptual understanding regarding a specific math concept. In order for an individual to have an accurate, in-depth understanding, they must be able to make explicit connections between concepts. When used as a teaching tool, concept maps “help students reflect on, and make connections among, concepts in mathematics” (Hoffman Bartels, 1995, p. 549).

The same applies to educators as learners in PL settings; mapping can be a valuable way to understand a teacher’s pedagogical mathematics knowledge and growth (Chichekian & Shore, 2013). Teachers in both the role of educator and learner (e.g., in PL
contexts) benefit from mapping in mathematics: “concept maps challenge teachers and students to make connections beyond discrete mathematical facts and operations” (Chichekian & Shore, 2013, p. 51). Kinchin and Hay (2000) view mapping as a metacognitive tool that promotes “understanding in which new material interacts with [an individual’s]… existing cognitive structure” (p. 44).

A total of seven maps were analyzed for this thesis, with particular attention paid to the maps from Carey and Patricia. The content maps were analyzed in the following ways: I counted and compared the number of words and diagrams pre (i.e., the initial number of words and diagrams on the map) and post (i.e., the number of added words and diagrams, as well as the total number of each); I considered the number of new ideas (analysis of breadth); and I considered the number of elaborations (analysis of depth). I also considered overall themes in map concepts both pre and post. The analysis of this data provided insight into changes in educator learning and perceptions over the course of the intervention study (from Day 1 to Day 5).

3.5.3 Consideration of additional data

In addition to the analysis of field notes, the focus group transcription and educator content maps, a couple of other data points were analyzed to consider the learning of the team. Journals were used to supplement data from field notes, content maps and focus group interviews. I considered the number of entries per journal, the reported amount of time spent on each tasks and common themes in my analysis. Again, journal entries for each of the embedded cases (Carey and Patricia) were considered in more detail.
I also recorded the frequency of meeting attendance by the school’s principal, as administrator involvement relates directly to key findings of the literature reviewed in chapter two.

### 3.5.4 Validating data

Researchers must address potential limitations (e.g., misinterpretations) in their data by performing validation techniques. There are many different ways of enhancing the validity of qualitative research. One of the methods for triangulating suggested by Stake (1995) is investigator triangulation, whereby a researcher’s observations are presented “to a panel of researchers or experts to discuss alternative interpretations” (p. 113). After analyzing the data, I presented my results two other M4YC researchers on the project who considered my analysis and offered a few suggestions for re-framing prominent themes and for alternative interpretations of some of the data. For the most part, however the three of us agreed on the analysis and drew the same overarching conclusions from the data.

### 3.6 Ethical Considerations

Prior to collecting and analyzing data, ethical consent was gained from both Trent University and OISE. In all M4YC studies, the investigators work with partner school boards to identify participants for all M4YC studies. School board partners approach schools and teachers to see if they are interested in volunteering for the project as an enhanced professional learning opportunity. This is, therefore, not a random sample population but rather a best-case approach. The participants of this M4YC study have signed consent letters and understand that data from the study has the potential to be analyzed and published.
As the M4YC study is classroom-embedded with the goal of enhancing regular classroom activity, there are minimal risks to participants. Practices of teaching and learning took place as usual. The documentation of this process is what is unique, but data collection remains unobtrusive and naturally reflects the processes of educators engaged in professional learning.

The benefits of participating in this M4YC project are plenty. Educators are provided with extensive opportunities for collaboration with their colleagues during the regular school day, they have support from researchers and other members of their team, and they have an opportunity to increase their mathematics content knowledge. As participants in an exciting and novel research project, M4YC participants are involved in developing unique insights into the mathematic abilities of young children, playful pedagogies and the effects of teaching math through spatial reasoning.

Other ethical considerations include participant withdrawal and anonymity. Participant withdrawal from any part of the project was possible at any time with no risk to the individual choosing to withdraw. None of the participants chose to remove themselves from this project. In addition, all participants mentioned in this thesis remain anonymous as does the school and the school board.
Chapter Four: Findings

4.1 Introduction

In this chapter, I consider themes in the data, for both the large case (the educator team) and each embedded case (the kindergarten teacher and the math coach). I consider data from coded material – the field notes and focus group interview – as well as from the content maps. In the discussion of data, I intend to answer my research questions:

• What are the benefits and challenges of a JK-Grade 2 educator professional learning intervention study focusing on spatial reasoning in mathematics?

• What are the effects of implementing spatial reasoning tasks on educators’ conceptual understanding of spatial reasoning?

4.2 Educator learning: The case of the educator team

The educator team is made up of all the primary teachers from one school. The educator team consists of a total of five teachers (two JK/SK teachers, one Grade 1 teacher, one Grade 2 teacher and one Grade 2/3 teacher) and two early childhood educators (ECEs), who work in the kindergarten classrooms. A board-level math coach was also part of the team and spent time working with teachers and ECEs in their classrooms. When asked about previous PL opportunities, educators expressed limited math PL and no PL in the area of geometry and spatial sense. Principal leadership was very transient over the course of the school year, with the administration changing three times. The third (last) principal was most involved in the project (she was present at two meetings, on Days 3 and 4).

Educator learning was evident throughout the intervention study, as is supported by the open coding of qualitative data (based on utterances in field notes and the focus
group interview). Four overarching themes regarding educator learning were identified in coding. These helped to cluster and classify the smaller, sub-themes found in the data.

Table 2 presents total code counts (frequencies) for each of the themes and sub-themes identified in the open coding process. The four large themes that emerged around educator learning are: learning through reflection; learning about content; learning through implementation; and learning by observing children.

Table 2. Codes and frequencies for all identified sub-themes in educator data, grouped by common theme (a-d), from most frequent to least frequent

<table>
<thead>
<tr>
<th>Code</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Learning by observing children</td>
<td>190</td>
</tr>
<tr>
<td>Detailed observations of student learning</td>
<td>178</td>
</tr>
<tr>
<td>Rising estimate of what children can do</td>
<td>12</td>
</tr>
<tr>
<td>b. Learning through implementation</td>
<td>64</td>
</tr>
<tr>
<td>Detailed task planning</td>
<td>37</td>
</tr>
<tr>
<td>Reference to the “3Vs” (visualize, verbalize, verify) strategy of mathematics communication</td>
<td>14</td>
</tr>
<tr>
<td>Playful and engaging tasks</td>
<td>8</td>
</tr>
<tr>
<td>Challenges</td>
<td>5</td>
</tr>
<tr>
<td>c. Learning about content</td>
<td>49</td>
</tr>
<tr>
<td>Geometry and Spatial Sense</td>
<td>46</td>
</tr>
<tr>
<td>Connections to other strands</td>
<td>3</td>
</tr>
<tr>
<td>d. Learning through reflection</td>
<td>20</td>
</tr>
<tr>
<td>Reflections on Professional Learning</td>
<td>15</td>
</tr>
<tr>
<td>Changes in teaching</td>
<td>5</td>
</tr>
</tbody>
</table>

The frequency of these themes is an indication of professional learning in the intervention program. In order to illustrate the power of these themes, quotes have been pulled from
the data. The quotations for each of the four overarching themes help to illustrate the depth, breadth and nature of teacher learning in this school-based intervention study.

4.2.1 Learning by observing children

4.2.1.1 Detailed observations of student learning

The opportunity for the detailed observation of student learning was, by far, the most common theme. Each session focused largely on the debriefing of teacher observed student reasoning. During meetings, tasks were often implemented with small groups of students, who were pulled from their classrooms to allow for focused, collaborative observations by the team. The quotes coded for this theme are instances of teacher discussion around observations of student learning.

On Day 2, teachers had the opportunity to observe pairs of students work through a symmetry task, where students worked together to build a symmetrical design around a line of symmetry using pattern blocks on a magnetic cookie sheet. When debriefing observations of student thinking, teachers had pointed observations and questions, based on their focused attention to student learning throughout the task: “The fact that the shapes weren’t tight (floating), really stumped [the student] at first, but she knew it was not right”; “[Students were] very precise on the line of symmetry, making tiny corrections”; and “[Students] constantly telling you what it looks like – gestalt very strong”. The team summarized SK learning by stating that, by the end of their explorations, students were “quicker to grasp the reflection concept; increased the complexity of the design, distance from line, relationship of one figure to another; and [they focused on building the] whole or part design instead of one individual piece.”
In another instance, on Day 4, the educator team debriefed a mental rotation task involving finding a missing puzzle piece. The discussion included comments that students “got better over time” and that they “caught on really quickly in smaller groups.”

A kindergarten teacher described a discussion she had with her students around mentally rotating a triangle. She:

showed different triangles and asked them to talk about what shape. Most of them knew they were all triangles, but would say it’s upside down. Then [we] talked about what does it mean to make a triangle (reviewed the rule: 3 sides and 3 corners), then they were ok with anything being a triangle. (Field notes, Day 4)

In addition to the above sample of field note quotes from debriefing student learning, Table 3 provides a summary of a discussion on Day 4, where educators were asked to reflect on some of the overall changes in their students’ spatial reasoning in the form of a summary of observed student learning.

Table 3. Summary of observed change in spatial reasoning of the JK-Grade 2 students on Day 4 of the professional learning

<table>
<thead>
<tr>
<th>Skill Attained</th>
<th>Comments from Educators</th>
<th>Frequency of Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Language</td>
<td>Students using positional language: Above and below, “stack” versus “on top”</td>
<td>All 7 educators</td>
</tr>
<tr>
<td></td>
<td>Students increasing precision in language: Explaining their thinking; more mathematical language; verbalizing answers and instructions</td>
<td></td>
</tr>
<tr>
<td>Gestalt*</td>
<td>Students saying things like “reminds me of…” and “looks like…”</td>
<td>All 7 educators</td>
</tr>
<tr>
<td>Gains in specific math understanding</td>
<td>Knowledge of symmetry; better understanding of transformations (flips/reflections and turns)</td>
<td>All 7 educators</td>
</tr>
<tr>
<td>Seeking challenges</td>
<td>Students are asking to be challenged more</td>
<td>All 7 educators</td>
</tr>
<tr>
<td>Visualization</td>
<td>Improvement in student visualization strategies</td>
<td>4 educators</td>
</tr>
<tr>
<td>Increase in confidence</td>
<td>Students confidence with language and willingness to share increasing</td>
<td>2 educators</td>
</tr>
<tr>
<td>Increased perseverance</td>
<td>Students showing increased perseverance on tasks</td>
<td>1 educator</td>
</tr>
</tbody>
</table>
Gestalt refers to seeing the whole shape of an object and likening it to something else, for example, thinking that an arrangement of pattern blocks looks like a butterfly.

4.2.1.2 Rising estimation of what children can do

Educators discussed the exploration of various types of spatial reasoning tasks (from the field test booklet) and its impact on increasing their estimation of what young children can do in mathematics. This discussion came out frequently in the focus group interview, especially when asked to reflect on their key learning from the study. The Grade 2 teacher commented that “with these tasks, even though some of them were challenging for students, they were reachable, and I think that was key”. A kindergarten teacher stated a change in her thinking from the beginning of the study:

I remember that, when I first looked at the [field test booklet] in our first PD session, I remember flipping with [her ECE] through the manual saying, ‘oh this is too challenging, they will not be able to do this.’ Now I look at the book and we have tried the majority of the activities and our children have succeeded and really surprised us every time. (Focus group)

Another JK/SK educator said: “I thought it was pretty powerful to know that our kids could do it too. You might need to simplify an activity a little bit, but just to know they could do it” (Focus group).

These comments from teachers of the youngest students in the project are particularly inspiring. A kindergarten teacher also commented that:

Capability is so big, you sometimes think they cannot do that, they are too young… how many times they have surprised me, for example [with the] barrier game [a task focusing on location and orientation], a student said, “that is it?” We thought it would be a challenge and it was not. They surprise you. (Focus Group)

In field notes, when debriefing tasks, comments on a rising estimate of children’s capabilities also came up. Educators commented on a general sense of surprise in their student’s abilities and successes with the tasks.
4.2.2 Learning through implementation

4.2.2.1 Detailed task planning

The detailed discussion of task planning is a key feature of the M4YC study process and educators spent a great deal of time planning and discussing best-practices together because of the nature of the professional learning. The following sequence is an example of dialogue between Grade 2 teachers regarding task planning:

I think we gave them a lot of language, it makes sense to remove it when they have it… The more complex the information, the more they have to consider at once, and the more they are going to struggle with… [What can we do] to build confidence [and] what could we do if they are struggling? (Field notes, Day 3)

Educators left each meeting with a sense of what they were going to do between meeting dates. At the end of Day 2, Carey and her ECE discussed which tasks they planned to focus on and stated their intent to “continu[e] with symmetry, pattern blocks and… have them share what they made. Continue it with whole class, figure it out as a center. Quick things in the morning: paper punch folding, the folded symmetry shape ones, and the shape transformer” (Field notes). An ECE added on to planning on Day 3 by suggestion a modification for students struggling with a barrier game: “could use colours or numbers as orientation for JKs who might find these difficult at first” (Field notes).

The Grade 2 teacher left the second meeting with a plan to continue exploring tasks that focused on symmetry and mental rotation: “each morning [we will do] one of the simple ones, and each week pick one that is more of a task (Field notes).

4.2.2.2 Strategies of mathematics communication

The concept of the 3Vs (visualize, verbalize, verify) was developed through the M4YC research program. It is proving to be a very effective way of engaging children in
spatial reasoning concepts as it provides an underlying structure of communication (see http://tmerc.ca). The 3Vs strategy offers educators and students the opportunity to slow the process of visualizing, verbalizing and verifying while working through a task.

Educators reflected positively on this strategy. For example, when asked a question about key learnings and take-aways from the intervention study, the Grade 1 teacher said:

I find that, with visualization, they are better at choosing the manipulative they are going to use... Because of the games and activities that we have been doing in spatial sense, requiring them to build it in their mind or think about it before they do it - they are doing that in other areas as well. And they understand when I say, take a moment and picture it in your brain. They get what that means now. (Focus group)

Also, in the focus group discussion around key learning, several educators commented on the importance of visualization as a spatial reasoning strategy, for example, they commented that students were “using spatial reasoning to help them in other areas.”

When asked about a most powerful take away from the study, the Grade 1 teacher commented on student’s ability to verbalize their thinking:

It always surprised me every single time... their ability to verbalize and say why they did what they did. Verbally they can tell me why they did it and why it made sense to them, and a lot of these activities involved a lot of talking... I was writing a lot of quotes down. (Focus group)

The same teacher went on to comment on an expanding view of visualization, from literacy to mathematics, over the course of the study and through experiences with the spatial reasoning tasks:

This whole task has made my idea of visualization completely change, because if you were to say to me visualization before, I would immediately think literacy, and I would immediately think, play the movie in your head while I read to you. I have never actually taken the time to think about it as a plan. Picture it, plan it, how are you going to go about it, what manipulative are you going to choose that is going to help you solve this? I have never thought of it as a plan. (Focus group)
4.2.2.3 Exploring playful and engaging material

Educators commented on the fact that both they and their students became excited about exploring playful tasks and engaging in new content material. An educator mentioned her wish for more playful tasks in the classroom: “I wish I had something like this field test booklet for the whole curriculum” (Field notes, Day 4). This appreciation for tasks like the ones in the field-test booklet was also mentioned by another educator: “I am so glad we have stuff like this, because this is one strand I do not have much. I do not know what to do with them.” The lead researcher gave context to applying a playful pedagogy in mathematics that is engaging for the students: “playful tasks with strong mathematical intent, playful with a little challenge or reveal that ups the ante, also seems to entice them… to be challenged more” (Field notes, Day 4). Also, on Day 4, the Grade 2 teacher simply stated that the “kids loved the activities”

4.2.3.4 Challenges

On a few occasions, the educator team expressed concerns with challenges related to their learning. For example, on Day 4, a member of the team viewed the spatial reasoning tasks as separate from the rest of the curriculum, saying that they are “hard to tie to the curriculum”. When asked about what they found the most challenging about the PL study, one kindergarten teacher expressed that a “personal challenge I had to overcome was my own familiarity with spatial reasoning and language behind it, as well as taking observation notes around spatial reasoning” (Focus group).
4.2.3 Learning about content

4.2.3.1 Geometry and spatial sense

At the first meeting, the team of educators reported no previous professional learning in geometry, so this is a rather novel theme in the data for this team. One educator mentioned she was “feeling crappy as a teacher because I have not been doing geometry like this…” Through exploration of the spatial reasoning tasks, educators were seeing connections between different spatial concepts and other areas of the curriculum, even beyond mathematics, for example, the Grade 1 teacher drew a connection between art and perspective taking, a valuable type of spatial reasoning:

One of us was saying, views [i.e., perspective taking] is not in the curriculum, but it is, it is in the art curriculum and because I do not teach art, I did not even think of that … just because it is not in the math curriculum does not mean it is not in their curriculum. (Focus group)

Educators also spent time discussing specific concepts they explored through the tasks, including positional language, transformational geometry, attributes of shapes, patterning, symmetry, gesture, and the use of a range of manipulatives (e.g., pattern blocks, interlocking cubes, puzzles).

4.2.3.2 Connections to other strands (i.e., understanding how spatial reasoning supports other mathematics learning)

Educators described the connections they made between spatial reasoning and other areas of mathematics and the curriculum. The Grade 1 teacher stated: “we are starting to understand that strands are connected and overlapping” (Field notes, Day 3). A kindergarten teacher observed spatial reasoning helping students conceptualize number: “subitizing [knowing the quantity of a small number of dots without counting]… kids were way better after doing these activities… we were wondering if it was because of
these activities” (Field notes, Day 3). These quotes illustrate how the teachers were learning about strand interconnectedness and about how spatial reasoning can support learning in all strands of mathematics, not just geometry; educators found links between spatial reasoning and number sense, for example.

4.2.4 Learning through reflection

4.2.4.1 Reflections on professional learning

Most of the reflection that occurred on the professional learning study took place during in the focus group interview. Educators left with a sense of being “kept accountable”, they appreciated “opportunities to talk” and “liked observing small groups… [it] gave us that hands on experience before we tried it in the classroom.” When asked if they had learned something about themselves as teachers, a few memorable quotes include: “I can teach math… I was not confident at all in the beginning” (ECE); “[I am] more confidence in spatial reasoning” (Kindergarten teacher); and “[I] want to keep learning about this and find the time to do it. I keep wanting to learn more about it” (ECE).

4.2.4.2 Changes in teaching

Educators spoke about the changes in their teaching practices and pedagogies as a result of the project. Field notes and the focus group interview data show that educators reflected on changing perspectives towards teaching and mathematics over the course of the study. Educators described how, prior to the study, their teaching and planning focused on completing one strand before going to the next (they taught in distinct units) instead of teaching more fluidly by implementing different content areas and math strands simultaneously. As a result of their learning, they were revisiting math strands
over the year instead of teaching them in silos. For example, in the focus group, the Grade 1 teacher explained:

I had to wrap my head around a personal challenge. I was done geometry and spatial sense per se of my unit, but it was ok to keep doing these activities even though it was not obviously the unit that we were covering at that time. But I knew it had a bigger, greater meaning, and they were learning something from it and it was going to help them in other areas. But, just for me I was not used to something like that, and I needed to be like, ok even though we have done this and moved on and I need to go on to something else, it is going to help them in the long run.

The Grade 2 teacher felt a lack of authority to revisit strands multiple times a year:

My thinking has changed about that, and I do revisit a lot more, not just the spatial reasoning stuff, other things that I was teaching. I remember always thinking, there is not enough time for number sense…why am I only doing it two times a year? And I think now, what was I thinking? Who was stopping me from doing number sense all year long? Because the curriculum is written a certain way, you categorize things. …Wow, that was not good teaching. Even with spatial reasoning, because even when I got to geometry, it is like one or two expectations, it was like, one day, let us move on. Now I am like, woah… (Focus group)

4.2.5 Content map findings

The analysis of educator team content maps also yielded important insight into educator learning. The content maps were constructed on Day 1 of the intervention study. The content maps were considered in terms of what educators added to their maps. The seven maps include six maps created by the educators (5 teachers and 1 ECE; the other ECE did not complete her own map) and one map created by the math coach. Table 4 outlines the pre and post word counts in content maps. All but one educator added to their map; the Grade 2/3 teacher was absent the last day so she did not any additions.
Table 4. Analysis of content maps, including pre and post word counts (ordered by the total number of concepts, from greatest to least)

<table>
<thead>
<tr>
<th>Educator</th>
<th>Number of Initial Words</th>
<th>Number of Initial Diagrams</th>
<th>Number of Words Added</th>
<th>Number of New Diagrams</th>
<th>Total Words</th>
<th>Total Diagrams</th>
<th>Total Concepts (words + diagrams)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Math Coach (Patricia)</td>
<td>57</td>
<td>0</td>
<td>136</td>
<td>0</td>
<td>193</td>
<td>0</td>
<td>193</td>
</tr>
<tr>
<td>JK/SK teacher</td>
<td>85</td>
<td>0</td>
<td>92</td>
<td>0</td>
<td>177</td>
<td>0</td>
<td>177</td>
</tr>
<tr>
<td>JK/SK teacher (Carey)</td>
<td>51</td>
<td>9</td>
<td>72</td>
<td>1</td>
<td>123</td>
<td>10</td>
<td>133</td>
</tr>
<tr>
<td>Grade 2/3 teacher</td>
<td>101</td>
<td>2</td>
<td>N/A*</td>
<td>N/A*</td>
<td>100</td>
<td>2</td>
<td>102</td>
</tr>
<tr>
<td>Early Childhood Educator</td>
<td>48</td>
<td>0</td>
<td>52</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Grade 2 teacher</td>
<td>60</td>
<td>1</td>
<td>36</td>
<td>0</td>
<td>96</td>
<td>1</td>
<td>97</td>
</tr>
<tr>
<td>Grade 1 teacher</td>
<td>29</td>
<td>0</td>
<td>32</td>
<td>0</td>
<td>61</td>
<td>0</td>
<td>61</td>
</tr>
</tbody>
</table>

*The Grade 2/3 teacher was not present at the final meeting and therefore did not add to her map. Note on word counts: hyphenated words counted as 2 words; "gr. 4-6" = 3 words; "3D" = 1 word; "GSS" = 1 word

Table 5 below lists the initial ideas, new ideas and elaborations on content maps.

There was growth in both the breadth (increase in the number of new ideas) and depth (elaborations on initial ideas) of educator understanding about teaching geometry and spatial sense over the course of the professional learning.

Table 5. Analysis of content maps, including the number of initial ideas, new ideas and elaborations, in the same order as Table 4

<table>
<thead>
<tr>
<th>Educator</th>
<th>Initial Ideas</th>
<th>New Ideas</th>
<th>Elaborations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Math Coach (Patricia)</td>
<td>27</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>JK/SK teacher</td>
<td>7</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>JK/SK teacher (Carey)</td>
<td>19</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>Grade 2/3 teacher</td>
<td>10</td>
<td>N/A*</td>
<td>N/A*</td>
</tr>
<tr>
<td>Early Childhood Educator</td>
<td>11</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Grade 2 teacher</td>
<td>10</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Grade 1 teacher</td>
<td>5</td>
<td>8</td>
<td>0</td>
</tr>
</tbody>
</table>
*The Grade 2/3 teacher was not present at the final meeting and therefore did not add to her map*

Educators added anywhere from 3 to 11 new ideas to their maps at the final meeting in April, indicating an increase in the number of new ideas about geometry and spatial sense. Three educators elaborated on their initial ideas (2, 5 and 6 times) when they revisited their maps, again indicating an increase in new ideas and an expansion in their understanding.

In general, the initial content maps included geometry and spatial sense concepts and the mention of phenomena discussed in the curriculum (Ontario Ministry of Education, 2005). Common words found on the initial content maps include: 2D shapes, 3D figures, sorting, building, identifying and language. In contrast, on the final versions of the content maps, educators added to their initial descriptions of the geometry strand, as it appears in the curriculum, and included topics like: reference to specific tasks, spatial reasoning concepts (e.g., gestalt, 3Vs, symmetry, mapping, perspective, composing).

The content maps highlight educator learning in a similar way to the powerful quotes in field notes and the focus group. It appears that some of the major themes found through coding field notes and the focus group interview came through in the content maps. References to three of the main themes are included in the maps: learning by observing children, learning through implementation and learning about content. Several direct quotes and summaries of the maps are evidence of these themes around educator learning as seen in the content maps.

A kindergarten teacher wrote about detailed observations of student learning: “increased observations and tracking surrounding spatial reasoning.” She also wrote
about “increasing challenges in spatial reasoning as compared to previous years,” indicating a rising estimate of what children can do. Educators mentioned the “3Vs” (e.g., “visualize, verbalize, verify… this has been used more frequently and kids are ‘seeing’ things more clearly”). They wrote about high levels of student engagement in the tasks. One educator listed a number of geometry and spatial sense tasks explored throughout the study: “GSS -- directional language, position discussion/debate, putting together, building, mapping with directions, putting shapes together to fill space/make other shapes, symmetry/mirror image, building up and out rather than just flat.” This elaboration points to an expanding appreciation for the range of mathematics content important for exploration with children. A cross-strand connection between fractions and tangrams was also made: “kids used parts to make a whole, then described how much.”

4.2.6 Journals

The educator team completed journals over the course of their professional learning. In the journals, educators were asked to record information about the implementation of tasks from the field-test booklet, including the date, the amount of time spent on the task, and any observations or comments they made while doing the task. The journals offer important insight into educator learning.

Journals were received from four different classrooms and the math coach (a total of five journals were analyzed). There were only five journals because the kindergarten teachers and ECEs completed their maps together and one teacher did not hand her map in. The level of detail in the five journals and the amount of time spent on tasks varied significantly, as is indicated in Table 6 (see number of entries and time on task columns).
Table 6. A summary of journals and overview of nature of the educator comments, sorted by number of entries (from greatest to least)

<table>
<thead>
<tr>
<th>Educator</th>
<th>Number of entries (tasks done)</th>
<th>Range of time spent on each task</th>
<th>Nature of comments, with quotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 1 teacher</td>
<td>15</td>
<td>5-30 minutes</td>
<td>Comments on student learning, student strategies for approaching tasks, student engagement, materials used and instructional decisions made. “Got into a great discussion”; “Students were more eager”</td>
</tr>
<tr>
<td>JK/SK teacher (Carey) &amp; ECE</td>
<td>12</td>
<td>5-40 minutes</td>
<td>Comments on student engagement, teacher collaboration, student success with tasks, student quotes indicating thinking processes and reference to spatial concepts discussed in PL (e.g., 3Vs, gestalt, gesture). “Lots of excitement and interest”; “I was surprised how well they did”</td>
</tr>
<tr>
<td>Math coach (Patricia)</td>
<td>6</td>
<td>5-45 minutes</td>
<td>Comments on student engagement, references to spatial concepts discussed in PL (e.g., gestalt, positional words, gesturing), student engagement and instructional decisions (i.e., re: questioning)</td>
</tr>
<tr>
<td>JK/SK teacher &amp; ECE</td>
<td>6</td>
<td>15-40 minutes</td>
<td>Comments on student engagement, references to spatial concepts discussed in PL (e.g., 3Vs, gestalt), instructional decisions made, materials used and teacher collaboration. “Students asking to be challenged”; “Students who normally would not participate were eager to play”</td>
</tr>
<tr>
<td>Anonymous journal (either the Grade 2 or the Grade 2/3 teacher)</td>
<td>2</td>
<td>15-25 minutes</td>
<td>Comments on teaching and implementation of tasks, student engagement, student strategies and challenges and teacher collaboration</td>
</tr>
</tbody>
</table>

The variation in the number of tasks completed over the course of the project as well as the amount of time spent on each task is interesting to consider in terms of the amount to which teachers learned, the challenges they faced, and the general outcomes of the project. The overall comments and direct quotes from the journals indicate that the
educators were applying their learning of spatial reasoning to their teaching, they were carefully observing student thinking and were noticing high levels of engagement and excitement amongst students working on tasks.

The journals included mention of teacher actions (e.g., “played in round-robin games”; “we practiced visualizing”; “began with easier shapes and lines of symmetry and continued to more complex ones”), observations of student learning (e.g., “students stuck on gesture for ‘T’; no vocabulary”; “loads of gestures – full body, hand, two fingers”; “students engaged and had fun guessing the shapes – challenged to describe their thinking”), and several direct quotes from students were recorded, as seen in Table 6.

It is also interesting to note which types of spatial reasoning tasks were considered by educators and reported on in the journal entries. Over the course of the study, the team tried five of the seven categories of tasks as described in Chapter 3. A total of 10 visualization tasks, 8 tasks on symmetry, transformation and coordination, 7 tasks on mapping, location, orientation and gestalt, 5 tasks on composing and decomposing 2D and 3D shapes, and 4 mental rotation tasks were reported on.

4.3 Educator learning: Two case studies

Two cases were selected in order to more closely consider educator learning in this mathematics intervention study. Albeit unique cases, they offer insight into the benefits and challenges of teaching spatial reasoning over the intervention study. Tables 7, 8 and 9 below, are taken from the tables presented earlier in this chapter, but present data for only the two cases of focus for this section of findings—Carey, the kindergarten teacher and Patricia, the math coach. The teacher is a full-day kindergarten teacher
(teaching JK/SK with an ECE). The math coach is an employee of the board and was a PL participant who spent time co-teaching with educators at the school.

Table 7. Analysis of Carey and Patricia’s content maps

<table>
<thead>
<tr>
<th>Educator</th>
<th>Number of Initial Words</th>
<th>Number of Initial Diagrams</th>
<th>Number of Words Added</th>
<th>Number of New Diagrams</th>
<th>Total Words</th>
<th>Total Diagrams</th>
<th>Total Concepts (words + diagrams)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carey (teacher)</td>
<td>51</td>
<td>9</td>
<td>72</td>
<td>1</td>
<td>123</td>
<td>10</td>
<td>133</td>
</tr>
<tr>
<td>Patricia (coach)</td>
<td>57</td>
<td>0</td>
<td>136</td>
<td>0</td>
<td>193</td>
<td>0</td>
<td>193</td>
</tr>
</tbody>
</table>

Table 8. Further analysis of Carey and Patricia’s content maps

<table>
<thead>
<tr>
<th>Educator</th>
<th>Initial Ideas</th>
<th>New Ideas</th>
<th>Elaborations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carey (teacher)</td>
<td>19</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>Patricia (coach)</td>
<td>27</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 9. A summary of Carey and Patricia’s journals

<table>
<thead>
<tr>
<th>Educator</th>
<th>Number of entries (tasks done)</th>
<th>Range of time spent on each task</th>
<th>Nature of comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carey &amp; ECE (teacher)</td>
<td>12</td>
<td>5-40 minutes</td>
<td>Comments on student engagement, teacher collaboration, student success with tasks, student quotes indicating thinking processes and reference to spatial concepts discussed in PL (e.g., 3Vs, gestalt, gesture)</td>
</tr>
<tr>
<td>Patricia (coach)</td>
<td>6</td>
<td>5-45 minutes</td>
<td>Comments on student engagement, references to spatial concepts discussed in PL (e.g., gestalt, positional words, gesturing), student engagement and instructional decisions (i.e., re: questioning)</td>
</tr>
</tbody>
</table>

4.3.1 Carey: The Kindergarten teacher

A few powerful quotes from field notes and the focus group interview highlight learning for Carey, the kindergarten teacher. In response to a question on her key
learnings, the teacher commented on changes in her teaching and a rising estimate of what kids can do:

I think for me too I have noticed that our curriculum is really lacking in this area, and so before, following Math Makes Sense [a math textbook], it is very basic teaching, just knowing the shapes and positional words, and it turns out there is this whole other world of activities and things that children can do, that they are very capable of doing, so why were we not we doing it before? (Focus group)

Carey also recognized the shift in her thinking about teaching through playful and engaging tasks: “Like how it goes along with our idea of it being play-based, hands on with the kids, very easy to pick up and do, not a huge thing, not a lot of writing/paper-pencil, just a lot of talking with the kids” (Focus group). The teacher also stated a change in her teaching pedagogy in response to comments regarding curriculum and teaching in discreet strands (e.g., teaching number sense multiple times over the year): “You have to allow yourself to be fluid and flexible with teaching” (Focus group).

Building on a discussion of changes in teaching and a rising estimate of what children can do, Carey said that she was “not feeling constrained to the grade in the curriculum” (Focus group) when asked to reflect on her students’ key learnings. Later, in the focus group interview, she elaborated: “I will teach this unit a lot differently in the future, not just as a unit, but do activities throughout the year” (Focus group) as a way of reflecting on her learning about herself as a teacher. Carey reflected on her experiences with play-based teaching of tasks and her developing understanding of the importance of fluid, engaging teaching and commented that her teaching practices were changing because of what she had experienced in the intervention study.

When debriefing observations of student thinking, Carey commented on her experiences with detailed observations and said: “You can really see how doing this more
they would fly with it. [Do you think you got better at observing?] Yes, I feel like I know more about what to listen for” (Field notes, Day 2). She reported an increase in her abilities to observe students in an effective way over the course of the study.

Carey had a very detailed journal, where she documented specific student responses and her observations during tasks (see Table 9). On 12 occasions, Carey tried out tasks from the field-test booklet (12 was the second highest number of entries). In her entries, Carey noted things like student excitement, student gesturing, use of the 3Vs, discussion of the spatial nature of tasks, and intentional, specific observations of student learning. Her journal, therefore, provides evidence of learning about spatial reasoning as discussed in the PL meetings. Two of the tasks were done over a 40 minute block, a longer duration in comparison to other educator’s journals. Figure 3 is a snapshot of her journal:

<table>
<thead>
<tr>
<th>Date</th>
<th>Task Description</th>
<th>Length of Time</th>
<th>Observations/Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feb 10/15</td>
<td>Symmetry Paintings</td>
<td>done in centre time</td>
<td>students had to paint one side of the heart until we put them together - pulled apart to reveal symmetrical - good</td>
</tr>
<tr>
<td>Feb 12/15</td>
<td>missing puzzle pieces</td>
<td>40 mins total</td>
<td>started as large group became activity into computer - let kid on bright side - kids were gesturing - twisting hands/heads - very excited about it - once did that - students broken into small groups a trebuchet - got to manipulate paper to see if pieces fit - first visualized then verbalized guess then got to verify by checking to see piece that fit.</td>
</tr>
<tr>
<td>Feb 11/15</td>
<td>non-landing art</td>
<td>45 min block</td>
<td>students use 12 squares to trace on paper - overlap/merge them over the page.</td>
</tr>
<tr>
<td>Nov 15</td>
<td>non-landing art</td>
<td></td>
<td>trace maybe 3-5 square in different ways (keep horizontal/vertical) - once done, students had to point out the overlapping parts (where the square/rectangle has been created).</td>
</tr>
</tbody>
</table>

Figure 3. A snapshot of Carey’s journal entries (kindergarten teacher)
A short vignette on Carey’s changing conceptualizations of symmetry offers an interesting view into this particular educator’s learning over the study. The spatial concept of symmetry is one that Carey develops and refines over the course of the PL. The first entry in her journal is on a symmetry task she initiated, where students painted and folded an image to explore the line of symmetry. In her observations, she writes things like students “pulled [the paper] apart to reveal symmetry”, “talked about the line of symmetry”, and “good visual.” On Day 2, in the field notes, she reflects on the field-test task of having to copy the other half of a symmetrical design (using pattern blocks). She and her ECE planned on “continuing with symmetry, pattern blocks and [to] go back to have them share what they made…” In another meeting debrief, Carey reflected on her experience observing symmetry tasks, saying “I feel like I know about what to listen for.”

In her content map, Carey’s initial ideas (see Figure 4) represent a curricular view of Geometry and Spatial Sense; the concepts she mentions in her map appear in the Ontario Mathematics curriculum (Ontario Ministry of Education, 2005). In listing things like 2D shapes, 3D figures, spatial sense and position, she refers to curriculum areas such as an understanding of geometric properties, geometric relations and movement.

With a total of 133 concepts (words and diagrams) and five elaborations on her final content map, it appears that Carey spent a considerable amount of time reflecting on her own learning, her students’ learning and the various spatial reasoning concepts she developed over the course of the study. She added 72 words to her content map, comprised of 11 new ideas and 5 elaborations (see Figure 5).
The ideas Carey added to her map at the end of the study, as seen in Figure 5, indicate a broadening of her understanding of geometry and spatial sense and her comments reflect a more conceptual understanding of spatial reasoning concepts. For example, Carey adds ideas about mapping, the 3Vs, gestalt, symmetry, location and location words, and expands on her previous “spatial sense” bubble. The items she mentions on her map in Day 5 go beyond what is mentioned in the curriculum.
Figure 5. Completed content map for the kindergarten teacher (Carey), showing the 19 initial ideas, 11 new ideas and 5 elaborations

Her more general comments at the bottom of the map also indicate a pre-post shift in her pedagogical understanding. At the outset of the PL study, she considers her teaching pedagogy, stating that she teaches geometry “using guided instruction, play, small groups, prompts, inquiry.” At the end of the project, she appears to have broadened
her view of teaching geometry and spatial sense, writing that she “now know(s) that there are so many aspects to teaching this unit/strand of math…” This comment eloquently demonstrates a change in her perceptions over the course of the intervention study. Carey makes a mention of symmetry during the focus group interview: “Symmetry is not in our [JK/SK] curriculum, but it is something we can still talk about. [Students] picked up on it.” With all of these reflections and experiences around teaching and observing symmetry tasks, Carey adds the idea of symmetry as an entirely new concept to her final map. She draws a symmetrical butterfly in the bubble where she writes the word, and extends a series of task descriptions from it: “with pattern blocks on cookie sheets”, “line of symmetry”, “guess the folded shape” and “hole punch activity.” It is evident that through implementing tasks, writing journal entries, and discussing and debriefing observations with the team, she reflected a great deal on this specific type of spatial reasoning.

Overall, it appears that Carey gained a great deal from this intervention study; her teaching pedagogies, practices and student observations all changed as a result of her growing understanding of spatial reasoning and its applications in early years classrooms.

4.3.2 Patricia: The math coach

As a math coach, Patricia offers support in numeracy to JK-Grade 8 teachers across the school board. Patricia was present at meetings and was an active participant in the PL study. One very powerful quote came from the math coach in the focus group interview regarding playful and engaging tasks and a rising estimate of what children can do:

I was just reflecting back to everyone saying, ‘I did not think my kids would be able to,’ ‘I did not think they would be successful,’ ‘I did not think they would be
ready,’ – matching it with that and thinking, well, maybe they could even though it is not comfortable for us in that moment, maybe that could be the bridge from, they are coming from a very play-based [kindergarten program] into a less play-based [program], even though I think Grades 1 and 2 should still have a lot of that element in them, maybe these kinds of activities are going to be those things that they are just dying to do because they have a bit of familiarity with it, because it is fun, it is thoroughly engaging.

Overall, there are fewer quotes from Patricia. One possible explanation for this is that, instead of being part of the primary teaching division at the school, she provided overall support (i.e., she rotated among different classrooms and co-taught, as opposed to teaching and exploring all tasks in one classroom). At the meetings, the classroom teachers and ECEs spent time debriefing what they had observed, and the math coach did not have much time to comment. This does not mean, however, that she did not gain a great deal of insight and knowledge from the project, as is indicated by both her journal entries and her content map. Her experience was unique, as she had the opportunity to observe learning in all the JK-Grade 2 classrooms as a co-teacher and co-facilitator. It appears that her varied opportunities led to a rich development of her conceptual knowledge of spatial reasoning.

Figure 6 is a snapshot of the journal Patricia completed. Her entries (a total of 6) involve observations from a number of different classrooms where she co-taught and co-facilitated student thinking around the spatial reasoning field test tasks. Her experience was unique in that she was able to observe student learning in all classrooms, from JK-Grade 2. In her journal entries, Patricia makes notes about the student learning and thinking she observed when co-teaching in three different classrooms involved in this study (the Grade 2/3 class and two kindergarten classrooms). The following snapshot includes three entries from the same day.
Comments in her journal like “crazy engaged!” and “many gestures, lots of reference to gestalt” indicate that Patricia was connecting the learning from the study, where the team focused closely on how to carefully look for certain aspects of spatial thinking in students, to her observations of students at work.

It is possible to paint a similar picture of Patricia’s developing understanding of puzzles. Patricia writes an entry in her journal on co-teaching a task on identifying a missing puzzle piece, a task that involves mental rotation. In her observations of JK/SK learning, she writes “crazy engaged” and “many gestures, lots of reference to gestalt.” In field notes, she mentions this task again, commenting on students experiencing “challenges with the thickness and thinness [of missing pieces and] trouble eliminating shapes if they didn’t have an obvious feature that made them stand out.” After these experiences with puzzles, she adds the following to her initially brief mention of puzzles.
on her map: “beyond the fill or create what’s mapped on paper – moved into some shapes and designs that needed to be visualized. Puzzles where kids used part to make a whole.” The combination of these experiences helped Patricia develop a bigger understanding of puzzling and the spatial reasoning actions involved in such a process.

Figure 7. Initial content map for the math coach (Patricia), showing 27 ideas

The math coach’s content map was also very impressive in terms of revisions and elaborations from Day 1 and Day 5. Patricia’s initial ideas (see Figure 7) indicate an
understanding of the Geometry and Spatial Sense strand as it appears in the curriculum (Ontario Ministry of Education, 2005).

Figure 8. Completed content map for the math coach (Patricia), showing the 27 initial ideas, 4 new ideas and 6 elaborations
It is interesting to note that the math coach recorded “visualize, verbalize, verify” on her initial content map. As the board has been focusing on spatial reasoning and has had exposure to the M4YC children project, it appears that she captured this idea prior to participating in this study.

Patricia had 193 concepts (total number of words and diagrams) recorded on her final map, the highest number of any educator. She added 136 words on Day 5, by far the most added of all educators, and more than doubled her initial word count of 57. Her map shows 27 initial ideas, 4 new ideas and 6 detailed elaborations, again the most elaborations of the team (Figure 8).

Additions to her map indicate that she is developing an understanding of the “no-ceiling” curriculum, where she recognizes that “even very young kids were successful” and “3 and 4 years olds showed more success than many grade 6’s!” when presented with more challenging spatial reasoning tasks. Her understanding of spatial reasoning extends beyond the more basic aspects of the curriculum as she adds mapping and coding, barrier games, more positional language, different view of buildings (perspective taking), and visualizing, verbalizing and verifying to her map.

4.4 Summary

This chapter has presented findings from data that was collected and analyzed from this classroom-based intervention study. Presenting a collective view of the entire educator team offers an overview of educator experiences throughout the study. The focus on the two cases provides a more detailed portrayal of individual experiences. The next chapter will offer further interpretations of this data and provide possible answers to my research questions.
Chapter Five: Discussion and Implications

5.1 Summary of findings

In this chapter, I discuss the findings presented in Chapter Four and answer my two research questions. Through my work, I have gained deeper insight into the benefits and challenges of a JK-Grade 2 professional learning intervention study that focused on mathematics and spatial reasoning. I have also been able to consider the effects of implementing spatial tasks on educators’ conceptual understanding of spatial reasoning.

This study supports findings in the literature review where I discussed a number of features of effective PL. Professional learning that is classroom-embedded, focused on mathematics content, and that considers effective teaching strategies are shown to be beneficial for educator learning (Bruce et al., 2010; Desimone, 2011; Polly et al., 2014). This intervention study included all three of these as well as other key features. It is the combination of factors discussed in the literature review (classroom-embedded programming, the development of collaborative relationships, a focus on content and pedagogy, and a deep consideration of both teacher and student learning outcomes) that make for an effective professional learning study.

If we consider each of these factors as individual threads in a woven fabric, and view an entirely effective PL program as a perfectly woven fabric, then it makes sense that only when all threads (factors) are in place will the fabric be complete and be help strongly together. In other words, I discuss the strength of the fabric woven in this PL study by considering each factor in light of the study and use my research questions as a framework to explore the metaphor. Unless a PL program has all of these key characteristics, I argue it will not be truly beneficial.
5.2 Research Question 1: What are the benefits and challenges of a JK-Grade 2 educator professional learning intervention study focusing on spatial reasoning in mathematics?

My first research question asks about the benefits and challenges of a JK-Grade 2 professional learning intervention study focusing on mathematics and spatial reasoning. Since this question considers both benefits and challenges, I have decided to separate my discussion and interpretation of findings into two sections: first, I discuss the benefits of the intervention study and then I consider the challenges.

5.2.1 Benefits of the intervention study

Overall, educator learning was evident in the data. In field notes and the focus group interview, educators’ comments were grouped into four main areas of learning, identified through coding, and indicate a range in educator learning (see Table 2).

5.2.1.1 Learning by observing children

Learning by observing children was by far the most prominent theme in the data. This theme incorporated educators discussing both a rising estimate of what children can do and detailed observations of student learning. This theme relates directly to the benefits of classroom-embedded PL, one of the main threads in the woven fabric of effective professional learning. This study provided educators with many opportunities for conducting careful and pointed observations of their students while implementing the spatial reasoning tasks from the field-test booklet. The opportunity to spend time collaboratively debriefing observations was a key component of this study and led to educators commenting a great deal on student learning.
These findings are supported by the literature, which states that a key feature of effective PL is collaboration; researchers and teachers need opportunities to work together to develop collaborative relationships, in order to focus on student learning, thinking, teaching and consideration of best practices together (Stylianides & Stylianides, 2013). Each meeting day in this intervention study was structured around long periods of collective debriefing and discussion around student thinking about the tasks.

5.2.1.2 Learning through implementation

Learning through implementation was the second most frequently reported area of educator learning. This theme includes a discussion of challenges (to be interpreted in a later section of this chapter), playful and engaging tasks, and reference to the “3Vs” strategy of math communication. This area of learning connects to the thread representing a focus on content and pedagogy. Educator quotes for this theme indicate high levels of excitement and engagement; implementation of the playful tasks was enjoyable for the JK-Grade 2 educators and their students. The educator team had the opportunity to learn about playful pedagogy from the lead researcher, which connected literature around the importance of playful pedagogy and early years mathematics programming: guided play (Ginsburg, Lee & Boyd, 2008; Weisberg et al., 2015) is a powerful way for young children to learn math (Caldera et al., 1999; Docket & Perry, 2010; Newcombe & Frick, 2010). These findings, therefore, connect well to research that considers the links between teacher instructional practices and student learning as a key feature of effective PL (Polly et al., 2014). The benefits of this focus on playful pedagogy as the instructional practice is, therefore, supported by research.
Code counts indicate that the team benefited and learned from collaboratively discussing tasks in the field-test booklet. The ability to collaboratively work on task planning is directly related to the mention of another key thread in the woven PL fabric—collaboration and group discussion: “close collaboration between researchers and teachers… increase[s] the likelihood that the results of the [PL] research will be directly applicable (instead of merely potentially relevant) to practice” (Stylianides & Stylianides, 2013, p. 334).

In addition, the benefits of educators exploring the field-test booklets collaboratively before implementing tasks on their own is supported by literature. Borko (2004) argues for PL to include time for educators to do mathematics activities themselves. This intervention study had participants working through spatial reasoning activities; they spent time grappling with different and novel concepts through field-testing the spatial reasoning tasks together.

5.2.1.3 Learning about content

Content learning was evident in a number of areas of the data: in field notes and the focus group interview, in content maps and in journal entries. These findings again represent strength in the thread encompassing a focus on content learning and pedagogy. According to Hill (2004), professional learning should focus on math content and student and teacher learning outcomes. In this study, research-supported initiatives like spatial reasoning content, a focus on challenging early years mathematics and playful pedagogy were all at the forefront. Through implementing spatial reasoning tasks, debriefing observations of student learning and reflecting on a specific way of teaching mathematics
(i.e., through playful pedagogy), educators explored spatial reasoning and gained insight into the benefits of teaching spatial reasoning in mathematics.

It is clear that, despite initial confusions and an apparent lack of confidence and familiarity with spatial reasoning, educators developed conceptual knowledge of spatial reasoning and saw many connections between spatial reasoning and other strands of mathematics that they could make with their students. This is important, as indicated in the literature, because spatial reasoning is an effective approach to solving a wide range of mathematics problems so when mathematics is approached spatially, many students are more successful at reasoning through concepts and accessing the material (Casey et al., 2008; Ontario Ministry of Education, 2014).

Through this direct focus on spatial reasoning, educators expanded their understanding of geometry and spatial sense. Based on findings from the field notes and focus group, educators reported changes in their approaches to teaching, which implies a shift in pedagogy. Educators saw how, when applied across all strands, spatial reasoning is helpful for their students (e.g., they saw links between spatial reasoning and number sense). This emphasis on “spatializing” the curriculum and applying spatial reasoning to strands beyond geometry has been found to be extremely helpful in increasing young children’s access to mathematics in other studies as well (Newcombe, 2013). In the specific examples of Carey and Patricia, they developed content understanding in many areas (e.g., in symmetry and puzzles), as was described in the two short vignettes.

These increases in appreciation for teaching mathematics and spatial reasoning, therefore, links directly to the literature on the benefits of providing enriching math experiences for young children. The design of spatial reasoning tasks in the field-test
booklet in this intervention study had these promising research findings in mind, so it is not surprising that educators expressed gains in their content understanding through teaching spatial reasoning in mathematics.

5.2.1.4 Learning through reflection

This theme includes comments on changes in teaching and reflections on professional learning in general. In this study, participants spent a great deal of time reflecting on their own learning through journals and content maps. Educators commented on changes in how they were teaching math, an important outcome of the study. These changes highlight the value of the intervention study in introducing a new way of teaching mathematics with spatial reasoning and are connected to literature in the area. For example, Desimone (2009) found that the focus on “intellectual and pedagogical change” supports educator growth. In this study the focus on spatial reasoning, a typically underrepresented area of mathematics (Sinclair & Bruce, 2014), and an emphasis on educator reflection of their learning (i.e., through maps and journals) both inspired growth.

5.2.2 Challenges of the intervention study

In order to have a more complete appreciation for educator learning in this intervention study, it is important to consider both the benefits and the challenges of such an endeavor. In this section, I consider the second half of my first research question (around the challenges) and discuss factors of this intervention study that perhaps had limitations on the amount of educator learning that took place. Despite the many beneficial outcomes on educator learning and the weaving of a relatively strong fabric, based on the above discussion, a few challenges weaken its strength. These include time,
administrator support, educator perceptions and participation, and implementation of tasks.

5.2.2.1 Time

This intervention study lasted for four months (from January to April) and educators and researchers met for meetings on five occasions, for a total of 32.5 hours. Time is of important consideration in effective professional learning literature, and is, therefore, another major thread in a strongly woven professional learning fabric. A call for sustained learning is made in the literature (Borko et al., 2000; Cohen & Hill, 2000; Franke et al., 2001) and Grant and Kline (2004) argue for no less than 43 hours of professional learning. If I use these guidelines to assess this intervention study, it appears that it falls short by about 10 hours of PL. Despite being sustained, it was perhaps not long enough.

Another representation of time is the amount of time educators spent on the tasks. This is indicated in their journal entries (Table 6). Keeping in mind the possibility for reporting errors (i.e., that some educators did not document all the tasks they tried) and possibility of journals being incomplete, it appears there was very limited time on task for some participants. The range is from 2 entries to 15 entries, which indicates a variation in levels of investment in the project. These seem like relatively low numbers of entries in journals (2, 6, 12, 15) considering that this intervention study occurred over four months, with lots of time in between meetings to implement tasks.

5.2.2.2 Administrator support

Another area of weakness in the woven fabric I am depicting, is that of administrator support. Over the course of the study, administration changed three times.
There was, therefore, no consistency and very minimal support in PL meetings from the administration. The third principal spent only two of the five meeting days with the team. This factor of school context is of particular concern to some researchers in the field who argue that administrator involvement enhances both teacher learning and student achievement in professional learning (Goldring & Pasternack, 1994; Gumus, 2013). The thread for administrator support is therefore quite weak in the woven PL fabric.

5.2.2.3 Educator perceptions and participation

Despite a number of positive quotes from educators throughout the study, there certainly was some variation amongst educator perceptions and participation. In considering the powerful quotes pulled as evidence of teacher learning for each of the four themes, the kindergarten educators and the Grade 1 teachers are all featured prominently. Other teachers (i.e., the Grade 2 and Grade 2/3 teacher) did not participate as much. The Grade 2/3 teacher did not complete her content map and was not present for the focus group interview.

Educators mentioned a few challenges over the study, indicating some hesitancy with seeing the connections between spatial reasoning and other areas of mathematics. This is not surprising given these teachers reported no professional learning in the area of geometry and spatial sense. The lack of familiarity with spatial reasoning and a reluctance to see a fit between spatial reasoning in their program indicate that there are areas for growth in this educator team. Educator’s attitudes, content knowledge and confidence are all key factors in effective teaching (Moss, Bruce & Bobis, 2016) so it can be said that challenges in this area also weaken the strength of the PL fabric.
5.2.2.4 Implementation of tasks

Another feature of this intervention study is that very little time was spent on the co-creation of tasks. In previous cycles of M4YC professional learning, the main focus of the team has been on the development of exploratory tasks and a culminating lesson to share with other researchers and educators (as in the lesson study model; see http://tmerc.ca). Despite the opportunity to employ rich, playful and exciting spatial tasks with their students, this group of educators did not have the opportunity to design tasks, which reduced the level of active participation in the PL. As the literature indicates, active and engaged participation is key for effective PL (Desimone, 2011; Polly et al., 2014). This is, therefore, another weak thread in the woven PL fabric.

5.3 Research Question 2: What are the effects of implementing spatial reasoning tasks on educators’ conceptual understanding of spatial reasoning?

In this section, I address my second research question. Some of the findings lend themselves to a discussion of educator conceptual understanding better than others and so for this section, I refer to the table of observed change in students’ understanding of spatial reasoning (Table 3), content maps and journal entries.

Based on the findings presented in Table 3, educators reported development in a range of areas related to the spatial reasoning content they were introduced to over the intervention study. All educators observed their students using positional language, increasing precision in their language and verbalizing more accurately. All educators observed students saying things like it “reminds me of” and “looks like”; they were recognizing the gestalt in objects (seeing the whole shape of an object and likening it to something else), a key area of observation in children’s spatial thinking. Gains in specific
spatial mathematics understanding were documented; for example, all educators reported student gains in knowledge of symmetry and a better understanding of transformations.

All educators commented on students seeking challenges. Four educators noted improvements in their students’ visualization strategies. Two educators commented that students gained confidence with language and a willingness to share their thinking. One educator saw her students showing increased perseverance on tasks. Each of the above provide evidence for student learning and consequent developments in educator conceptual knowledge, as a result of implementing spatial reasoning tasks in their classrooms.

In the content maps, three educators elaborated on their existing ideas and six educators added new ideas on Day 5 (a wide range of 32-136 words were added). These additions can be interpreted as either increases in educator depth and breadth of their understanding of spatial reasoning, or simply that new ideas were being formulation and old ideas were expanded on. I lean towards the former interpretation as educators added concepts directly learned and discussed in the PL regarding spatial reasoning (e.g., 3Vs, spatial concepts addressed in the tasks, such as composing/decomposing, using precise positional language, mapping and building by both receiving and giving directions, symmetry, etc.) and included mention of experiences (e.g., to observe students closely), another feature unique to this study. In general, there was evidence of a shift from a purely curricular understanding of geometry and spatial sense to a broadened understanding of spatial reasoning and its applications.

These findings connect to the literature. Research on the effects of spatial reasoning in early years classrooms is showing trends towards the extension of:
primary school geometry from its typical passive emphasis on vocabulary (naming and sorting shapes by properties) to a more active meaning-making orientation to geometry (including composing/decomposing, classifying, mapping and orienting, comparing and mentally manipulating two- and three-dimensional figures). (Sinclair & Bruce, 2015, p. 320)

Journal entries also indicate educators developed spatial reasoning conceptual understanding over the study. The inclusion of a discussion of instructional decisions made during implementation of spatial tasks (e.g., materials choice, questioning, observing), spatial reasoning concepts (e.g., 3Vs, gestalt, gesture, positional words), comments on student engagement with the tasks, surprises in student performances, and observations of student strategies all indicate positive learning about spatial reasoning over the study. Considering these findings, the thread of mathematic content focus, again, appears very strong.

A general shift in the concept maps was also noted. The shift was from a simplistic, curricular focused view of geometry and spatial sense, to a broader understanding of spatial reasoning concepts and their application to the strand.

5.4 Major findings

Through a discussion and interpretation of findings from this intervention study, it is clear that educators learned in a number of key ways. Through the implementation of pre-designed tasks, the nature of meetings, where deliberate debriefing and reflection on student thinking and learning took place, and the careful planning of additional tasks, led to learning in four key areas: learning by observing children, learning through implementation, learning about content and learning through reflection. Evidence for this learning has been discussed throughout this discussion.
I believe one of the major findings of this study is that educators did not have an active hand in the development of the tasks they implemented. It appears that their pedagogical and content learning was limited (especially since it appears that not all educators participated to their full extent). By implementing pre-designed tasks, educators did not have as much ownership over what they were teaching than if they had played a hand in creating the tasks. In other lesson study cycles in the M4YC project (see http://tmerc.ca), educators and researchers have worked together to design tasks and have a much more active role in the professional learning cycle. Conversely, in this intervention study, educators took on an active role in observing children and debriefing collaboratively, but they did not have agency in task design, which seems to have affected the buy-in and engagement of some of the participants.

Regardless of how playful and engaging the tasks in the field-test book were, the educators could not fully adopt them as their own. This is an important consideration when we consider how to effectively implement and disseminate new mathematics programming. It appears that it is not enough to provide tasks to educators for implementation, but that educators must take a hand in the design for more fulsome learning. There is great importance in the co-creation of tasks during a professional learning program and potential limitations associated with using only prescribed materials.

Despite strong threads in collaboration, classroom-embedded learning and a focus on content and pedagogy, there are weaker threads throughout this intervention study. The amount of time spent in the study and on tasks between meetings was seemingly low, administration involvement was transient and lacking, and the opportunity for active
participation (i.e., in the form of co-developing of tasks) was limited as a result of using pre-designed tasks in the field-test booklet. This means, therefore, that the overall strength of the metaphorical woven fabric used to represent this professional learning study is somewhat compromised. The foundational threads that are represented in the structure of the PL study are all very strong (the items discussed in the benefits section), but the supporting threads (those discussed in the challenges section) require some revisions and strengthening.

Overall, this intervention study yielded impressive evidence of educator learning around spatial reasoning, playful pedagogy, and a rising estimate of what young children can do in mathematics. These findings support previous research studies in the field. As this is an area of developing research in education, the continuation of studies such as this one and the overall M4YC project are of great benefit to the field of education and will help to increase our knowledge around the importance of early years mathematics and the positive opportunities spatial reasoning provides to young learners and their educators.

5.5 Limitations

This thesis would not be complete without a discussion of this study’s limitations. With a team of only seven educators and one math coach, it is a small study. The fact that all educators came from the primary division at one school is important to take into consideration as this means that the educators teach in the same school environment. This is helpful in discussion factors of school context, but is somewhat limiting in applying results to other schools. The school of study is also a unique environment, as the majority of students are of low socio-economic status and school performance on EQAO in
mathematics in consistently below average. These factors limit generalizability of findings.

Despite providing opportunities for detailed analysis and specific considerations of a particular participant in research, case study methodology offers limited ability to generalize. It is important, therefore, to consider the findings presented here, particularly in the cases of Carey and Patricia, with recognition that the results indicate learning for just two educators in one school team over one intervention study.

Teacher reflection is also important to discuss in this section on limitations. As the research team was present at all meetings and they conducted the focus group interview, participants could have felt an incentive to keep their discussion to positive learning outcomes, perceptions of the study and their experiences with implementing the spatial reasoning tasks. It is not so easy to discuss downfalls, limitations and challenges of a research project when the research team who has designed the project is asking the questions.

5.6 Future research

Based on this discussion and interpretation of findings, I argue for the continuation of this type of work, as it once again appears that professional learning studies that focus on the exploration of teaching early years mathematics through playful spatial reasoning are of significant benefit to the field of education. Future research of professional learning studies should continue to place an emphasis on educator learning.

Along with teacher professional learning comes the modification of tasks themselves, allowing for time spent generating and co-creating activities, and not just the field-testing of pre-designed tasks. Further explorations of teacher learning when the co-
creation of tasks is added on to the existing features of the examined intervention study will offer more insight into the benefits and challenges of this work. The challenges, especially, are what will provide insight and recommendations for future research and lead to the even stronger professional learning opportunities in this developing area of mathematics education.
References


Trent University, School of Education and Professional Learning. Trent Math Education Research Collaborative. Retrieved from [http://tmerc.ca](http://tmerc.ca)


Appendix A

2015 M4YC Teacher Data Collection Instruments

Teacher Map Prompts

*Teacher Map Prompt for Day 1:* What geometry activities and concepts are your students doing/have they done/going to do this academic year?

Teacher Map Prompt for Day 2: *Please add to your map in a different colour.* Describe the spatial reasoning activities and concepts your students have done this academic year. Also add any additional spatial reasoning activities you plan to do with your students next year.

Focus Group Questions

1. Describe your key learnings from teaching mathematics tasks that incorporated spatial reasoning. [About spatial reasoning, about mathematics/connections with different areas of mathematics, about mathematics teaching, about observing students...]
2. What did you find most powerful about teaching and engaging in spatial reasoning and why?
3. Implementation of tasks: Please describe how you implemented the tasks? [What are the benefits of repeatedly visiting spatial reasoning tasks over time?] What is some advice you would give on how to implement/use the tasks? [how often, when, what kind of organization/structures help?]
4. What did you find most challenging (the barriers) about teaching and engaging in spatial reasoning and why? [What are the challenges of repeatedly visiting spatial reasoning tasks over time?] What could support you in overcoming these challenges, e.g., was there more that could support you in taking observations?
5. Describe your students’ key learnings from mathematics tasks that incorporated spatial reasoning. [About spatial reasoning, about mathematics/connections with different areas of mathematics.../about other areas of the curriculum. Student metacognition: are students saying anything about improvements in visualization, how visualization helps them?]
6. What was key, powerful, different for you in terms of our process and work together? What was your experience with this PL, compared to other forms of PL?
7. Have you learned something about yourself as a teacher?
Appendix B
Images from the Field-Test Booklet

Field-test booklet table of contents

Sample task

Folding Fun

Description
Children use imagination to anticipate how paper that has been folded and hole-punched will look when the paper is unfolded. In particular, children are challenged to visualize and reason about how the pattern of holes will appear once the paper is opened.

Purpose
To develop children’s visualization and spatial reasoning skills

Materials
Hole punch, small square pieces of paper, Challenges (template available)

Instructions
1. Gather children in a semicircle with a clear view of the teacher.
2. Hold up piece of square paper and clearly show the children that you fold it in half along the horizontal midline and using the hole punch, punch a hole in the top left corner.
3. Challenge children to visualize/imagine what the piece of paper will look like once unfolded (how many holes and where will they be located?).
4. After discussing their visualization predictions with classmates, present four multiple-choice options of what the unfolded paper might look like; have children select the best option. (See image below.)

Extensions
The challenges created for this activity increase in complexity, both in terms of where the holes are on the paper (vertical, horizontal, or diagonal) and also with increasing numbers of dots. To extend this activity even further, rather than offering a choice of 4 possible outcomes for the unfolded paper, have children first visualize the solution to a new challenge and then provide them with paper and a hole punch to confirm/disprove their visualization predictions. Another extension would be to work with this activity in reverse. Present children with a flat piece of paper (with no holes) with a specific pattern of holes in it. Have children ‘work backwards’ as they try to figure out how the piece of paper was folded and hole-punched in order to create the given pattern of holes.

Special Notes
This task not only supports visualization but also provides children with ways to engage in increasingly complex symmetry reasoning. Additionally, this task can lead to important mathematical discussions about multiplication as children are challenged to consider the relationship between the number of folds and the number of resulting holes.
Book cover, in press

Enrich Your Geometry Curriculum and Extend Your Students’ Spatial Reasoning