The Roles of Symbolic Mapping and Relational Thinking in Early Reading and Mathematics

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Boston College Electronic Thesis or Dissertation, 2016

BOSTON COLLEGE
Lynch School of Education

Department of Counseling, Developmental, and Educational Psychology

Applied Developmental and Educational Psychology Program

THE ROLES OF SYMBOLIC MAPPING AND RELATIONAL THINKING IN EARLY READING AND MATHEMATICS

Dissertation

by

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submitted in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy

May 2016

Abstract

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This research explored the roles of symbolic mapping and relational thinking in early reading and mathematics learning. It examined whether symbolic mapping and relational thinking were predictive of children's reading and mathematics knowledge; the extent to which these domain-general cognitive scores explained correlations between the two domains; and whether these cognitive scores mediated relations between verbal intelligence and reading and mathematics. Furthermore, the present research explored whether home learning experiences were predictive of children's symbolic, relational, reading, and mathematics scores.

Participants in Study 1 were 86 preschool children from the Boston area. Children completed an assessment of verbal intelligence and a range of symbolic, relational, reading, and mathematics measures. Results showed that reading and mathematics scores were highly correlated; symbolic and relational scores were predictive of domain-specific performance; and symbolic and relational thinking mediated relations between verbal intelligence and reading and mathematics knowledge. These findings suggest that symbolic mapping and relational thinking may provide foundational cognitive skills that support early learning.

Study 2 investigated whether home learning experiences were related to children's symbolic, relational, reading, and mathematics scores. Participants were the 86 parents of children from Study 1. Parents reported the frequency with which they and their child engaged in various activities. Findings showed a significant relation between symbolic learning experiences and children's reading and mathematics scores, but no relations between learning experiences and children's symbolic or relational scores. There was a strong association between parents' beliefs about the importance of mathematics for kindergarten readiness and children's reading and mathematics scores. The results suggest that homes rich in symbolic learning experiences may best support children's early learning, but parental beliefs about mathematics may differentiate highly effective and less effective learning environments.

Taken together, these two studies contribute to our understanding of the constructs of symbolic and relational thinking as foundations for early learning in reading and mathematics. Findings are discussed in terms of their implications for improving school readiness via increased intentionality in early educational activities.

Acknowledgements

First, I want to gratefully acknowledge my committee members for their invaluable input and support throughout the many stages of the dissertation process. I could not have asked for a more encouraging and insightful committee than Dr. Laski, Dr. Vasilyeva, and Dr. Páez to guide me in figuring out what I wanted to study; designing my study; and wading through, interpreting, and summarizing my data. Individually, I would like to thank Dr. Páez for enriching my perspective on the equally important, multiple dimensions of early childhood development. I would also like to thank Dr. Vasilyeva for your guidance throughout my five years at Boston College, from being the professor of my favorite class in my first semester to advising me as I taught my own course this semester. Lastly, I need to thank Dr. Laski for your immeasurable support as my advisor over the last five years. You not only have helped me better understand the research process and clarify my thinking and writing, you have also guided me through the various obstacles graduate students face as they work to define themselves.

Thank you to the Boston College Lynch School of Education for supporting my research with the Dissertation Fellowship. The fellowship was a great honor and not only allowed me to make tremendous progress in a short period of time, but also gave me the motivation I needed to persevere during difficult stretches. Knowing that others believed in the value of my research gave me great validation and encouragement.

I would like to thank Ally Dellheim and Joanna Schiffman for their assistance with data collection, as well as their willingness to help me problem solve through tricky situations. I cannot thank enough the wonderful directors and teachers who welcomed me into their centers. I witnessed firsthand how many responsibilities these educators need to balance in their daily lives, and yet they were still willing to welcome me into their hallways. I am also immeasurably thankful for the parents who consented to participate in the study, and for their fun, curious, and remarkable children who continually made me smile and offered glimpses into the fascinating ways that young children see and process the world.

I would not have made it through my five years at BC without the support of my friends. To my college blocking group (Christine Ahn, Anna Paula Brito, Neha Chauhan Woodward, Kristen Hamelin Tracey, Jenny Jacobs, Lauren Jones, and Muriel Payan) and my girls' night group (Annice Correia Gabel, Lindsay Emmanuel, Julia McGuirk, and Madelyne Ogren), thank you for being there for me, whether I needed to vent or celebrate. Thank you also to my cohort at BC: Anna Ermakova, Miriam Heyman, and Jacqueline Simms. What an incredible stroke of luck to be in the same cohort as you three. You all are smart, humble, and inspiring.

I know also that I am tremendously lucky to have had the love and support of my family throughout my life— my brother, Mike Collins, and my sister-in-law, Katie Collins, and my parents, Jim and Janet Collins. To my brother, Mike, thank you for being there for the important stuff but making me laugh about the less important stuff. To my sister-in-law, Katie, thank you for being such a positive addition to my life, offering the support that only a sister can provide. And thank you both for bringing my two beautiful nephews into the world, who always remind me about why I love research on early childhood. Mom and Dad, thank you for always supporting me, but allowing me to figure out some things for myself. The more I have learned about child development, the more grateful I have become that I was raised with such nurturing, balanced, and supportive parents and positive role models. Thank you for continually trying to understand what exactly I was doing in this whole Ph.D. thing, even if it didn't always make sense. Thank you also for always coming to all my soccer games and band/orchestra concerts, and for being proud of me. This dissertation is dedicated to you.

Finally, to my husband, Alex D'Amour, who not only served as my statistical consultant and personal chef, but also has listened to me talk through ideas, voice frustrations, and otherwise worry about all aspects dissertation, thank you for being there for me through it all. You make me better in every way. I love you.

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Chapter 1: Introduction

As early as kindergarten, children show marked individual differences in reading and mathematics. These differences are highly predictive; children's reading and mathematics knowledge in preschool and kindergarten predicts their future academic achievement from early elementary school through adulthood (Aunola, Leskinen, Lerkkanen, & Nurmi, 2004; Bodovski & Farkas, 2007; Claessens & Engel, 2013; Cunningham & Stanovich, 1997; Duncan et al., 2007; Furnes & Samuelsson, 2009; Geary et al., 2013; Hooper, Roberts, Sideris, Burchinal, & Zeisel, 2010; Jordan, Kaplan, Ramineni, & Locuniak, 2009; Juel, 1988; Mazzocco & Thompson, 2005; La Paro & Pianta, 2000; Penno, Wilkinson, & Moore, 2002; Romano, Babchishin, Pagani, & Kohen, 2010; Stanovich, 1986; Stevenson & Newman, 1986; Watts, Duncan, Siegler, & Davis-Kean, 2014) and even predicts their employment prospects upon entering the workforce (Geary et al., 2013; Ritchie & Bates, 2013). Thus, in order to better prepare individuals for academic and professional success, it is critical for researchers and educators to understand the factors underlying individual differences in early childhood knowledge and identify potential levers for increasing the achievement of all children.

A number of socio-environmental and cognitive factors predict individual differences in early reading and mathematics knowledge. For example, socio-environmental factors such as parental education and frequency of book reading in the home (Sénéchal & LeFevre, 2002), and cognitive factors such as phonological awareness and processing speed (Catts, Gillispie, Leonard, Kail, & Miller, 2002), have been shown to account for significant portions of variance in early reading performance. Likewise, frequency of informal numeracy activities and exposure to number words in the home

(LeFevre et al., 2009; Levine, Suriyakham, Rowe, Huttenlocher, & Gunderson, 2010), as well as visuospatial working memory (Bull, Espy, & Wiebe, 2008) and approximate number system acuity (Halberda, Mazzocco, & Feigenson, 2008), predict individual differences in early mathematics. Research has also demonstrated that knowledge in these domains can be affected by domain-specific instructional interventions, such as phonological awareness training (Blachman, Tangel, Ball, Black, & McGraw, 1999) and dialogic reading (Zevenbergen & Whitehurst, 2003) for reading, and concepts-based mathematics curricula (Sarama & Clements, 2004; Starkey, Klein, & Wakeley, 2004) and number board games (Siegler & Ramani, 2008) for mathematics.

In addition to understanding sources of domain-specific individual differences and testing domain-specific intervention strategies, however, it may also be fruitful to consider how knowledge in the two domains may be related and whether single interventions may simultaneously support both domains. Research has repeatedly shown correlations between early reading and early mathematics performance (e.g., Cirino, 2011; Claessens & Engel, 2013; De Smedt, Taylor, Archibald, & Ansari, 2010; Hecht, Torgesen, Wagner, & Rashotte, 2001; Hooper et al., 2010; Lerkkanen, Rasku-Puttonen, Aunola, & Nurmi, 2005; Purpura, Hume, Sims, & Lonigan, 2011; Welsh, Nix, Blair, Bierman, & Nelson, 2010), and difficulties in the two domains are often comorbid (Archibald, Oram Cardy, Joanisse, & Ansari, 2013; Barbaresi, Katusic, Colligan, Weaver, & Jacobsen, 2005; Light & DeFries, 1995). Yet, these two areas are generally treated as unrelated domains of early education. Few studies have explored the extent to which the two domains may require similar types of thinking, or how knowledge in one area might be capitalized upon to improve knowledge in the other. The goal of the present study was to propose and investigate previously unexplored factors that may explain relations between early reading and mathematics—specifically, symbolic mapping and relational thinking.

Chapter 2: Literature Review

Empirical Connections between Reading and Mathematics

Substantial empirical evidence indicates connections between early reading and early mathematics knowledge. According to one large meta-analysis of over 60 studies, early reading and mathematics performance are correlated with an average of $r = 0.50$ (La Paro & Pianta, 2000). Knowledge in the two areas is not only correlated, but also predictive longitudinally, with knowledge in each subject area predicting unique variance in the other (Claessens & Engel, 2013; Lerkkanen et al., 2005; Purpura et al., 2011; Watts et al., 2014). Controlling for early mathematics knowledge as well as general intelligence and socioeconomic status, reading knowledge at the start of preschool predicts unique variance in mathematics performance in kindergarten (Purpura et al., 2011) and through fifth grade (Watts et al., 2014). Likewise, math abilities at the start of kindergarten are highly predictive of eighth grade performance in reading (Claessens & Engel, 2013). Despite these empirical connections, research has yet to adequately consider *why* these relations exist.

Existing Explanations for Connections between Reading and Mathematics

Extant explanations for links between early reading and early mathematics consist of factors that are broad-reaching and influence numerous aspects of development. For instance, a range of socio-environmental factors have been shown to be related to early success in each domain. Socioeconomic status, for example, repeatedly has been shown to be related to academic achievement (Jordan et al., 2009; National Research Council, 1998). A number of theories have been proposed to explain poverty's effects on development, including the negative influences of family stress (Evans & Kim, 2013;

McLoyd, 1998) and family's reduced abilities to invest in high quality learning environments for their children (e.g., Gennetian & Miller, 2002). In addition, the frequency and quality of learning experiences in the home have been linked to both reading (National Research Council, 1998) and mathematics (LeFevre et al., 2009; Levine et al., 2010) in preschool.

Additionally, a number of general cognitive abilities have been shown to be related to performance in both domains. General intelligence, for example, is not surprisingly related to children's knowledge in each domain. One longitudinal study found that children's IQ in elementary school accounted for 59% of variance in mathematics performance and 48% of English performance in high school (Deary, Strand, Smith, & Fernandes, 2007). Others argue that working memory may be even more important for school success than intelligence. Working memory is predictive of both reading and mathematics in the early years (Gathercole, Pickering, Knight, & Stegmann, 2004), and one study found that working memory at age 5 was a stronger predictor of reading and numeracy scores at age 11 than was IQ (Alloway & Alloway, 2010).

Language is very important in both reading and mathematics learning as well. Numerous studies have shown relations between language and performance in each domain. For instance, phonological awareness, or "the ability to detect or manipulate the sound structure of oral language" (Lonigan, 2006, p.78), is undeniably essential to reading, but has also been shown to be predictive of mathematics performance, perhaps due to the necessity to store and use verbal information for digits (De Smedt et al.,2010; Hecht et al., 2001). Other research with students with specific language impairments suggests that language may play a critical role in learning the counting sequence and place value (Donlan, Cowan, Newton, & Lloyd, 2007). Preliminary evidence suggests the relation may be bidirectional: one study found that an intensive early mathematics curriculum positively influenced students' oral language compared to students not receiving the curriculum (Sarama, Lange, Clements, & Wolfe, 2012).

Identifying Mechanisms

Though these socioeconomic and cognitive factors provide a starting point for understanding connections across domains, identifying the *mechanisms* through which these broad factors influence performance in reading and mathematics requires further investigation. For instance, poverty itself does not directly influence reading and mathematics, but is instead mediated through a number of processes. With regard to intelligence, the question remains: what does higher IQ enable students to do more easily, effectively, or efficiently that leads to better performance in early reading and mathematics? Understanding these mechanisms would provide clarification about specific areas of cognition that might be targeted to improve performance in both domains.

In order to identify the mechanisms through which broader factors may support higher performance in both domains, however, it is necessary to understand what tasks in the two domains have in common. A critical analysis of the deep structures of various tasks in the two domains, followed by analysis of the types of cognition underlying successful performance on these tasks, may be an important step in understanding early learning in reading and mathematics.

Analysis of Superficial Versus Deep Structures in Early Reading and Mathematics

It is possible that early reading and mathematics have been treated as separate, unrelated domains because they possess superficial differences. Within the problem solving literature, the distinction has been made between superficial features and deep structures of different problems. For example, Chi, Feltovich, and Glaser (1981) described physics problems as a combination of superficial features, such as the objects referred to in the problem or keywords, and deep structural features, such as major physics principles underlying problems. Individuals are more likely to successfully transfer problem solving strategies between problems with similar surface features than they are between problems sharing only deep structural similarities (Catrambone & Holyoak, 1989; Chi et al, 1981; Chi & VanLehn, 2012; Gick & Holyoak, 1980; Reed, Dempster, & Ettinger, 1985; Ross & Kennedy, 1990). Pedagogical approaches that intentionally highlight deep structural similarities are usually necessary for students to make connections between superficially different, but structurally similar, problems (Catrambone & Holyoak, 1989; Needham & Begg, 1991).

I propose that the distinction between superficial features and deep structures is also relevant for conceptualizing the similarities and differences among many of the foundational skills in early reading and mathematics. In other words, many domain-specific skills in early reading and mathematics, though differing in superficial features, may share deep structural similarities specifically relating to symbolic mapping and relational thinking. To examine this possibility, I conducted a rational task analysis of specific skills within each domain that develop during preschool. The skills included in the analysis are some of the earliest acquired within each domain and have been either theorized or empirically shown to be related to later achievement within their respective domain.

The analysis suggested that early skills in both reading and mathematics may share some common deep features – specifically, mapping labels to symbols and symbols to referents, thinking about part-whole relationships, and making comparative judgments. Both reading and mathematics are based on a system of symbols—letters and numerals, respectively. Thus, many of the earliest skills focus on developing memory for, semiotic knowledge of, and fluency with the domain's symbols, before then progressing to combining and manipulating symbols in meaningful ways. In addition, both reading and mathematics require children to reflect on how different elements of information and meaning relate to one another, such as through composing and decomposing words and numbers, or comparing different sounds and quantities. Thus, skills in the two domains seem to share a deep focus on relational thinking.

The result of the rational task analysis, with skills organized by similar deep features, is presented in Table 1. In the sections that follow, I elaborate on the potential relations between symbolic mapping and relational thinking and individual skills in each domain.

Table 1

Hypothesized Shared Deep Features in Reading and Mathematics

Deep Feature	Domain	Domain-specific Skill
Symbolic Mapping		
Mapping Symbols to Labels	Reading	Letter Identification
	Math	Numeral Identification
Mapping Symbols to Referents	Reading	Letter-Sound Knowledge
	Math	Numeral-Quantity Knowledge
Relational Thinking		
Comparative Thinking	Reading	Rhyme Awareness
	Math	Magnitude Comparison
Part-whole Thinking	Reading	Phonological Operations
	Math	Non-symbolic Arithmetic

Symbolic Mapping in Early Reading and Mathematics

Symbols—specifically letters and numerals—are the foundation of both reading and mathematics. Within each domain, children must learn several associations for each symbol, including its visual shape (with both lowercase and uppercase forms for letters), its name, and its referent (i.e., sounds for letters and quantities for numerals). They must then successfully map among these different associations in order to navigate more complex problems (e.g., word reading, arithmetic problems) within each domain. The present study conceptualized symbol learning within each domain as encompassing two main parts: mapping symbols to labels and mapping symbols to referents. Research supports this conceptualization of symbol learning in the two domains and suggests that, for both letters and numbers, children map the name and the referent to the symbol in separate processes and can sometimes struggle to make connections across the different representations (Benoit, Lehalle, Molina, Tijus, & Jouen, 2013; Bialystok, 2000; Bialystok & Martin, 2003; Johnston, Anderson, & Holligan, 1996; McBride-Chang, 1999).

Mapping symbols to labels. Labeling symbols with their names is a critical early skill in both reading and mathematics. Attaching letter names to letter symbols, or letter identification, is one of the strongest predictors of reading performance (Foulin, 2005; Hammill, 2004; Hiebert, Cioffi, & Antonak, 1984; Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004; Snow, Burns, & Griffin, 1998). One meta-analysis found that letter identification before formal schooling and later reading abilities were moderately to highly correlated, with the median correlation from 24 studies being r = 0.56 (SD = 0.12) (National Research Council, 1998). Another study found a correlation as high as r = 0.83 (Stuart, 1995). In many cases the number of randomly presented letters a kindergartner successfully names is nearly as good of a predictor of future reading achievement as an entire standardized assessment (Snow et al., 1998).

Research on numeral identification is less prevalent but has begun to receive more attention in the past decade. Available research suggests that numeral identification is correlated with other measures of mathematical knowledge, such as numerical magnitude estimation (Berteletti, Lucangeli, Piazza, Dehaene, & Zorzi, 2010; Kolkman et al., 2013), and that the speed with which children are able to name Arabic numerals predicts math achievement (Swanson & Kim, 2007). Indeed, some have argued that children's facility with numeral identification in kindergarten and first grade can be a screening tool for future mathematics difficulties (Chard et al., 2005; Lembke & Foegen, 2009). Thus, in both reading and mathematics, mapping symbols to labels is one of the earliest skills acquired and is highly predictive of future proficiency.

Mapping symbols to referents. Beyond simply learning to recognize and name symbols, another critical skill in early reading and mathematics development is mapping between symbols and their referents. Symbols are only meaningful if children understand their relation to their referents. In early reading, this skill entails knowing the sound(s) represented by each letter. Letter-sound knowledge is widely regarded (Byrne, 1998; Foulin, 2005; Stuart & Coltheart, 1998) as foundational to the alphabetic principle, or "the notion that letters in print essentially stand for phonemes in speech" (Foulin, 2005, p. 129). Indeed, mastery of letter-sound knowledge is predictive of reading success (Schatschneider et al., 2004).

In early math, mapping symbols to referents entails understanding the quantity represented by the symbol. Children's ability to link symbols with quantities in early childhood is predictive of their mathematics performance (Krajewski & Schneider, 2009; Krajewski, Schneider, & Niedling, 2008). The ease with which children access quantitative information from numerals and make comparisons between quantities represented by numerals is correlated with their performance on calculation and math fact fluency tasks (Holloway & Ansari, 2009). Indeed, numeral knowledge has been shown to mediate the relation between informal mathematical knowledge and formal mathematical knowledge, but only when knowledge of both numeral name and numeral quantity is present (Purpura, Baroody & Lonigan, 2013). Thus, the ability to understand the meaning conveyed by symbol-referent mappings is critical for both early reading and early mathematics.

On a conceptual level, the shared deep features related to symbolic mapping in the two domains is apparent. Limited correlational research suggests that symbolic knowledge in the two domains is correlated (Matthews, Ponitz, & Morrison, 2009; Piasta, Purpura, & Wagner, 2010; Purpura et al., 2011), and that the processes of acquiring this symbolic knowledge in each domain are parallel (Benoit et al., 2013; McBride-Chang, 1999). Related research by Koponen and colleagues lends support for the possible role of symbolic mapping in early reading and mathematics; their study found that the facility with which children can retrieve associations between visual and verbal information from memory predicted both their word reading and their single digit arithmetic (Koponen, Aunola, Ahonen, & Nurmi, 2007).

Relational Thinking in Early Reading and Mathematics

While symbols may serve as the foundation of both reading and mathematics, relational thinking is also essential for early learning. Relational thinking is broadly defined "the ability to discern meaningful patterns within otherwise unconnected information" (Dumas, Alexander, & Grossnickle, 2013). It entails making comparisons and recognizing similarities and differences between sets of information to discern meaningful relationships, structure, and patterns. Within this broad definition, relational thinking has multiple subcomponents, including analogical reasoning, part-whole thinking, and comparative thinking. Within both early reading and mathematics, children must identify patterns, make comparisons, and reason about how different sounds, quantities, and general concepts relate to each other. Though relational thinking is a nebulous concept encompassing multiple forms, the present study focuses on two types: comparative thinking and part-whole thinking.

Comparative thinking. Both reading and mathematics require children to compare and contrast domain-specific information and input. Children must compare different sounds and quantities with each other in order to identify patterns and distinguish between different sets of information, such as different words and quantities. In early reading, comparative thinking may be critical for phonemic awareness, or more specifically for the ability to recognize similar sounds across words. For example, rhyming tasks require children to compare sounds and recognize similarities across sounds and words, and research suggests that activities involving rhyming promote word learning (Harper, 2011; Read, 2014). Other sound comparison tasks, such as initial phoneme matching tasks, show rapid development during the preschool years and are moderately to strongly correlated with other measures of reading knowledge (Carroll, Snowling, Hulme, & Stevenson, 2003).

Within early mathematics, comparative thinking may be important for accuracy on magnitude comparison tasks. Extensive research has shown that the ability to compare the magnitudes of two Arabic numerals is highly predictive of mathematics performance (Bugden & Ansari, 2011; De Smedt, Verschaffel, & Ghesquiére, 2009; Holloway & Ansari, 2009; Landerl & Kölle, 2009; Sasanguie, De Smedt, et al., 2012; Sasanguie, Göbel, Moll, Smets, & Reynvoet, 2013; Sasanguie, Van den Bussche, & Reynvoet, 2012). Typically this relation is attributed to the ability to access quantitative information from symbols; yet general comparative thinking may also be involved.

Therefore, there is reason to believe that general comparative thinking may play a role in both early reading and early mathematics.

Part-whole thinking. As with comparative thinking, part-whole thinking may be important for both reading and mathematics. Both domains require the combination of units of information (parts) to create new units of meaning (wholes). In early reading, part-whole thinking, like comparative thinking, may be essential to phonemic awareness. Phonemic awareness in early childhood is predictive of concurrent and future reading performance (Adams, 1990; Lundberg, Olofsson, & Wall, 1980; Stanovich, 1986; Tunmer & Nesdale, 1985). In order to understand words as combinations of sounds, children must think about how individual sound units combine and interact to create words. Common assessments of phonemic awareness include tasks such as phoneme blending and deletion. Blending is the ability to combine sounds to create words (e.g., /k/ /æ/ /t/ = *cat*), while phoneme deletion is the ability to remove phonemic segments from words to create new words [e.g., What is *stall* without the /s/? (*tall*)] (Wagner, Torgesen, & Rashotte, 2013). Though these tasks require children to think about how parts of words combine and relate to each other within and across words, the relation between these skills and part-whole thinking has never been assessed in empirical research, to the author's knowledge.

Although its connection with reading is largely unexplored, part-whole thinking is commonly thought of as a requisite for mathematical cognition and problem solving. Early work by Piaget (1965) proposed that part-whole thinking, or recognizing that parts make wholes and wholes are divided into parts, underlies children's basic understanding of number. Part-whole thinking is important for varied tasks such as set counting

(Resnick, 1983) and missing-addend arithmetic problems in early childhood (Sophian & McCorgray, 1994), to fractions (Miura, Okamoto, Vlahovic-Stetic, Kim, & Han, 1999), decimal place value (Hunting, 2003), and proportions (Davis, 2003) in middle childhood and adolescence. Non-symbolic arithmetic tasks, for example, ask children to think about how sets of objects combine, or how a single set is decomposed (Levine, Jordan, & Huttenlocher, 1992). Thus, both reading and mathematics require the ability to compose and decompose domain-specific components of information—sounds and quantities—and would appear to relate to general part-whole thinking.

The Present Study

An analysis of shared deep features between early reading and mathematics and a review of the empirical literature raised the question: what role may symbolic mapping and relational thinking play in early reading and mathematics and the relation between the two domains? And, if symbolic mapping and relational thinking are important across the two domains, what sorts of learning experiences may support the development of these types of cognition? The present research explored these questions through two simultaneous studies: the first investigated the roles of symbolic mapping and relational thinking in early reading and mathematics, and the second explored the extent to which early learning experiences in the home may support the development of not only domain-specific reading and mathematics knowledge, but also domain-general symbolic mapping and relational thinking.

Study 1. The purpose of Study 1 was to explore the relations between symbolic mapping and relational thinking and early skills in reading and mathematics, as well as to ascertain whether these processes contribute to the associations between knowledge in the two domains. There were three research questions.

Research Question 1. Do individual differences in symbolic mapping and relational thinking predict individual differences in reading and mathematics knowledge in preschool children? Does this relation hold after controlling for children's verbal intelligence?

Given my analysis of the shared deep features related to symbolic mapping and relational thinking in early reading and mathematics, I predicted that symbolic mapping and relational thinking would predict both reading and mathematics knowledge. I expected these relations to remain even after controlling for children's verbal intelligence. This pattern of results would provide evidence for the idea that the shared deep features of early reading and mathematics tasks tap specifically into symbolic mapping and relational thinking. Thus, symbolic mapping and relational thinking should support children's success on early reading and mathematics tasks, above and beyond their verbal intelligence.

Research Question 2. Do specific early reading and mathematics skills reflect parallel underlying operations and processes relating to symbolic mapping and relational thinking?

Based on a rational task analysis, I identified specific skills in each domain that were hypothesized to share parallel deep features, as presented previously in Table 1. I predicted that the strongest correlations across domains would be between skills sharing parallel deep features. I also predicted that the skills sharing parallel features would load together in a factor analysis.

Research Question 3. Do symbolic mapping and relational thinking explain the relation between reading and mathematics knowledge in early childhood?

I hypothesized that previously documented relations between reading and mathematics are explained, at least in part, by their shared relations with symbolic mapping and relational thinking. Thus, I predicted that reading and mathematics knowledge would be highly correlated, but that these correlations would be decreased or eliminated when controlling for symbolic mapping and relational thinking.

Study 2. Research has shown significant relations between home learning experiences and children's knowledge in reading and mathematics, as well as children's more general cognitive processes, such as executive functions (Anders et al., 2012; Burgess, Hecht, & Lonigan, 2002; Griffin & Morrison, 1997; LeFevre et al., 2009; Levine et al., 2010; Manolitsis, Georgiou, & Tziraki, 2013; Rhoades, Greenberg, Lanza, & Blair, 2011; Sarsour et al., 2011; Sénéchal & LeFevre, 2002). Given these relations, the purpose of Study 2 was to investigate whether specific home learning experiences might also support symbolic and relational thinking, in turn supporting children's reading and mathematics knowledge. There were two research questions.

Research Question 1. Do symbolic and relational learning experiences in the home predict individual differences in symbolic mapping, relational thinking, and reading and mathematics knowledge?

I predicted that experiences related to symbolic and relational thinking would be more predictive of individual differences in symbolic mapping, relational thinking, and reading and mathematics knowledge than other types of learning experiences, controlling for children's verbal intelligence.

Research Question 2. Do symbolic mapping and relational thinking mediate the relation between home learning experiences and knowledge in reading and math? Do they predict across domains?

I predicted that home learning experiences related to symbolic and relational thinking would predict reading and mathematics knowledge. Moreover, I predicted improved symbolic mapping and relational thinking would mediate the relations between symbolic learning experiences and relational learning experiences and reading and mathematics knowledge.

It was hoped that the present studies would provide insight into the shared features underlying early mathematics and reading skills. This knowledge, in turn, could provide insight into potential mechanisms for supporting young children in mastering both domains. Furthermore, the presented study sought to elucidate the types of learning experiences in early childhood that might provide children with cognitive foundations for future learning.

Chapter 3: Study 1

Method

Participants

Participants in the present study were 86 preschool children recruited from ten preschools in the greater Boston area. An a priori power analysis suggested that a sample size of at least 80 children would provide power of 0.80 across all analyses, with an assumption of a medium effect size of $f^2 = 0.15$ (Soper, 2015). Forty-nine percent of children ($n = 42$) were male, and the mean age was 4 years, 5 months ($SD = 9$ months), with a range from 3 years, 0 months through 5 years, 10 months. Thirty-four percent of children were three years old, 45% were four years old, and 21% were five years old (n's = 29, 39, and 18, respectively).

The majority of children came from advantaged families. Nearly all (92%) of parents were married, and highly educated: collapsing across both parents, the highest parental degree was a doctorate or professional higher degree (i.e., M.D., J.D., or Ph.D.) for 43% of families, a master's degree for 36% of families, a bachelor's for 16% of families, and less than a bachelor's degree for just 5% of families. Half of the sample reported making over $142,500 per year, the maximum category on the parent survey. Dividing the reported income category by the number of people supported by that income, the estimated mean income per-capita was $29,500, with a range from $2,500 through $49,500 (although this value should be interpreted with caution given the high percentage of families earning any amount upwards of $142,500 per year).

Race/ethnicity information, also collected from parent surveys, reflected a moderately diverse group of children, with 61% of children identified as

White/Caucasian, 17% Asian, 7% Hispanic/Latino, 4% Black/African American, 11% biracial, and 1% other races. Sixteen percent of children were dual language learners, coming from homes where English was not the primary language, but attending fully English-speaking preschools and demonstrating facility with completing direct assessments in English. One student was dropped from analyses based on limited English proficiency.

Procedure

In three or four one-on-one sessions with an experimenter, children completed a verbal intelligence assessment and a number of reading, math, symbolic mapping, and relational thinking tasks. The verbal intelligence assessment was administered during session 1 for all children, and the remaining reading, math, symbolic mapping, and relational thinking measures were administered in random order across the following two or three sessions (a fourth session was added in 26% of cases to fit within classrooms' time restrictions or to adjust for the attentional demands of individual children). Sessions were completed within the preschool center at a private table, either in the classroom, the hallway, or a quiet room nearby. In nearly all cases, sessions were completed during center time, group activities, or free play during the morning.

Measures

Children completed a total of 13 measures, summarized below in Table 2.

Table 2

Summary and Description of Measures by Domain

Domain	Task	Description
Verbal Intelligence		
	1. Peabody Picture Vocabulary Test (PPVT-IV)	Point to one of four pictures representing a verbally-stated vocabulary word
Symbolic Mapping		
	2. Wechsler Preschool and Primary Scale of Intelligence (WPPSI-IV) - Animal Coding subtest	Mark certain shapes whenever they see particular animals
	3. *Comprehensive Test of Phonological Processing (CTOPP-2)* -Rapid Object Naming subtest	Name a series of pictures as quickly as possible
Relational Thinking		
	4. WPPSI-IV - Object Assembly subtest	Assemble puzzle pieces as quickly as possible
	5. Odd-One-Out task	Identify which of four shapes does not belong based on color, size, or shape
Reading		
	6 & 7. Letter Identification & Sound	Name letters and give their sounds
	9. Rhyming	Identify words that rhyme
	8. CTOPP-2 Blending & Elision subtests (aka Phonological Operations)	Combine and take away phonemes to form new words
Mathematics		
	10 & 11. Numeral Identification and Give-N	Name numerals and count out the corresponding number of blocks
	12. Magnitude Comparison	Identify which of two numerals or two sets of dots is more
	13. Non-symbolic Arithmetic	Add and subtract blocks to/from hidden sets

Verbal intelligence. As a measure of children's verbal intelligence and language abilities, the *Peabody Picture Vocabulary Test, Fourth Edition*, (PPVT-IV; Dunn & Dunn, 2007), was administered. The PPVT measures individuals' receptive vocabulary and is widely used as a measure of children's verbal intelligence (Altepeter, 1985; Byrne, 1998). In the PPVT-IV, children are asked to point to one of four pictures corresponding with a spoken vocabulary word. Administration typically takes 10-15 minutes. The test has strong psychometric properties: internal consistency reliability $\alpha = 0.94$ and test-retest reliability $\alpha = 0.93$ (Dunn & Dunn, 2007).

Symbolic mapping. Children's general symbolic mapping was assessed through two measures. The first, the *Animal Coding* task of the *Wechsler Preschool and Primary Scale of Intelligence, Fourth Edition*, (WPPSI-IV; Wechsler, 2012), asks children to match animal pictures with basic shapes. A key is provided to show children which shapes to pair with which animals. Children then have two minutes to select the corresponding shape for a series of animal pictures using an ink dauber. They are scored for the number of shapes correctly selected within the given time, minus the number of incorrect shapes selected.

The second measure, the *Rapid Object Naming* subtest of the *Comprehensive Test of Phonological Processing – Second Edition*, (CTOPP-2; Wagner et al., 2013), asks children to name a series of pictures as quickly as they can. This measure was conceptualized as a measure of children's facility with applying verbal labels to visual pictures representing real-word objects (i.e., symbols). Before beginning, children complete a practice round where they are asked to name each of the images and receive feedback from the experimenter. They are then scored based on the amount of time taken to complete the task, with higher scores indicating slower (i.e., poorer) performance.

Performance on the two symbolic mapping tasks was correlated at $r(84) = -0.40$, $p < 0.001$.

Relational thinking. Children's general relational thinking was assessed through two measures. The first, the *Object Assembly* task of the *Wechsler Preschool and Primary Scale of Intelligence, Fourth Edition*, (WPPSI-IV; Wechsler, 2012), asks children to assemble pieces of a puzzle within 90 seconds. Puzzles increase in difficulty until the child cannot complete the puzzle in the time allotted. Children are scored based on the number of successfully conjoined pieces within each puzzle, as well as their time to complete the puzzle.

The second measure of children's relational thinking was the *Odd-One-Out* task (Chalmers & Halford, 2003). The Odd-One-Out task presents children with a series of pictures of four objects, three of which have one or more attributes in common (color, shape, or size), and a fourth that does not share that trait. The child is asked to identify which one is different from the others: "Some of these things are the same. One of them is different. Which one of these is not like the others?" Items ranged in difficulty based on the number of irrelevant dimensions along which the pictures differ, from zero irrelevant dimensions to two irrelevant dimensions. Accuracy on the task has been shown to be correlated with mathematics fluency and numeral comparison (Nosworthy, Bugden, Archibald, Evans, & Ansari, 2013). See Figure 1 below for examples from the task.

Figure 1

Odd-One-Out Task Examples

Practice Round (Relevant Dimension = Shape)

One Irrelevant Dimension (Relevant Dimension = Color)

Two Irrelevant Dimensions (Relevant Dimension = Size)

Performance on the two relational thinking measures was correlated at $r(84) = 0.46$, $p < 0.001$.

Reading and mathematics measures.

Mapping symbols to labels.

Letter identification. Children's ability to map symbols to labels in the context of reading was assessed via letter identification. This task asked children to name a series of randomly presented lowercase and capital letters shown one at a time. The child was shown the letter on a card and asked "What letter is this?" Children were asked either the capital or lowercase version of all 26 letters, with letters randomly selected for each category. Scores were based on the proportion of letters correctly identified. Self-corrects were permitted. Letter identification was assessed simultaneously with letter-sound knowledge, as described two paragraphs below.

Numeral identification. Children's ability to map symbols to labels in the context of mathematics was assessed through numeral identification. This task asked children to produce a number word when shown a numeral. The child was shown a randomly presented numeral on a card and asked "What number is this?" Numerals ranged from 1-15. Children were scored based on the proportion of numerals correctly named. Self-corrects were permitted. Numeral identification was assessed simultaneously with numeral-quantity knowledge, as described two paragraphs below.

Mapping symbols to referents.

Letter-sound knowledge. Children's ability to map symbols to referents in the context of reading was assessed through their letter-sound knowledge, which was administered in conjunction with letter identification. Children were randomly shown all 26 letters, randomly assigned to be capital or lowercase, and asked first to name them (the letter identification task), and then to say what sound they make ("What sound does [x] make?"; the letter-sound knowledge task). If the child misidentified the letter during the letter identification task, he/she was corrected before being asked to say the letter's sound: "Actually, this is [x]. What sound does [x] make?" Reflecting the primary sound pairing children learn, and with the goal of minimizing the likelihood of awarding credit for guessing, only hard sounds were accepted for letters "c" and "g" (as in "cat" and "goat," *not* "celery" and "giant"), and only short forms were accepted for vowels (as in "apple," "egg," "iguana," "octopus," and "umbrella," *not* "ape," "evade," "ice," "open," or "use"). If the child produced any of these secondary sounds for letters, they were given a second chance to produce the primary (i.e., hard or short form) sound. If a child responded by producing a word that starts with the letter, such as saying "apple" when shown the letter "a," they were asked again to say just the sound of that letter. Scores were calculated based on the proportion of letters for which the child produced an acceptable sound.

Numeral-quantity knowledge. Children's ability to map symbols to referents in the context of mathematics was assessed through their knowledge of absolute numerical quantity. The Give-*N* task (Wynn, 1992) asks children to hand a certain number of objects (ranging from 1-6) to the experimenter. The Give-*N* task was administered in conjunction with the numeral identification task. After the child was shown a numeral and asked to identify it, he/she was then asked to count out that number of blocks. If the child misidentified the numeral during the numeral identification task, he/she was corrected before being asked to count out that many blocks: "Actually, this is [x]. Can you count out [x] blocks?" In prior studies using the Give-*N* task, the number was recited out loud to the child; however, in the current study, the numbers were shown as printed numerals in addition to being read out loud. This change in protocol made this task more parallel to the letter-sound knowledge task. Scores were calculated based on the proportion of numerals for which the child produced the correct quantity of blocks.

Comparative thinking.

Rhyme awareness. Children's ability to think comparatively in the context of reading was assessed through their ability to think about how parts of words compare to each other, as measured through their rhyme awareness. Children's ability to recognize rhymes was assessed using an adaptation of the Rhyme Matching task used by Carroll and colleagues (2003). In the Rhyme Matching tasks, children are shown a picture of an object (e.g., a cat) and asked which of two words, shown also as pictures, rhymes with that object (e.g., hat or dog). Following the procedures of Carroll and colleagues (2003), there were 16 trials. In 8 of the trials, the distractor, non-rhyming word was semantically/thematically related to the prompt (e.g., cat – dog), while in the remaining 8 trials, the distractor was phonologically related to the prompt, without rhyming (e.g., bell—ball). Trials were presented in a random order for each child. Trials were randomly ordered for each child. Scores were calculated based on the number of correctly identified rhyme pairs.

Magnitude comparison. Children's ability to think comparatively in the context of mathematics was measured through their accuracy in comparing the magnitudes of numerals and quantities. An adapted version of the Numeracy Screener (Nosworthy et al., 2013) was used. The Numeracy Screener is a paper-and-pencil assessment that asks children to choose the larger number within 56 pairs of numerals and 56 pairs of sets of dots, completing as many as possible within 2 minutes for each section (i.e., numerals and dots). Numerals and quantities range in magnitude from 1-9. The Numeracy Screener is intended for grades K-3; thus the test was adapted to be appropriate for preschool children. Specifically, to reduce fatigue, the time for each section was reduced to 1 minute. Additionally, in cases where children demonstrated difficulty using a pencil, children were given the option to point to the bigger number/quantity, rather than use a pencil to mark it. Children's magnitude comparison scores were calculated as the total number correct minus the number incorrect across the numeral and dot subsections.

Part-whole thinking.

Phonological operations. Children's ability to think about part-whole relationships in the context of reading was assessed through their phonological operations, or phoneme blending and phoneme deletion, capabilities. These tasks were drawn from the *Comprehensive Test of Phonological Processing – Second Edition* (C-TOPP-2; Wagner et al., 2013). The CTOPP-2 is a standardized assessment for individuals aged 4 years through 24 years, 11 months. It includes twelve subtests of phonological measures, including the Phoneme Blending into Words subtest and the Elision subtest that were used in the present study. The Phoneme Blending into Words subtest asks children to listen to individual phonemes and then combine them into words (for instance, combining “c,” “a,” and “t” to form “cat”). The Elision subtest measures phoneme deletion abilities and asks children to delete a specified phoneme from an orally-presented word in order to produce a familiar word (e.g., *what is bold without the /b/ sound?*). For each subtest, a stop point is reached when the child misses 3 items in a row (Wagner et al., 2013). Raw scores from the two subtests were standardized and averaged to compute a phonological operations composite score.

Non-symbolic arithmetic. Children’s ability to think about part-whole relationships in the context of mathematics was assessed using the *Nonverbal Problems* task developed by Levine and colleagues (1992). In this task, the experimenter shows the child a certain number of blocks; covers them and adds or subtracts some; and then asks the child how many blocks there are in total under the cover. Children were given credit for either the production of a set with the correct number of blocks, or for verbally stating the correct sum/difference. There were six addition problems and six subtraction problems, with sums/differences less than or equal to 6. Total number correct across the 12 items was used as each child’s non-symbolic arithmetic score.

Results

Table 3 below presents the overall descriptive statistics of performance across all the measures. Preliminary MANOVA models found no differences by school, gender, race, bilingual household (any exposure to non-English in the home), or SES after controlling for verbal intelligence. Unsurprisingly, when comparing 3-, 4-, and 5-year-olds, there were considerable age group differences, even after controlling for verbal intelligence; thus, age was used as a covariate, in addition to verbal intelligence, throughout all analyses. A table of descriptive statistics by age across the 13 measures can be found in Appendix A.

Table 3

Overall Descriptive Statistics

Task	Score Type	Mean (SD)	Min	Max
PPVT-IV	Raw Score (Ceiling Item-Errors)	92.23 (22.61)	25	136
Symbolic Mapping				
Animal Coding	Raw Score: (Number Correct-Number Incorrect)	19.23 (11.60)	0	45
Rapid Object Naming	Raw Score (Number of Seconds to Complete)	57.09 (18.72)	29	120
Relational Thinking				
Object Assembly	Raw Score (Total correctly joined pieces)	19.05 (7.57)	2	34.5
Odd-One-Out	Number Correct (Max = 26)	18.45 (4.67)	5	26
Reading Measures				
Letter Identification	Number Correct (Max = 26)	20.05 (7.29)	0	26
Letter Sound	Number Correct (Max = 26)	11.56 (7.49)	0	25
Rhyming	Number Correct (Max = 16)	11.97 (3.05)	5	16
Blending & Elision	Blending Raw Score	8.23 (5.26)	0	24
	Elision Raw Score	6.14 (5.06)	0	17
	Mean of Standardized Raw Scores	-0.02 (0.89)	-1.39	2.24
Math Measures				
Numeral Identification	Number Correct (Max = 15)	10.85 (3.82)	1	15
Give-N	Number Correct (Max = 15)	10.09 (4.34)	1	15
Magnitude Comparison	Difference Score (Number Correct – Number Incorrect)	34.59 (20.34)	-10	77
Non-symbolic Arithmetic	Number Correct (Max = 12)	6.71 (3.25)	0	12

Correlational Analyses

A full bivariate and partial (controlling for age and PPVT) correlation matrix is presented in Appendix B. As expected, reading and mathematics knowledge were moderately to highly correlated across nearly all skills measured. Bivariate correlations across domains ranged from $r(84) = 0.37 – 0.74$. The strongest cross-domain correlations were between letter identification and numeral identification, which were bivariately correlated at $r(84) = 0.74$. After controlling for age and verbal intelligence, cross-domain partial correlations ranged from $r(82) = 0.15 – 0.69$, with letter identification and numeral identification again showing the strongest correlation at $r(82) = 0.69$. After controlling for age and verbal intelligence, non-symbolic arithmetic was no longer correlated with letter-sound knowledge ($r(82) = 0.15$) or phonological operations ($r(82) = 0.19$).

Symbolic Mapping and Relational Thinking as Predictors of Reading and Mathematics

To test my first research question (Do individual differences in symbolic mapping and relational thinking predict individual differences in reading and mathematics knowledge in preschool children? Does this relation hold controlling for children's verbal intelligence?), I created composite scores for symbolic, relational, math, and reading skills. First, I checked whether the measures within each intended composite were correlated. The two symbolic mapping measures (Animal Coding and Rapid Object Naming) were correlated at $r(84) = -0.40$, $p < 0.001$, indicating that children with higher scores on the Animal Coding task tended to be faster on the Rapid Object Naming task. The two relational thinking measures (Object Assembly and Odd-One-Out) were correlated at $r(84) = 0.46$, $p < 0.001$. The four reading measures were moderately to highly correlated, with r's ranging from 0.39 – 0.65, all p's < 0.001, and the four math measures were all highly correlated, with r's ranging from 0.53 – 0.72, all p's < 0.001. I then created the composite scores. To do this, I combined the separate measures within each reasoning type and domain type by standardizing children's scores on each task, and then averaging their scores within each reasoning type and domain. (Note: scores for the Rapid Object Naming task were reverse scored before standardizing, such that higher scores corresponded with better performance.)

Bivariate and partial correlations among the four composite scores are presented below in Table 4. As expected, the reading and math composite scores were highly correlated, even after controlling for age and verbal intelligence: $r(81) = 0.67$, $p < 0.001$. Furthermore, as hypothesized, the symbolic and relational composites continued to be correlated with the reading ($r(81) = 0.47$, $p < 0.001$; and $r(81) = 0.33$, $p = 0.002$, respectively) and mathematics ($r(81) = 0.51$, $p < 0.001$; and $r(81) = 0.46$, $p < 0.001$, respectively) composites, even after controlling for age and verbal intelligence.

Table 4

Pearson Bivariate and Partial Correlations, Controlling for Verbal Intelligence and Age

	Symbolic		Relational		Reading	
	Bivariate	Partial	Bivariate	Partial	Bivariate	Partial
Symbolic						
Relational	0.42***	0.15				
Reading	0.62***	0.47***	0.62***	0.33**		
Math	0.65***	0.51***	0.69***	0.46***	0.80***	0.67***

** $p < 0.01$, *** $p < 0.001$ (2-tailed).

After confirming both bivariate and partial correlations among the variables of interest, I ran a series of OLS regressions to explore how these variables were related when modeled simultaneously. Models 1a and 1b measured the relative effects of symbolic and relational thinking on reading and mathematics scores. Models 2a and 2b measured these effects while also controlling for age and verbal intelligence. Regression results are presented in Table 5 below.

Table 5

Standardized OLS Regression Coefficients for Symbolic and Relational Thinking Predicting Reading and Mathematics Skills, Unadjusted and Controlling for Age and Verbal Intelligence

	Unadjusted Model 1		*Adjusted Model 2*	
	Reading	Math	Reading	Math
Age			0.11	0.10
Verbal Intelligence			0.18	0.06
Symbolic	0.43***	0.43***	0.38***	0.40***
Relational	0.44***	0.52***	0.29**	0.43***
R^2	0.54	0.64	0.57	0.65
F	47.68***	72.40***	26.46***	36.65***

** $p < 0.01$, *** $p < 0.001$

The OLS regression results showed that both symbolic and relational thinking were significantly predictive of both reading and mathematics scores, above and beyond the influence of age and verbal intelligence. Without any covariates, the two cognitive composites explained 54% of variance in reading skills and 64% of variance in math skills. In fact, these scores were so strongly predictive of children's reading and mathematics skills that adding verbal intelligence and age to the model did not contribute a significant increase in variance explained in either Model 2a or 2b.

To determine the unique variance accounted for by each cognitive composite, I conducted a series of step-wise regressions. Entering age, verbal intelligence, and symbolic skills first, I found that relational skills contributed an additional 4% of variance explained in reading skills and 9% of variance explained in math skills. On the other hand, entering age, verbal intelligence, and relational skills first, I found that symbolic skills contributed an additional 11% of variance explained in reading skills and 12% of variance explained in math skills. All of these R^2 changes were significant at the $p < 0.01$ level.

Symbolic Mapping and Relational Thinking as Mediators between Verbal Intelligence and Reading and Mathematics

I also considered whether symbolic and relational thinking may serve as mediators between verbal intelligence and reading and mathematics. First, I conducted a series of OLS regressions to measure the relation between verbal intelligence and reading and mathematics. I then added the symbolic and relational composite scores to the models. The results of OLS regressions with verbal intelligence predicting reading and mathematics, before and after adding symbolic and relational thinking composites, are presented in Table 6.

Table 6

Standardized OLS Regression Coefficients for Verbal Intelligence Predicting Reading and Mathematics Skills, Controlling for Age, Without and With Symbolic and Relational Thinking

	Unadjusted Model 1		*Adjusted Model 2*	
	Reading	Math	Reading	Math
Age	0.36***	0.42***	0.11	0.10
Verbal Intelligence	0.36**	0.32**	0.18	0.06
Symbolic			0.38***	0.40***
Relational			0.29**	0.43***
R^2	0.41	0.40	0.57	0.65
F	26.90***	28.10***	26.46***	36.65***

Having observed that the relation between verbal intelligence and reading and math dropped below significance after adding symbolic and relational composites, I tested for mediation using the Hayes (2013) PROCESS macro in SPSS. PROCESS tests for direct and indirect effects and provides bootstrap and Monte Carlo confidence intervals for inferences about indirect effects. Results are presented below in Figure 2 (Reading) and Figure 3 (Mathematics). Analyses found that the relations between verbal intelligence and reading and mathematics were mediated through symbolic and relational thinking. The bias-corrected confidence interval of the standardized indirect effect of verbal intelligence on reading through symbolic and relational thinking, controlling for age, met the standards for statistical significance (bootstrap CI = 0.04 – 0.31). The bias-corrected confidence interval of the standardized indirect effect of verbal intelligence on math, through symbolic and relational thinking, controlling for age, was similar (bootstrap CI = 0.06 – 0.39).

Figure 2

Mediation Model: Verbal Intelligence Predicting Reading, Mediated through Symbolic and Relational Thinking and Controlling for Age

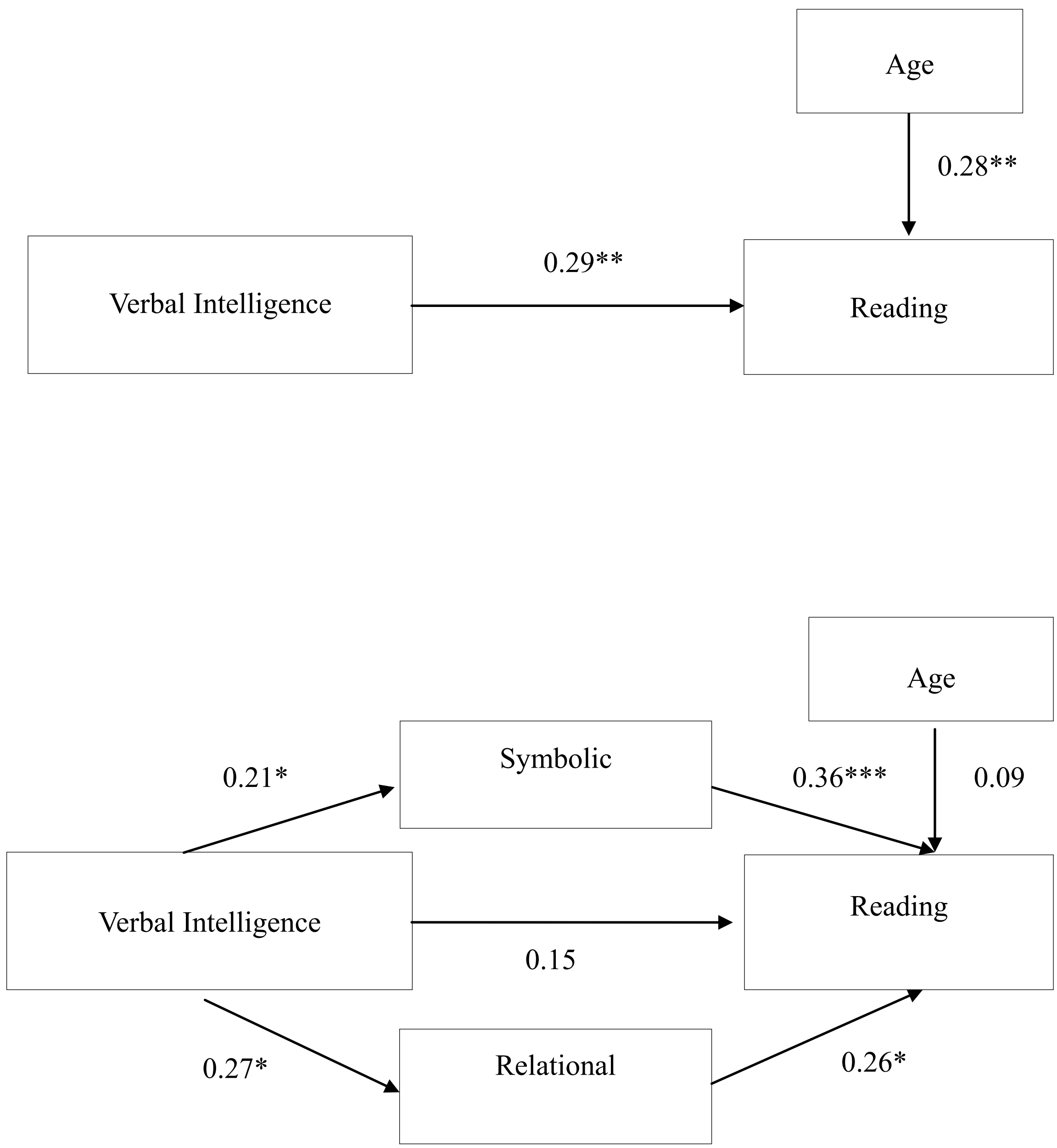
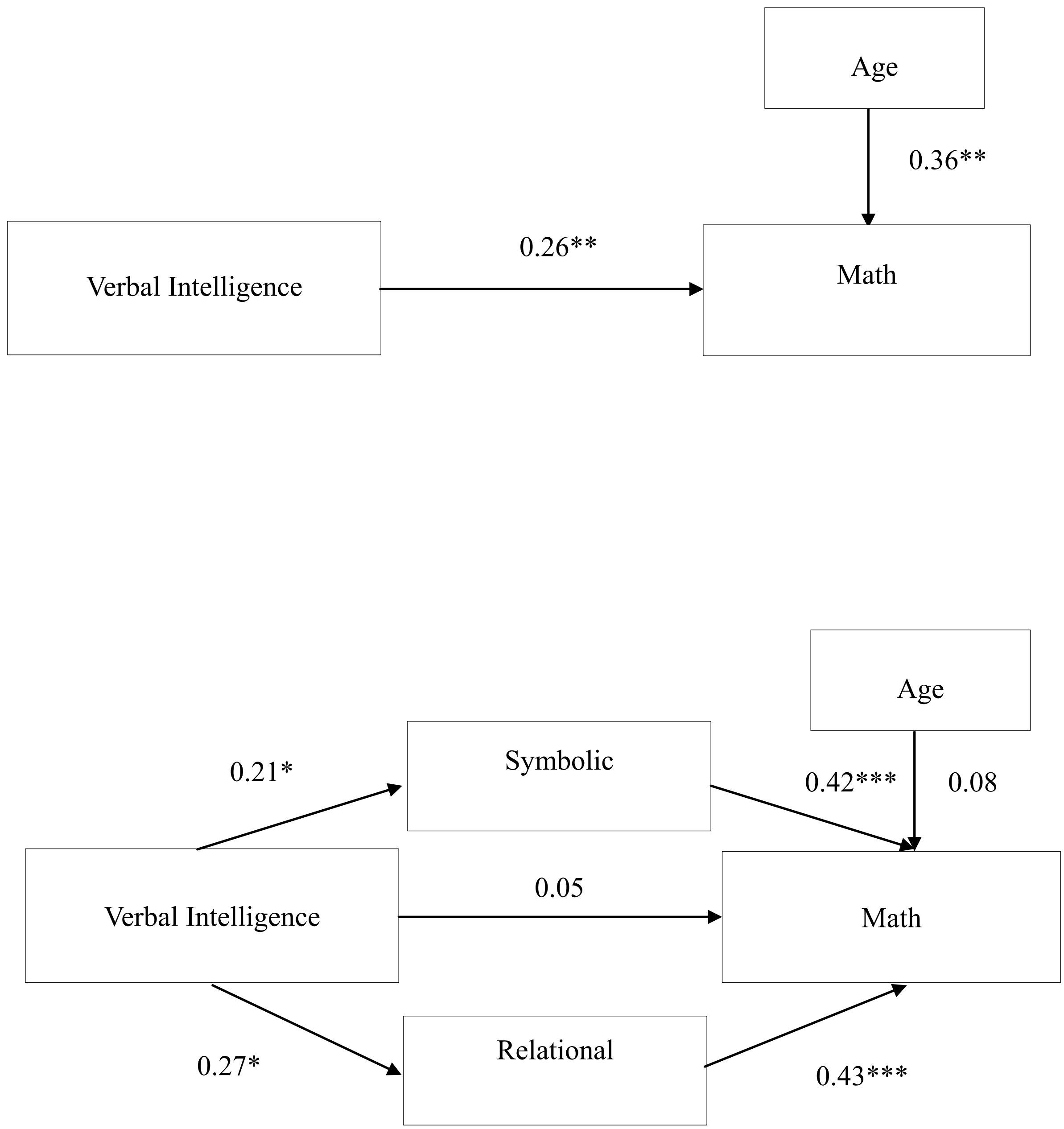


Figure 3

Mediation Model: Verbal Intelligence Predicting Mathematics, Mediated through Symbolic and Relational Thinking and Controlling for Age



Parallel Skills in Reading and Mathematics

To address the second research question (Do specific early reading and mathematics skills reflect parallel underlying operations and processes relating to symbolic mapping and relational thinking?), partial correlations between accuracy on the tasks listed in Table 1, controlling for age and verbal intelligence, were examined. Results are displayed in Table 7 below, with hypothesized parallel skills' correlations highlighted in gray.

Table 7

Partial Correlations between Reading and Mathematics Skills, Controlling for Age and Verbal Intelligence

	Mathematics Skills			
	Num ID	Give-N	Mag Comp	NonSym Arith
Reading Skills				
Letter ID	0.69***	0.51***	0.37***	0.34***
Letter-Sound	0.53***	0.30***	0.45***	0.15
Rhyme	0.29**	0.50***	0.39***	0.38***
Phonological	0.32***	0.33***	0.39***	0.19

Overall correlations did not support the hypothesis that the theorized parallel skills would be more strongly correlated to each other than to other cross-domain skills, with one notable exception: letter and numeral identification, which were correlated at $r(82) = 0.69$. According to the Meng, Rosenthal, and Rubin (1992) method of comparing dependent correlations, letter ID was more strongly correlated with numeral ID than were letter sound ($z = 2.14$, $p = 0.02$), rhyme awareness ($z = 3.73$, $p < 0.001$), or phonological operations ($z = 3.60$, $p < 0.001$). Likewise, numeral identification was more strongly correlated with letter identification than were Give-*N* ($z = 2.41$, $p = 0.01$), magnitude comparison ($z = 3.66$, $p < 0.001$), or non-symbolic arithmetic ($z = 3.71$, $p < 0.001$). In fact, these two skills were even more strongly correlated with each other than they were with some skills within their own domain. Letter identification was more strongly correlated with numeral identification than it was with rhyme awareness ($z = 4.23$, $p < 0.001$) or phonological operations ($z = 3.91$, $p < 0.001$), though not more strongly than with letter-sound ($z = 1.59$, $p = 0.06$). Likewise, numeral identification was more strongly correlated with letter identification than it was with magnitude comparison ($z = 2.23$, $p = 0.01$) or non-symbolic arithmetic ($z = 2.93$, $p = 0.002$), though not more strongly than with Give-*N* ($z = 1.44$, $p = 0.07$).

To further explore relations among the different skills within and across the two domains, an exploratory factor analysis tested how the eight reading and mathematics skills naturally loaded. Using varimax rotation with an Eigenvalue cutoff of 1.00, the exploratory factor analysis revealed a single factor (Eigenvalue = 4.97; $\chi^2(28) = 426.85$, $p < 0.001$), indicating that, despite their separate domains, all eight skills showed loadings of at least 0.71 on a single factor, which explained 62% of all variance. A follow-up reliability analysis found that the eight skills had a Cronbach's alpha of $\alpha = 0.91$.

Even though the exploratory analysis revealed a single factor, it was still possible that forcing a two-factor structure could reveal additional information. To test whether the skills tended to load more strongly by domain (i.e., reading versus math) or by hypothesized deep structure (i.e., symbolic versus relational), a follow-up confirmatory factor analysis, forcing two factors, was conducted. In this analysis, a second factor

(Eigenvalue = 0.86) was extracted, which accounted for an additional 11% of variance. Results of these factor analyses are presented below in Table 8.

Table 8

Exploratory and Confirmatory Factor Analysis Factor Loadings for Children's Reading and Mathematics Skills

	Exploratory	Confirmatory	
		1	2
Letter ID	0.78	0.26	**0.85**
Letter-Sound	0.77	0.28	**0.83**
Rhyme Awareness	0.71	**0.80**	0.19
Phonological Operations	0.77	**0.57**	0.51
Numeral Identification	0.80	0.35	**0.79**
Give-N	0.86	**0.77**	0.44
Magnitude Comparison	0.85	**0.72**	0.47
Non-symbolic Arithmetic	0.76	**0.82**	0.24

Notes: Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.[a]

Factor loading patterns overall provided support for the hypothesized deep structural symbolic and relational similarities underlying skills in the two domains. Three of the four variables hypothesized to require relational thinking loaded strongly on the first factor: rhyme awareness, magnitude comparison, and non-symbolic arithmetic, and the fourth hypothesized relational task, phonological operations, demonstrated a slightly higher loading on factor 1 despite loading moderately on both factors. Likewise, three of the four tasks hypothesized to require symbolic mapping loaded together on the second factor: letter identification, letter-sound knowledge, and numeral identification. Surprisingly, the fourth hypothesized symbolic task, Give-*N*, loaded more strongly on the first factor, contrary to the hypothesis. Nevertheless, Give-*N* was the only task to deviate from hypothesized patterns of factor loadings to reflect structural similarities relating to symbolic mapping and relational thinking, and thus the patterns overall supported the hypothesized parallel deep structures.

I next investigated whether these factor loadings may be reflective of differential roles of symbolic mapping and relational thinking. To test this idea, I saved the factor scores for factors 1 and 2 identified in Table 8, and then conducted OLS regressions, with symbolic mapping and relational thinking predicting children's scores on each of the two factors, controlling for age and verbal intelligence. Results, presented below in Table 9, demonstrated an interesting pattern. Both symbolic mapping and relational thinking were predictive of children's scores on factor 1 (rhyme awareness, phonological operations, Give-N, magnitude comparison, and non-symbolic arithmetic; referred to as "Complex Skills" for simplicity), explaining over half (52%) of the variance in these skills. These relations would be expected based on the nature of the complex tasks, which often required both symbolic knowledge and relational thinking. For example, in order to compare magnitudes of numerals, children would need to understand the quantity represented by the numeral as well as compare across quantities. On the other hand, only symbolic mapping was predictive of children's scores on factor 2 (letter identification, letter sound, and numeral identification; referred to as "Basic Skills"), and it accounted for just 19% of the variance in these skills.

Table 9

Standardized OLS Regression Coefficients for Symbolic Mapping and Relational Thinking Predicting Factor Loadings of Reading and Mathematics Skills, Controlling for Age and Verbal Intelligence

	Factor 1: Complex Skills		*Factor 2: Basic Skills*	
	β	*T*	β	*t*
Age	0.11	1.00	0.05	0.35
Verbal Intelligence	0.12	1.20	0.05	0.41
Symbolic	0.31**	3.48	0.27*	2.30
Relational	0.37**	3.33	0.17	1.18
R^2	0.52		0.19	
F	21.71***		4.62**	

Notes: Factor 1 = Rhyming, Phonological Operations, Give-N, Magnitude Comparison, and Non-symbolic Arithmetic. Factor 2 = Letter Identification, Letter Sound, and Numeral Identification.

* $p < 0.05$, ** $p < 0.01$

Symbolic Mapping and Relational Thinking as the Source of Correlations between Reading and Mathematics

To address my third research question (Do symbolic mapping and relational thinking explain the relation between reading and mathematics knowledge in early childhood?), the first step was to examine how controlling for symbolic mapping and relational thinking affected the relation between reading and mathematics. Thus, I first compared three correlations between the reading and mathematics composites: a partial correlation controlling for age only ($r(83) = 0.72$), a partial correlation controlling for age and verbal intelligence ($r(82)$ =0.67), and a partial correlation controlling for age, verbal intelligence, symbolic mapping, and relational thinking ($r(79) = 0.52$). Thus, controlling for symbolic mapping and relational thinking decreased the partial correlation between reading and math from 0.67 to 0.52, even after already controlling for age and verbal intelligence.

Because statistical methods for comparing correlations do not allow for testing overlapping partial correlations (i.e., comparing r_{xy} and r_{xyz}), I next conducted a series of linear regressions to examine how well the domain scores could predict each other, both with and without the reasoning scores as covariates. The first set of models predicted reading composite scores. Model 1a tested how well math composite scores predicted reading composite scores, controlling for age and verbal intelligence. Model 2a tested how well math composites predicted reading, again controlling for age and verbal intelligence, but also adding in symbolic mapping and relational thinking. The next set of models predicted math composite scores. As with the reading models, Model 1b tested how well reading composite scores predicted math composite scores, controlling for age and verbal intelligence. Likewise, Model 2b predicted how well reading composites predicted math, again controlling for age and verbal intelligence, but also adding in symbolic mapping and relational thinking. Standardized regression coefficients are presented in Table 10.

Regression results showed strong predictive properties of the two composite scores when predicting each other. In both Model 1a and Model 1b, the domain composites were significant predictors of each other, with both math predicting reading, $\beta = 0.67$, $p < 0.001$, as well as reading predicting math, $\beta = 0.68$, $p < 0.001$, above and beyond the effects of age and verbal intelligence. The significantly predictive relationships between the two domains remained even after controlling for symbolic and relational reasoning as well, though somewhat tempered: math's predictive coefficient decreased to $\beta = 0.57$, $p < 0.001$, while reading's predictive coefficient decreased to $\beta = 0.47$, $p < 0.001$. Symbolic mapping and relational thinking were not predictive of reading scores after controlling for age, verbal intelligence, and mathematics scores. On the other hand, controlling for age, verbal intelligence, and reading scores, both symbolic and relational skills were predictive of math performance, with $\beta = 0.23$, $p = 0.003$ and $\beta = 0.30$, $p = 0.001$, respectively.

Table 10

Standardized OLS Regression Coefficients for Reading and Mathematics Domain Composites Predicting Each Other, Without and With Symbolic and Relational Thinking

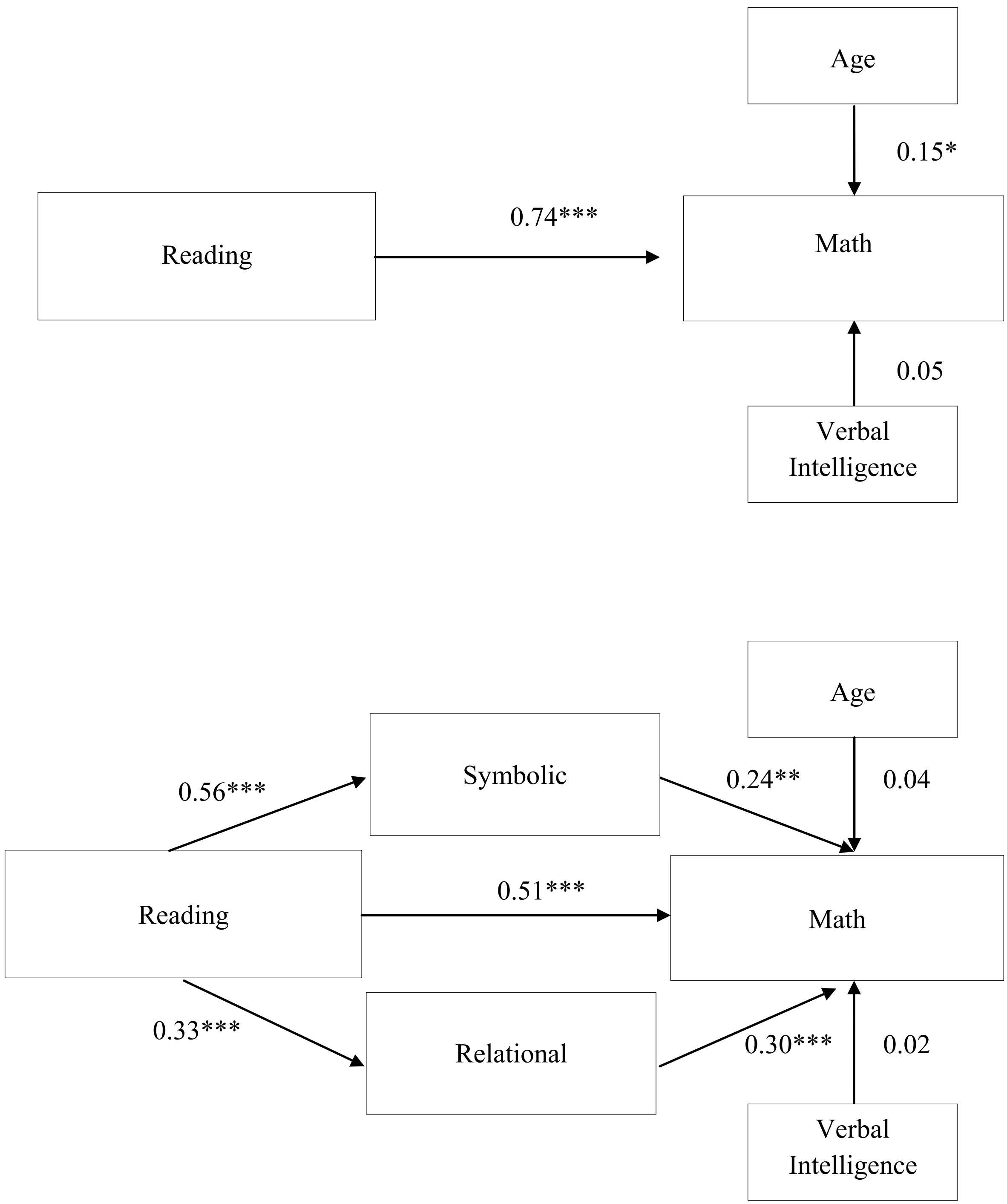
	Model 1a		*Model 2a*	
	β	*t*	β	*t*
Reading				
Age	0.08	0.98	0.06	0.63
Verbal Intelligence	0.17*	2.19	0.15^t	1.81
Symbolic Mapping			0.15^t	1.78
Relational Thinking			0.04	0.43
Math Composite	0.67***	8.26	0.57***	5.34
R^2	0.68		0.68	
F	56.89***		34.12***	
	Model 1b		*Model 2b*	
	β	*t*	β	*t*
Math				
Age	0.18*	2.27	0.05	0.56
Verbal Intelligence	0.06	0.78	-0.03	-0.33
Symbolic Mapping			0.23**	3.06
Relational Thinking			0.30**	3.49
Reading Composite	0.68***	8.26	0.47***	5.34
R^2	0.68		0.74	
F	56.67***		45.08***	

t $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Next, I tested for mediation using the Hayes (2013) PROCESS macro in SPSS. Analyses found no evidence of predictive relation of math with reading being mediated through symbolic and relational thinking, with a bias-corrected confidence interval of the indirect effect of math on reading including the number 0 (bootstrap CI = -0.02 – 0.24). However, there was evidence of mediation in the opposite direction, with the bias-corrected confidence interval of the indirect effect of reading on math, through symbolic and relational thinking, being positive (bootstrap CI = 0.10 – 0.43), and with both symbolic (CI = 0.05 – 0.28) and relational thinking (CI = 0.03 – 0.20) showing individual significant meditational effects. These results are pictured below in Figure 4.

Figure 4

Mediation Model: Reading Predicting Mathematics, Mediated through Symbolic and Relational Thinking, and Controlling for Age and Verbal Intelligence.



Discussion

Overall, results from Study 1 supported the general hypothesis that symbolic and relational thinking would be related to early reading and mathematics. Correlations, regressions, and mediational analyses provided a variety of evidence that these general cognitive skills are predictive of early learning in reading and math. Though both symbolic mapping and relational thinking are often part of larger IQ tests, these two specific general cognitive abilities were more predictive of domain scores than was verbal intelligence, even showing full mediation. These results suggest that prior links between intelligence and reading and mathematics may have been better explained by shared cognitive skills in symbolic mapping and relational thinking. This finding has specific implications for instruction, as it highlights two potential target areas for intervention.

Specific hypothesized parallel skills were somewhat less consistently supported. There was only limited evidence of parallel individual skills across domains that draw from these general cognitive resources similarly. While all four pairs of parallel skills were bivariately correlated, and three of the four pairs of parallel skills across domains were correlated even after controlling for age and verbal intelligence, the strength of these correlations did not reflect the hypothesized patterns that parallel skills would be more strongly correlated than non-parallel skills, with one exception. Namely, numeral identification and letter identification were strongly correlated even after controlling for age, verbal intelligence, symbolic mapping, and relational thinking, and the correlation between these two cross-domain skills was stronger than nearly all other correlations, whether within or across domains. This finding is consistent with prior research showing high correlations between these two skills (e.g., Purpura et al., 2011).

On the other hand, factor analyses provided some support for hypothesized deep structural similarities across domains based on symbolic mapping and relational thinking. Seven of the eight tasks loaded onto the two factors as expected, reflecting symbolic mapping tasks and more relational tasks, with just the Give-*N* task deviating from hypothesized loadings. The Give-*N* task's heavy reliance on counting abilities may explain its deviation from the expected pattern, as it is impossible to extricate symbolic knowledge from counting abilities given the task's design.

In addition, the follow-up analyses with the factor scores raised some important questions about the development of skills being assessed through these tasks. The grouping together of letter identification, letter-sound, and numeral identification as one factor, and all the other skills as another factor, suggests that these three skills are somehow different from the others. Scores on these three variables were predicted by children's general symbolic abilities, supporting the hypothesis that these are symbolic skills that would tap into general symbolic mapping abilities. Nevertheless, the general symbolic composite score, in addition to age and verbal intelligence, accounted for just a small portion (19%) of the total variance in scores on these three tasks. One possible explanation for this pattern is that learning letters, letter sounds, and number names are common activities in preschool classrooms and home learning activities, and thus performance on these tasks may be more influenced by experiences in the classroom or home. On the other hand, other skills like mapping numerals to quantities, comparing sounds and quantities, and performing operations with sounds and quantities—which all loaded together on factor 1—may be less emphasized in the classroom and instead may rely more on symbolic and relational thinking abilities. Supporting this interpretation, both general relational and general symbolic score composites showed strong, independently predictive relations with children's scores on factor 1. If these interpretations are correct, Study 2 could provide supporting information on whether skills on factor 2 are more strongly predicted by learning experiences than are scores on factor 1.

Finally, results pertaining to my third research question partially supported my hypothesis that symbolic mapping and relational thinking would mediate the relations between reading and mathematics knowledge. Mediational analyses found that symbolic mapping and relational thinking partially mediated the relation between reading composite scores and mathematics composite scores, above and beyond the influence of age and verbal intelligence. This result suggests that prior connections between early reading and early mathematics skills may have been the reflection of their shared reliance on symbolic mapping and relational thinking. In contrast, however, there was no evidence of the same relation in the opposite direction, with no mediation by symbolic mapping and relational thinking in the relation between mathematics knowledge and reading scores. These inconsistent results for research question 3 likely reflect the fact that both symbolic mapping and relational thinking were more strongly and consistently related to mathematics scores than to reading scores. In fact, adding the two general composite scores explained no additional variance in reading scores above and beyond the influence of mathematics scores.

Overall, the results of Study 1 provide new information about two potentially malleable skills for early success in reading and mathematics, but patterns suggested a stronger role in early mathematics than in early reading. For example, after controlling for age, verbal intelligence, and reading abilities, both symbolic and relational thinking continued to be predictive of early mathematics. The same relation did not persist in reading: after controlling for age, verbal intelligence, and math abilities, neither symbolic nor relational thinking were predictive of early reading. One potential explanation for this pattern may be that children are exposed to more instructional activities directly related to reading than to mathematics. Thus, instruction may compensate for individual differences in symbolic and relational thinking. On the other hand, children may be exposed to fewer or less diverse mathematical learning experiences. Therefore, the acquisition of mathematical skills may either be the product of a rich array of activities that develop symbolic, relational, and mathematical thinking simultaneously; or children may need to possess high symbolic and relational abilities to be able to glean mathematical knowledge from reduced or lower quality activities as compared to those related to reading. The present study precludes any definite conclusions on this point, but Study 2 poses the potential to elucidate the role of home learning experiences in supporting early reading, math, and symbolic and relational thinking.

Chapter 4: Study 2

Method

Participants

Participants in Study 2 were the 86 parents of children from Study 1 (the child's mother in 84% of cases). As previously stated, nearly all parents were married (92%), and highly educated: collapsing across both parents, the highest parental degree was a doctorate or professional higher degree (i.e., M.D., J.D., or Ph.D.) for 43% of families, a master's degree for 36% of families, a bachelor's for 16% of families, and less than a bachelor's degree for just 5% of families. Half of the sample reported earning a household income of over $142,500 per year, the maximum category on the parent survey. Dividing the reported income category by the number of people supported by that income, the estimated mean income per-capita was $29,500, with a range from $2,500 through $49,500 (although this value should be interpreted with caution given the high percentage of families earning any amount upwards of $142,500 per year).

Procedure and Measure

When completing the consent form for Study 1, parents also completed a parent survey. The survey consisted of two sections. To investigate the extent to which specific home learning experiences may support children's development in symbolic mapping, relational thinking, and reading and mathematics, the first section asked parents to report on how frequently they engage in 45 learning activities with their children. Many of the activities were drawn or adapted from LeFevre and colleagues' (2009) survey, while others were newly created for the present study. Activities related to early reading and early mathematics, as well as general learning experiences, such as identifying colors or watching educational television programs. A subset of questions related specifically to activities that may promote symbol learning (18 items; e.g., “identify the names of written numbers” or “talking about street signs or traffic lights”) and relational thinking (14 items; e.g., “sort things by color, size, or shape” or “comparing numbers of objects”). Parents were asked to report the frequency with which they engage in these activities on a 5-point Likert scale (from 0 = Never to 4 = Almost Daily).

Table 11 presents the 45 activities by activity category: Reading, Math, Symbolic, Relational, and Other. Because in the real world many activities incorporate multiple different topics and skill sets, items could double load onto more than one category.

Table 11

Hypothesized Activity Groupings

	Read	Math	Sym	Rel	Oth
1.Reading/reciting stories/poems that rhyme	x			x	
4. Telling bedtime stories	x				
9. Going to the library	x				
17. Identifying names of written alphabet letters	x		x		
18. Identifying sounds of alphabet letters	x		x		
28. Singing the ABCs	x				
36. Comparing characters in books	x			x	
40. Identifying words that rhyme or sound similar	x			x	
41. Reading picture books	x				
42. Printing letters	x		x		
3. Playing with number & letter blocks, magnets, etc.	x	x	x		
34. Playing card games with numbers or letters	x	x	x		
13. Counting objects		x			
14. Counting without objects		x			
23. Comparing prices while shopping		x		x	
26. Practicing sharing fairly		x		x	
29. Comparing numbers of objects		x		x	
38. Requesting a number of objects		x			
6. Counting down (10, 9, 8, 7. . .)		x			
7. Learning sums (e.g., 1+1=2)		x			

16. Measuring ingredients when cooking		x			
2. Identifying names of written numbers		x	x		
22. Reading prices while shopping		x	x		
8. Printing numbers		x	x		
45. Talking about values of coins		x	x		
30. Comparing written numbers		x	x	x	
37. Matching written numbers with groups of objects		x	x		
44. Identifying names of coins		x	x		
39. Playing board games with a die or spinner			x		
43. Identifying brand logos			x		
11. Playing “store” or “teacher”			x		
15. Talking about street signs or traffic lights			x		
25. Identifying icons on apps or computers			x		
21. Using maps			x	x	
12. Making general comparisons				x	
19. Talking about analogies				x	
20. Playing with puzzles				x	
5. Sorting things by size, color or shape				x	
27. Building Legos or with other blocks				x	
32. Recognizing and creating patterns				x	
10. Singing songs					x
31. Playing with “Play-Doh” or clay					x
24. Watching educational TV shows					x
33. Learning/recognizing shapes					x
35. Identifying colors					x
Total:	12	17	18	14	5

Following the questions on learning activities, an additional set of questions asked parents to rate the importance of 8 benchmark skills for kindergarten readiness. The survey asked parents, “In your opinion, how important is it for children to reach the following benchmarks prior to entering kindergarten?” with a five-point Likert scale ranging from 0 = “Not important” through 4 = “Very Important.” Four of the skills related to math: “Count to 10,” “Count to 100,” “Identify/recognize written numbers,” and “Simple sums (*ex.* 1 + 1 = 2).” The other four items related to reading: “Rehearse the alphabet," "Identify/recognize alphabet letters," "Print name," and "Print alphabet letters." These 8 items were drawn from LeFevre et al. (2009).

In the second section, parents reported demographic information, such as their educational background and socioeconomic status. The full parental questionnaire can be found in Appendix C.

Results

Preliminary analyses found no overall relations between frequency of activities reported and parental level of education, income, non-English language use in the home, race, or whether the respondent was the mother or father. Thus, to maximize parsimony, these variables were not included in the following analyses. Based on their known associations with children's scores from Study 1, child age and verbal intelligence were again used as covariates in models.

Benchmarks

Parents overall thought it was more important for children to meet the various reading benchmarks than the mathematics benchmarks. Out of a maximum of 4, the mean across the four reading benchmarks was 3.59 (SD = 0.59), while the mean across the four mathematics benchmarks was 3.16 (SD = 0.67). A paired samples t-test comparing these two means found a significant difference, t (79) = 7.36, $p < 0.001$. The individual benchmark item means are presented below in Table 12.

Table 12

Parents' Ratings of the Importance of Reading and Mathematics Benchmarks for Kindergarten Readiness

	Mean (SD)	Minimum	Max
Count to 10	3.96 (0.25)	2	4
Count to 100	2.43 (1.24)	0	4
Identify/recognize written numbers	3.56 (0.73)	1	4
Simple sums	2.68 (1.15)	0	4
Rehearse the alphabet	3.70 (0.66)	1	4
Identify/recognize alphabet letters	3.70 (0.64)	1	4
Print name	3.58 (0.77)	0	4
Print alphabet letters	3.38 (0.83)	0	4

Activities – Psychometric Analyses and Scale Construction

Descriptive statistics for all 45 activities can be found in Appendix D. Five of the 45 activities were included only to broaden the range of activities listed beyond just reading, math, symbolic, and relational domains (e.g., singing songs, learning colors) and were omitted from analyses. One item was reported as "never" occurring by the majority of parents ["Comparing prices while shopping (e.g. which costs more?)"], and was also excluded from analyses. The reliability among the remaining 39 items was quite high ($\alpha = 0.92$).

The first step was to check psychometric properties of the items hypothesized to reflect symbolic, relational, reading, and math activities. Initial analyses suggested some items were not correlating well with the rest of their scales. Within the symbolic activities scale, the item-total correlation for “Identifying icons on apps or computer software” was just $r = 0.21$, suggesting poorness of fit between this item and the rest of scale (Everitt, 2002). Compared to other items, this item would have the least effect on the scale’s variance if deleted and would also increase the scale’s alpha. Further analyses identified “Talking about street signs or traffic lights” to have both low item-total reliability ($r = 0.31$), to have minimal effect on the scale’s variance if deleted, and no effect on the scale’s reliability if deleted. Therefore, to improve the uniformity of the scale, these two items were dropped, resulting in a final scale consisting of 16 items with a reliability of $\alpha = 0.86$.

Within the relational activities scale, the same psychometric analyses identified “Reading/reciting stories/poems that rhyme” as having low item-total correlation ($r = 0.29$) and minimal impact on the scale’s variance and reliability if deleted. Therefore, this item was removed from the scale, resulting in a final scale consisting of 12 items with a reliability of $\alpha = 0.82$. (Please note, however, that this item was not deleted from the reading scale.)

Within the reading activities scale, three items were found to be problematic. The items “Reading picture books,” “Telling bedtime stories,” and “Printing letters” all had low item-total correlations (r’s = 0.16, 0.18, and 0.20, respectively), and all would have minimal effect on the scale’s variance and would increase reliability if deleted. Thus, they were deleted from the scale, resulting in a final scale consisting of 9 items with a reliability of $\alpha = 0.73$. (Please note, however, that the “Printing letters” item was not deleted from the symbolic scale.)

Finally, within the math activities scale, one item, "Counting without objects," was found to have low item-total correlation (r = 0.29), and minimal impact on the scale's variance and no impact on reliability if deleted. Thus, this item was removed from the composite score, resulting in a final scale consisting of 16 items with a reliability of α = 0.85.

Final activity groupings can be found in Table 13.

Table 13

Final Activity Groupings

	Read	Math	Sym	Rel	Oth
1.Reading/reciting stories/poems that rhyme *(dropped RL[1])*	x				
4. Telling bedtime stories					
9. Going to the library	x				
17. Identifying names of written alphabet letters	x		x		
18. Identifying sounds of alphabet letters	x		x		
28. Singing the ABCs	x				
36. Comparing characters in books	x			x	
40. Identifying words that rhyme or sound similar	x			x	
41. Reading picture books *(dropped)*					
42. Printing letters *(dropped RD[2])*			x		
3. Playing with number & letter blocks, magnets, etc.	x	x	x		
34. Playing card games with numbers or letters	x	x	x		
13. Counting objects		x			
14. Counting without objects *(dropped)*					
23. Comparing prices while shopping (*dropped)*					
26. Practicing sharing fairly		x		x	
29. Comparing numbers of objects		x		x	
38. Requesting a number of objects		x			
6. Counting down (10, 9, 8, 7. . .)		x			
7. Learning sums (e.g., 1+1=2)		x			
16. Measuring ingredients when cooking		x			
2. Identifying names of written numbers		x	x		
22. Reading prices while shopping		x	x		
8. Printing numbers		x	x		
45. Talking about values of coins		x	x		
30. Comparing written numbers		x	x	x	

37. Matching written numbers with groups of objects		x	x		
44. Identifying names of coins		x	x		
39. Playing board games with a die or spinner			x		
43. Identifying brand logos			x		
11. Playing "store" or "teacher"			x		
15. Talking about street signs or traffic lights *(dropped)*					
25. Identifying icons on apps or computers *(dropped)*					
21. Using maps			x	x	
12. Making general comparisons				x	
19. Talking about analogies				x	
20. Playing with puzzles				x	
5. Sorting things by size, color or shape				x	
27. Building Legos or with other blocks				x	
32. Recognizing and creating patterns				x	
10. Singing songs *(dropped)*					
31. Playing with "Play-Doh" or clay *(dropped)*					
24. Watching educational TV shows *(dropped)*					
33. Learning/recognizing shapes *(dropped)*					
35. Identifying colors *(dropped)*					
Total:	9	16	16	12	0

1. This item was dropped from the Relational scale only.
2. This item was dropped from the Reading scale only.

Activities – Descriptive Statistics

Overall, parents reported being very active in learning activities with their children. Out of the 34 items remaining after psychometric analyses and scale creation, parents reported engaging in 6.94 (*SD* = 5.17) activities on an "almost daily" basis. Table 14 presents the top six most common learning activities, all of which had a mean greater than 2.90, and the bottom six learning activities, all of which had a mean of less than 1.50. The most common activity reported by parents was "reading/reciting stories and poems that rhyme" (*M* = 3.47, *SD* = 1.01), followed closely by "counting objects" (*M* = 3.45, *SD* = 0.76). The least common learning activities were "reading prices while shopping” (*M* = 0.91, *SD* = 1.01) and “talking about values of coins” (*M* = 1.04, *SD* = 1.07).

Table 14

Most and Least Frequent Learning Activities

Activity	Mean (SD)	Min	Max
Reading/reciting stories and poems that rhyme	3.47 (1.01)	0	4
Counting objects	3.45 (0.76)	1	4
Identifying names of written alphabet letters	3.09 (0.97)	0	4
Identifying sounds of alphabet letters	2.99 (0.93)	0	4
Practicing sharing fairly	2.93 (1.27)	0	4
Building with Legos or other blocks	2.93 (0.99)	0	4
Playing board games with die or spinner	1.44 (1.18)	0	4
Going to the library	1.22 (0.87)	0	4
Identifying names of coins	1.21 (1.20)	0	4
Using maps	1.09 (1.06)	0	4
Talking about values of coins	1.04 (1.07)	0	4
Reading prices while shopping	0.91 (1.01)	0	4

On average, parents reported engaging in reading activities more often than math activities. The mean frequency across the 9 reading activities was 2.40 (*SD* = 0.59), while the mean frequency across the 16 math activities was 2.00 (*SD* = 0.64). A paired samples *t*-test found a significant difference between these two means, $t(85) = 7.68$, $p < 0.001$. Parents were also more likely to engage in relational activities than symbolic activities.

The mean frequency across the 12 relational activities was 2.28 (*SD* = 0.66), compared to a mean of 1.87 (*SD* = 0.67) for the 16 symbolic activities. A paired samples *t*-test found a significant difference between these two means, $t(85) = 8.96$, $p < 0.001$.

Research Question 1 - Using Activity Composite Scores to Predict Child Outcomes

To address my first research question in Study 2 (Do symbolic and relational learning experiences in the home predict individual differences in symbolic mapping, relational thinking, and reading and mathematics knowledge?) I needed to calculate four activity composites for each parent's responses on the home questionnaire: symbolic, relational, reading, and mathematics activities. To create composite scores for each grouping of activity, I first standardized each item and then took the mean of the standardized scores within each group of activities.

Symbolic and relational skills. First, I used these activity composite scores to predict children's scores on the symbolic and relational tasks from Study 1. Table 15 below presents results from OLS regressions predicting symbolic and relational thinking in children. Controlling for children's age and verbal intelligence, composite scores of parents' frequency of engaging in symbolic and relational activities failed to predict children's symbolic and relational thinking scores. In fact, adding the activity composites to the models explained zero additional variance in symbolic scores and just 1% of variance in relational scores. Therefore, my hypothesis that greater exposure to symbolic and relational activities in the home would predict higher symbolic and relational scores was not supported.

Table 15

Standardized OLS Regression Coefficients for Parental Symbolic and Relational Activity Composites Predicting Symbolic and Relational Thinking in Children

	Model 1a		*Model 2a*	
	B	*T*	β	*t*
Symbolic Thinking				
Child Age	0.29*	2.54	0.29*	2.34
Child Verbal Intelligence	0.25*	2.20	0.23t	1.79
Symbolic Activities			0.01	0.03
Relational Activities			0.03	0.19
R^2	0.22		0.22	
F	11.55***		5.67***	
	Model 1b		*Model 2b*	
	B	*T*	β	*t*
Relational Thinking				
Child Age	0.53***	5.89	0.52***	5.32
Child Verbal Intelligence	0.27**	3.06	0.31**	3.12
Symbolic Activities			-0.05	-0.39
Relational Activities			-0.04	-0.27
R^2	0.49		0.50	
F	39.79***		19.91***	

t $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Reading and mathematics skills. Next, I tested whether frequency of the various types of learning activities predicted children's reading and mathematics scores. To start, I tested the relations between reading and mathematics activities and children's reading and mathematics scores. Results from two OLS regression models are presented below in Table 16. Surprisingly, there were no relations between frequency of either reading or math activities and children's reading and math scores, controlling for children's age and verbal intelligence. Adding these activity composites to the models explained just 1% additional variance in both reading and mathematics scores.

Table 16

Standardized OLS Regression Coefficients for Parental Reading and Mathematics Activity Composites Predicting Reading and Mathematics Skills in Children

	Model 1a		*Model 2a*	
	β	*T*	β	*t*
Reading				
Child Age	0.36***	3.74	0.42***	4.03
Child Verbal Intelligence	0.38***	3.94	0.36**	3.51
Reading Activities			0.19	1.49
Math Activities			-0.09	-0.70
R^2	0.41		0.42	
F	28.28***		14.87***	
	Model 1b		*Model 2b*	
	β	*T*	β	*t*
Math				

Child Age	0.42***	4.34	0.43***	4.12
Child Verbal Intelligence	0.32**	3.29	0.35**	3.37
Reading Activities			0.04	0.34
Math Activities			-0.12	-0.86
R^2	0.40		0.41	
F	28.10***		14.10***	

t $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Next I considered whether symbolic and relational activities may predict reading and mathematics directly. OLS regression analyses showed a significant, positive relation between symbolic activities and reading performance, $\beta = 0.30$, $p = 0.04$, but not with math performance, $\beta = 0.16$, $p = 0.27$. There were no significant relations between relational activities and reading or math scores. These results are presented in Table 17 below.

Table 17

Standardized OLS Regression Coefficients for Parental Symbolic and Relational Activity Composites Predicting Reading and Mathematics Skills in Children

	Model 1a		*Model 2a*	
	β	*T*	β	*t*
Reading				
Child Age	0.36***	3.74	0.30**	2.86
Child Verbal Intelligence	0.38***	3.94	0.37**	3.56
Symbolic Activities			0.30*	2.09
Relational Activities			-0.17	-1.19

R^2	0.41		0.44	
F	28.28***		15.87***	
	Model 1b		*Model 2b*	
	β	*T*	β	*t*
Math				
Child Age	0.42***	4.34	0.37**	3.47
Child Verbal Intelligence	0.32**	3.29	0.34**	3.28
Symbolic Activities			0.16	1.11
Relational Activities			-0.17	-1.16
R^2	0.40		0.41	
F	28.10***		14.32***	

t $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Factors identified in Study 1. Finally, to fully understand the possible influence of home activities on children's reading and mathematics skills, parental activity composite scores were used to predict children's scores on the two factors identified in Study 1. Factor 1 encompassed a broad array of skills, including rhyme awareness, phonological operations, Give-N, magnitude comparison, and non-symbolic arithmetic. This factor will be referred to as "Complex Skills" for simplicity. Factor 2, on the other hand, consisted of more conventional reading and mathematics skills typically targeted in early learning, including letter identification, letter-sound knowledge, and numeral identification. This factor will be referred to as "Basic Skills." Results from Study 1 led to the hypothesis that factor 2 "Basic Skills" scores would be more strongly predicted by learning experiences than would factor 1 "Complex Skills" scores.

To test the potential influence on parental activities on these factors of child skills, I conducted series of OLS regressions, with activity composites predicting children's factor scores, controlling for age and verbal intelligence. Again, reading and math activity composites showed no relations with children's scores on the two factors. However, there were interesting patterns with the symbolic and relational activity composites. The results from these analyses are presented below in Table 18. Specifically, the frequency of symbolic activities in the home was positively predictive of children's scores on Factor 2, the Basic Skills factor consisting of letter identification, letter-sound knowledge, and numeral identification. On the other hand, there were no relations between frequency of symbolic or relational activities in the home and children's scores on the broad array of skills loading onto Factor 1. This pattern of results supports the interpretation of results from Study 1 that hypothesized that certain skills may rely more strongly on symbolic and relational thinking because these skills receive less direct support in learning activities in the home and classroom.

Table 18

Standardized OLS Regression Coefficients for Parental Symbolic and Relational Activity Composites Predicting Reading and Mathematics Factor Scores from Study 1

	Model 1a		*Model 2a*	
	B	*t*	β	*t*
Factor 1 (Complex Skills)				
Child Age	0.40***	3.93	0.42***	3.76
Child Verbal Intelligence	0.30**	2.94	0.30**	2.74
Symbolic Activities			-0.11	-0.72

Relational Activities			0.06	0.36
R^2	0.36		0.36	
F	22.80***		11.37***	
	Model 1b		*Model 2b*	
	β	*t*	β	*t*
Factor 2 (Basic Skills)				
Child Age	0.19	1.60	0.08	0.62
Child Verbal Intelligence	0.22	1.87	0.23	1.82
Symbolic Activities			0.46**	2.69
Relational Activities			-0.32	-1.84
R^2	0.12		0.20	
F	5.78**		4.94**	

t p < 0.10, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Research Question 2 – Symbolic Mapping and Relational Thinking as Mediators between Home Learning Experiences and Children's Outcomes

Unfortunately, because none of the home learning composites predicted individual differences in symbolic mapping or relational thinking scores, I was unable to test for the mediation effect hypothesized for research question 2 (Do higher symbolic mapping and relational thinking mediate the relation between home learning experiences and knowledge in reading and math? Do they predict across domains?). Mediation analyses require relations between the independent variables (in this case, home learning activities) and the mediator variables (symbolic and relational thinking) in order to calculate indirect effects (Baron & Kenney, 1986). In the present data, however, there was no evidence of this relation. In fact, when simultaneously entering both symbolic and relational activity composites, as well as children's symbolic mapping and relational thinking scores, into OLS regressions to predict children's reading and mathematics skills, beta coefficients were virtually unchanged compared to models with just activity composites (i.e., Table 17) or just children's symbolic mapping and relational thinking composites (i.e., Table 5 from Study 1). This pattern of results is to be expected given the lack of relation between learning activities and children's symbolic and relational thinking scores and suggests that activity composites and domain-general cognitive scores were orthogonal dimensions predicting children's reading and mathematics knowledge.

Controlling for Total Average Frequency of Parental Activities

Given the rather low variance explained by many of the models presented above, I conducted further analyses to better understand relations between home learning experiences and child outcomes. The idea of total average reported frequency of parental activities arose over two concerns. The first concern was that some parents may not have been very discerning in evaluating *relative* frequency of different activities and may have answered high across the items as a version of social desirability bias, or the tendency to answer research questions in a manner that others would view favorably. The second concern related to the idea of deliberate tradeoffs in prioritizing certain kinds of activities. Because parents' time is limited, there may be strategic benefits to focusing on specific kinds of activities and not engaging in others. Doing so would allow parents to devote greater time and attention to certain kinds of activities. If so, perhaps it is less a matter of absolute frequency and more a matter of relative frequency, or proportion, of different kinds of activities.

To address these two concerns, I explored whether controlling for total average reported frequency of parental activities might change relations between home activities and children's scores. I first created a composite score for total average reported activity frequency by standardizing each of the 39 activities and then taking the mean across all items. After adding this total average activity frequency composite score to the models, one notable change occurred. Supporting the idea of tradeoffs, there was a negative relation between total activities and a positive relation between symbolic activities and children's math scores when the two were entered simultaneously. In other words, controlling for total activities pushed the role of symbolic activities to significance in predicting math scores. Table 19 below presents these results for math outcomes. On the other hand, controlling for total activities had no effect on the relation between symbolic activities and children's reading skills, which was significant both with ($\beta = 0.59$, $p = 0.009$) and without ($\beta = 0.30$, $p = 0.04$) controlling for total involvedness.

Table 19

Standardized OLS Regression Coefficients for Parental Symbolic and Relational Activity Composites Predicting Mathematics Skills in Children, Controlling for Total Parental Activity Average Frequency

	Model 1		*Model 2*	
	β	*t*	B	*T*
Math				
Child Age	0.37***	3.47	0.30**	2.80
Child Verbal Intelligence	0.35**	3.28	0.37***	3.63
Symbolic Activities	0.16	1.11	0.71***	2.75
Relational Activities	-0.17	-1.16	0.43	1.55
Total Parental Activities			-1.11*	-2.54
R^2	0.41		0.46	
F	14.32***		13.52***	

t p < 0.10, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Parental Beliefs about Importance of Benchmarks

Finally I considered whether parental beliefs about the importance of reading and mathematics benchmark skills for kindergarten readiness might be related to children's reading and math scores. To investigate this possibility, I created two composite scores for parents' beliefs about the importance of reading and mathematics. Each composite score was created by standardizing the four items related to each domain (reading and mathematics) and then taking the average. Thus, each parent had two composite scores: beliefs about the importance of reading and beliefs about the importance of mathematics.

First, I explored whether parental beliefs were predictive of parents' frequency of engaging in various types of activities. A series of OLS regressions, controlling for age and verbal intelligence, found that beliefs about the importance of math, but not reading, were predictive of the frequency of total activities, symbolic activities, relational activities, reading activities, and math activities, with betas ranging from $\beta = 0.33 - 0.45$, and *p*'s ranging from 0.001 – 0.02. Thus, parents who believed math skills were more important also reported engaging in more learning activities, of all types, in the home.

Next, I tested whether parents' beliefs about the importance of reading and mathematics were predictive of children's reading and math scores. Interestingly, parents' beliefs about math consistently positively predicted children's reading and math skills, but beliefs about reading did not. In fact, beliefs about the importance of math were a stronger predictor than not only reading beliefs, but most activity measures as well. Beliefs about math were predictive even when considered simultaneously with the frequency of symbolic and relational activities or reading and math activities. Table 20 below presents the models with beliefs predicting children's reading and math scores, before and after controlling for symbolic and relational activities. Beliefs about math appeared to predict reading and math scores above and beyond the role of learning activities, with the value of the standardized coefficient for beliefs about mathematics either remaining roughly the same or even increasing after controlling for symbolic and relational activities.

Table 20

Standardized OLS Regression Coefficients for Parental Beliefs about Importance of Reading and Mathematics Predicting Reading and Mathematics Skills in Children, Controlling for Symbolic, Relational, and Total Activity Frequency

	Model 1a		*Model 2a*	
	β	*t*	β	*t*
Reading				
Child Age	0.38***	4.11	0.30**	2.89
Child Verbal Intelligence	0.35**	3.53	0.37**	3.61
Reading Importance Beliefs	-0.05	-0.40	-0.07	-0.57
Math Importance Beliefs	0.24*	2.16	0.26*	2.16
Symbolic Activities			0.48^{t}	1.77
Relational Activities			0.00	0.01
Total Activities			-0.43	-0.95
R^2	0.48		0.51	
F	17.06***		10.49***	

	Model 1b		*Model 2b*	
	β	*t*	β	*t*
Math				
Child Age	0.44***	4.53	0.34**	3.27
Child Verbal Intelligence	0.29**	2.81	0.34**	3.25
Reading Importance	-0.07	-0.60	-0.09	-0.75

Beliefs				
Math Importance Beliefs	0.19	1.66	0.27*	2.22
Symbolic Activities			0.67*	2.40
Relational Activities			0.33	1.13
Total Activities			-1.06*	-2.27
R^2	0.43		0.48	
F	14.14***		9.64***	

t p < 0.10, * *p* < 0.05, ** *p* < 0.01, *** *p* < 0.001

Patterns of the relations between beliefs about reading and mathematics and children's reading and mathematics scores were similar when controlling for activities grouped by subject area (i.e., reading and math activities), with beliefs about math again being the stronger and more consistent predictor of children's scores. The results of these models are shown in Appendix E.

Discussion

Results of Study 2 were mixed but overall suggested that engagement in symbolic activities in the home is promotive of children's reading and mathematics development. Though there were no relations between reading and mathematics activities in the home and children's reading and mathematics scores, there were positive associations between the frequency of symbolic activities and children's reading and math scores. Because these relations persisted even after analyses controlled for children's age and verbal intelligence, as well as total activity frequency and parental beliefs about early learning, the pattern of results indicate that home environments rich in symbols are promotive of children's reading and math learning. The symbolic activities scale included both domain-specific symbolic activities and domain-general symbolic activities. The variety in the types of activities included, and the persistent relations between symbolic activities and reading and mathematics scores, support the hypothesis that symbolic learning and symbolic thinking are important foundations for learning in both reading and math.

Potential Explanations for the Inconsistent Effects of Parental Activities

A challenge to this hypothesis and interpretation, however, is that the study failed to find any links between parent activities and children's symbolic and relational skills. The implications of this lack of relation are indeterminate. There are at least four potential explanations:

(1) There may have been inadequate variability across some activities;

(2) It may be a question of quality of activities, not frequency;

(3) Parents' responses may have been biased;

(4) These may not be malleable skills.

Each of these will be elaborated upon below.

Lack of variability. Psychometric analyses of the 45 activities included in the parent survey revealed a range in variability within different items. Some activities, such as "Printing letters," "Counting down," "Learning sums," and "Comparing written numbers" showed high variability between parents (*SD*s = 1.41, 1.40, 1.32, and 1.29, respectively). Others, though, showed low variability, including "Counting objects," "Reading picture books," and "Telling bedtime stories" (*SD*s = 0.76, 0.81, and 0.95, respectively). These items with low variability also happened to be the most common reading and mathematics activities that parents reported. It is distinctly possible that the reason that reading and mathematics activities did not predict reading and mathematics outcomes was that the most common activities were frequent across all parents, limiting the variability available to predict individual differences in children's scores.

The issue of inadequate variability also may be true for symbolic and relational activities. A number of the symbolic and relational activity items needed to be excluded from analyses based on either limited frequency or limited variability. For example, one of the relational activities, "Comparing prices while shopping," was the least common out of all 45 activities and was excluded from analyses due to both low frequency and low variability (M = 0.56, SD = 0.81). Other symbolic and relational items with low variability included "Identifying sounds of alphabet letters" and "Comparing numbers of objects" (SDs = 0.93 and 0.98, respectively). It is possible that with a larger, more diverse sample, these items may have provided more usable data to predict individual differences in children's scores.

Frequency versus quality. Another possible explanation for the lack of relation between parental reports of the frequency of symbolic and relational activities and children's symbolic and relational scores may be that the parent survey focused on frequency of activities, when the dimension that truly matters is *quality* of activities. The inconsistent connections between activities and children's scores suggest that frequency of activities may not be a valid measure in a predominantly middle-high income group of parents who were willing to participate in a research study on home activities. This self-selective group is presumably highly motivated to be actively involved in their children's learning. Perhaps, then, the dimension of import is quality, rather than quantity. While it is true that there were positive relations between beliefs about mathematics and the frequency of various types of learning activities, beliefs were a stronger predictor than frequency when entered into the same models simultaneously. Thus, maybe those who believe math is more important are not only engaging in learning activities more frequently, but also engaging in higher quality activities.

Biased responses. Another important issue to consider is how wording of particular questions may have influenced parents' answers. For instance, the use of the word "analogy" in "Talking about analogies (e.g., a bird's nest is like a house)" may have led parents to underreport the frequency of this type of activity because they associate analogies with more advanced tasks and cognition, such as high school aptitude tests. Likewise, parents may have fixated on particular parts of questions without understanding the intent of the question. For instance, parents may have focused on the words "apps" or "computer" when reading the item "Identifying icons on apps or computer software," and may have responded based on frequency of app or computer use, rather than on frequency of discussions about the icons as symbols. Furthermore, some questions were unclear, such as "Practicing sharing fairly (e.g., splitting cookies evenly)," which was intended to focus on dividing wholes into equal parts for sharing, but which parents would likely presume to include all sharing, such as allowing a friend to use a beloved toy. Lastly, at least two of the items on the parent survey were ambiguous: "Playing with number and letter blocks, magnets, etc." and "Playing card games with numbers or letters." In addition to potential confusion for parents, the ambiguity of these items complicated the creation of composite scores, as it was unclear why a parent answered a certain way—e.g., do they frequently use number blocks (a math activity), letter blocks (a reading activity), or both?

Parents' responses could have been inaccurate partly based on the content validity issues identified above. In addition, however, there are a number of potential bias issues whenever measures are self-reported. To start, there is the possibility that parents over-reported frequency of activities as a manifestation of social desirability bias (Maccoby & Maccoby, 1954). Parents want to think of themselves as good parents and be perceived as such. In fact, those who agreed to participate in the present study were self-selected and likely very motivated to be involved in their children's learning. Thus, parents may have consciously or unconsciously answered so as to appear as highly involved as possible. The fact that controlling for total activities changed the relation between symbolic activities and math scores suggests that there may have been some effects of social desirability bias in parents' responses. This suggests that those parents answering high across all the items, indiscriminately, were clouding the relation between symbolic activities and math performance in the earlier models.

Another potential bias in self-reports is the recency effect, or the tendency to have stronger memories for recent events (Ebbinghaus, 1913). In this case, parents may have overestimated frequencies based on whether they just recently engaged in that particular activity with their children. Taken together, these biases may have obscured a clearer understanding of the types of learning experiences that may predict children's symbolic and relational thinking.

Malleability of Symbolic and Relational Thinking. Finally, it is possible that this study found no links between parental reports of home learning activities and children's symbolic and relational thinking because these skills are not malleable, similarly to how many argue that general intelligence is a stable trait. This possible interpretation will be discussed at length in the general discussion.

The Importance of Parental Beliefs

An interesting finding in the present study related to the role of parental beliefs about the importance of various reading and mathematics skills for kindergarten readiness. Unsurprisingly, based on prior research (Cannon & Ginsburg, 2008; Galper, Wigfield, & Seefeldt, 1997; Musun-Miller & Blevins-Knabe, 1998), parents tended to value reading skills more highly than math skills. There were no relations between how important parents thought reading skills were for school readiness and children's reading and math scores, however. On the other hand, parents' beliefs about mathematics were strongly predictive of children's scores. In fact, parents' beliefs about the importance of mathematics skills were predictive of not only children's math scores, but also their reading scores.

These results, taken together with the results relating to parental activities in the home, were somewhat surprising but seemed to align with recent research. Though studies have frequently pointed to the importance of home learning experiences in supporting school readiness, a body of recent research has begun to add nuances to these proposed relations. Two new studies have found that home activities are not predictive of math performance in young children, but rather that parental beliefs about the importance of mathematics are more predictive (Missall, Hojnoski, Caskie, & Repasky, 2015; DeFlorio & Beliakoff, 2015). This suggests a potential change of tides, with parents being increasingly aware of the need to engage in learning activities with children, but with differences in the enthusiasm, depth, or creativity of these activities. Perhaps those parents who highly value mathematics are also more likely to find teachable moments that incorporate mathematics in ways beyond the traditional activities of counting and learning numerals.

Finally, the fact that parents in Study 2 thought reading was more important than math corroborated the hypothesis proposed in the discussion of Study 1: that general symbolic and relational thinking may be more important for math because children receive more direct support for reading than mathematics. Data from Study 2 lend credibility to this idea, with parents rating reading as more important and engaging in reading activities more frequently.

Chapter 5: General Discussion

The critical importance of early education has been demonstrated through innumerable studies using a variety of methods and with a diversity of samples (e.g., Barnett, 2008; Coley, Votruba-Drzal, Collins, & Cook, 2016; Gormley, Gayer, Phillips, & Dawson, 2005; Laosa, 2005; Reynolds, Temple, White, Ou, & Robertson, 2011; Schweinhart et al., 2005; Vandell, Belsky, Burchinal, Steinberg, & Vandergrift, 2010; Votruba-Drzal, Coley, Collins, & Miller, 2015). Moreover, accumulating evidence points to the persistent implications of individual differences in school readiness (e.g., Aunola et al., 2004; Duncan et al., 2007; Geary et al., 2013; Jordan et al., 2009; Juel, 1988; Ritchie & Bates, 2013; Romano et al., 2010; Stanovich, 1986; Stevenson & Newman, 1986). Thus, there has been increased focus in recent years on understanding the predictors of early knowledge in reading and mathematics. A range of empirical and statistical techniques have been used to understand the predictors of early reading and early math, including longitudinal studies (e.g., Alloway & Alloway, 2010; Fuchs et al., 2010; Hooper et al., 2010), associational studies (e.g., Hammill, 2004; Missall et al., 2015), and even behavioral-genetic approaches in older samples (Rimfeld, Kovas, Dale, & Plomin, 2015). These studies have focused on identifying socio-environmental (e.g., LeFevre et al., 2008; Levine et al., 2010) and cognitive (e.g., Geary et al., 2008; Fuchs et al., 2010) predictors of early reading and mathematics.

The present studies investigated a new explanation for individual differences in reading and mathematics knowledge, or more specifically the commonly documented correlation between early knowledge in the two domains. The present research argued that the two domains share a variety of deep structural features related to symbolic processing and relational thinking, and consequently that children's abilities in these types of domain-general thinking would be predictive of the domain-specific scores. Moreover, the present work hypothesized that specific learning experiences related to symbols and relational thinking in the home would in turn predict children's symbolic and relational thinking, as well as their reading and mathematics knowledge. It was believed that that obtaining a better understanding of the role of these two types of thinking in early learning could inform future research and practice by identifying potential levers to improve school readiness.

Taken together, the results of the two studies provided the first evidence to-date that symbolic and relational thinking may partially explain relations between early reading and early mathematics knowledge. Children's scores on domain-general symbolic and relational tasks were strongly predictive of their scores on reading and mathematics tasks, even after controlling for children's age and verbal intelligence. In addition, the frequency with which children participated in learning experiences related to symbols in the home was predictive of children's reading and mathematics scores. Consequently, the present results provide evidence that there may be potential ways to improve both early reading and mathematics through supporting the development of symbolic and relational thinking in early childhood.

The Value of Considering Symbolic and Relational Thinking

In many ways, symbolic and relational thinking provide greater clarity than prior explanations in understanding cognitive sources of performance in the two domains. In the present study, the relation between children's verbal intelligence and their reading and mathematics scores was completely mediated through symbolic and relational thinking. Though there were strong bivariate relations between children's verbal intelligence and both reading and mathematics, this relation was completely eliminated for mathematics, and reduced to trend for reading, after considering the role of children's symbolic and relational thinking. This pattern of results would suggest not only that symbolic and relational thinking may be important domain-general cognitive skills that underlie both reading and mathematics, but also that they may explain previously documented links between intelligence and reading and mathematics knowledge.

The identification of domain-general abilities beyond general intelligence is an important step forward in understanding how young children learn. Undeniably, intelligence testing is highly predictive (Gottfredson & Saklofske, 2009), with consistently documented relations between IQ and achievement across a range of cognitive and academic outcomes (e.g., Deary et al., 2007; Rohde & Thompson, 2007). To be sure, psychologists have become quite adept at measuring general intelligence and demonstrating the construct's criterion, predictive, and discriminant validity (Neisser et al., 1996). Nevertheless, within applied developmental psychology, intelligence, as a construct, is so nebulous as to be uninformative (Samuelson, 1976). For example, there is much disagreement on the specific structure of human intelligence (Gardner, 2011; Johnson & Bouchard, 2005; Johnson, Bouchard, Kruger, McGue, & Gottesman, 2004; Richardson, 2002), and whether or not, and the extent to which, intelligence is malleable has been a topic of debate for decades (Au et al., 2015; Chooi & Thompson, 2012; Wahlsten, 1997).

Unsurprisingly, the present study did find a positive association between children's verbal intelligence scores and their reading and mathematics knowledge. This relation likely reflects the fact that the PPVT assesses children's receptive vocabulary and has been considered a proxy for both their language and verbal intelligence abilities, both of which have been previously linked to reading and mathematics. The predictive value of these broad abilities, however, is not in question. Simply knowing that language or verbal intelligence predicts reading and mathematics knowledge provides minimal actionable information for early childhood educators and researchers. In other words, the field is in not yet in the position to begin designing interventions to increase language and/or verbal intelligence without knowing whether it would be worth the time, money, and effort required.

In contrast, symbolic and relational thinking, though often part of standard IQ tests, are two specific cognitive processing abilities within the broader, nebulous construct of intelligence that, in their specificity, offer potential targets for interventions to improve early learning. The present study's finding that these types of thinking are predictive of early reading and math knowledge, even after controlling for verbal intelligence, is a critical first step toward exploring these constructs as instructional levers to improve outcomes in both reading and math. Indeed, the frequency with which parents engaged in symbol-based activities in the home was predictive of children's reading and mathematics scores, lending credibility to the hypothesis that more intentional targeting of these types of thinking may support children's development.

Beyond simply identifying the relations between these types of thinking and reading and mathematics, however, the present study strove to understand the types of learning experiences that may support their development. In contrast to hypotheses, the results revealed no relations between symbolic and relational learning experiences in the home and children's symbolic and relational scores. Potential explanations for this lack of relation, as discussed previously, included insufficient variability, distinctions between frequency versus quality, potential biases in parents' responses, or the possibility that these skills were not actually malleable. This idea will be explored in the section below.

The Malleability of Symbolic and Relational Thinking

The present work hypothesized that early learning experiences develop children's symbolic and relational thinking, which in turn support children's reading and mathematics. The study's failure to show that parental activities predict children's symbolic and relational thinking complicates this argument, however. As previously mentioned, there are a number of potential explanations for this lack of relation in the current study, including some related to the present study's instrumentation and sampling, but also the possibility that these are not malleable skills. Perhaps, as many argue is the case with general intelligence, symbolic and relational thinking are actually stable traits that are largely genetically-based.

Evidence from other research challenges the argument that these are not malleable skills, however. Work by DeLoache and colleagues (2004), for example, found that young children trained to complete a relatively easy symbolic retrieval task were able to transfer their knowledge to more difficult symbolic retrieval tasks. The authors argued that children had abstracted a general knowledge of how to think about symbol-referent relations, irrespective of the specific symbols. Within relational thinking, recent research has found improvements in types of relational thinking, including patterning and spatio-relational tasks, following practice or instruction. For instance, one recent study found that training children to think relationally about pattern components improved their accuracy on patterning tasks (Fyfe, McNeil, & Rittle-Johnson, 2015). Furthermore, Kidd and colleagues (2013) found that training on patterns not only improved first grade children's knowledge of patterns, but also their general mathematics performance. Research with adults has also found evidence of malleability of relational thinking. Recent neurological research found that engaging in tasks requiring relational thinking about spatial positions may actually change the brain, with increased gray matter in the hippocampus after just 45 minutes of practice (Keller & Just, 2016).

Therefore, given the limitations of the present research and the prior evidence of malleability, the present study should not be interpreted as evidence that symbolic and relational thinking are not malleable skills. Future research should further investigate the possibility of symbolic and relational interventions in early childhood. This line of inquiry should include both an investigation of the types of activities that may best support these types of thinking, as well as the extent to which these activities may lead to real improvements in not only children's symbolic mapping and relational thinking, but also potentially their reading and mathematics knowledge.

The Importance of Intentionality in Supporting Symbolic and Relational Thinking

One additional nuance to consider in interpreting the results from the present studies is the role of intentionality in supporting early learning. Research in the problem solving literature has demonstrated the importance of explicit, intentional instruction to foster understanding of deep structural similarities between problems in elementary and high school students (Catrambone & Holyoak, 1989; Needham & Begg, 1991), and there is reason to believe this idea would apply to early childhood instruction as well. Indeed, in their book, *Developmentally Appropriate Practice in Early Childhood Programs*, Bredekamp and Copple stated that intentionality is one of the most important factors in good teaching (2009). Perhaps the symbolic and relational activities in the parent survey failed to predict children's symbolic and relational thinking scores because the parents were not aware of the need to emphasize symbols and relations. Consequently, the learning activities may have lacked intentionality.

Prior research has argued that it may be necessary for adults to intentionally structure activities to develop relational thinking in young children (Collins & Laski, 2015). Though patterning activities are presumed to be valuable learning experiences for future mathematics through the development of relational and algebraic thinking, Collins and Laski found that only certain kinds of patterning activities elicited relational strategies by preschool children. While duplicating and extending patterns elicited simple, appearance-based strategies, tasks that required children to think abstractly about the pattern unit elicited relational strategies. The authors then explained these results using the cognitive alignment framework for instructional design (Laski & Siegler, 2014), which argues that activities must be intentionally structured to elicit the type of thinking desired. More specifically, the desired type of thinking must be identified, activities must be structured around the desired thinking, and deliberate efforts must be made to draw attention to the key features of the activity that will elicit the desired thinking.

Therefore, it may be necessary for parents to be aware about the importance of symbolic and relational thinking so that they can be more intentional in how they structure activities. Without any awareness of the importance of symbolic and relational thinking, parents may not know how to talk about symbols and relations, or how to leverage these activities to promote the desired learning. This possibility was in some ways supported by the pattern of results relating to parental activities and children's scores on the two factors of skills identified from Study 1. The frequency of symbolic learning activities in the home may have been predictive of scores on the basic skills of Factor 2 (letter identification, letter-sound knowledge, and numeral identification) because parents were aware of the need to emphasize basic symbolic properties of letters and numerals, specifically their names as well as letter sounds. Conversely, the lack of link between frequency of symbolic and relational activities and the complex skills on Factor 1, including varied skills such as magnitude comparison and phonological operations, may reflect a lack of parental awareness of potential connections between symbolic thinking, relational thinking, and these early reading and mathematics skills. This intentionality interpretation may also partially explain the lack of relations between home learning activities and children's general symbolic and relational thinking scores. Future research should investigate whether training parents to talk about symbols and relations with their children promotes general symbolic and relational thinking, as well as a broader array of early reading and mathematics skills.

Limitations

As with any research, there were some limitations to the present study. One notable limitation of the present research is the absence of information about children's preschool classroom experiences. It is widely known that both home and school experiences contribute to early learning, and the present research focused exclusively on the important role of the home. However, preschool classrooms vary widely in their scope and quality of instructional activities (Justice, Mashburn, Hamre, & Pianta, 2008;

Mashburn et al., 2008). Classroom observations of learning activities, or a teacher survey indicating the frequency of different types of activities in the classroom, would have provided an additional dimension to consider when understanding individual differences in children's knowledge. In addition, it would have been useful to know how long each child had been attending center-based preschool, as learning would likely compound over time. Importantly, however, though small sample sizes within each classroom prevented multilevel modeling in the present study, there was no evidence of school-based differences in children's knowledge, nor were there associations between time of year (i.e., which month) the child was assessed and his/her scores, indicating that the missing data that would have been afforded by observations or teacher surveys may have explained only minimal additional variability in children's knowledge. Nevertheless, future research should investigate the role of the classroom in supporting the development of symbolic and relational thinking in children.

In addition, despite concerted efforts to recruit diverse families, the final sample was overall middle and high income, with half of the sample selecting the highest income category on the parent survey ($142,500 per year), and a majority being Caucasian (61%). Future research would implement modifications to the parent survey to increase the maximum income category to allow for more variation in income on the higher end. More importantly, however, the underrepresentation of low-income and non-white minority participants is a recognized, widespread, and significant problem in research that greatly limits not only generalizability but also precludes a true understanding of the multidimensionality of child development (Brannon et al., 2013; Garcia Coll et al., 1996; Quintana et al., 2006). The lack of diversity in the current sample not only may have limited generalizability, but also may have obscured a true picture of relations among the variables of interest.

Indeed, home learning environments may be especially important for low-income children. Behavioral-genetic research has argued that low-income children's IQ scores are much more strongly influenced by the home environment than are high-income children's scores, which may be more genetically based (Turkheimer, Haley, Waldron, D'Onofrio, & Gottesman, 2003). Other research has identified differences in home learning environments based on socioeconomic factors. Homes with higher income parents have been shown to have higher levels of cognitive stimulation, likely as a result of parents' increased job flexibility (Votruba-Drzal, 2003). Hart and Risley (1995) famously found that low-income children are exposed to 30 million fewer words in the first four years than their higher income peers. Levine and colleagues (2010) found that this discrepancy also extends specifically to number words, with children from higher income families being exposed to number words more frequently. Yet, the underrepresentation of low-income families in the present research limits its ability to understand the symbolic and relational learning experiences across diverse families. This is a particularly important area to consider in future research because prior studies have found that associations between socioeconomic status and academic outcomes may be mediated through domain-general cognitive abilities, such as executive functioning (Dilworth-Bart, 2012).

Furthermore, 80% of families in the present study had at least one post-graduate degree. Prior evidence has shown that parents with higher education levels are more likely to both create a richer learning environment in the home and to hold higher expectations for their child's academic development (Davis-Kean, 2005). Therefore, future research should continue the deliberate recruitment of a more diverse sample.

Implications & Conclusions

Despite these limitations, the present study provides compelling evidence of the potential importance of the constructs of symbolic and relational thinking in early childhood education. Future research should further explore specific types of learning experiences that may best support learning in these two areas, both at home and in the classroom.

Balance in Early Childhood Education. It is important to consider the present study within the broader context of balance in early childhood education. Developmentally appropriate practice in early childhood entails supporting the whole child: their cognitive, linguistic, social, emotional, motor, and moral development (Bredekamp & Copple, 2009). Free play is essential, yet has been in decline in recent years as classrooms move toward more instruction (Carlsson-Paige, 2008; Singer, Singer, Plaskon, & Schweder, 2003). It is imperative that early childhood classrooms not lose the centrality of play-based learning. At the same time, however, it would be ill-advised to ignore the accumulating evidence of the critical role early learning plays in laying the foundation for future schooling. The right balance of play and developmentally-appropriate instruction may be better achieved through greater intentionality.

By being more informed about predictors of reading and mathematics knowledge, and by understanding the types of thinking we want to promote, we can be more intentional in the activities we select to support children's learning. This will allow for greater balance in early childhood while also providing targetable mechanisms to improve school readiness for all children. The present study identified two potential targets for play-based learning and developmentally appropriate instruction: symbolic and relational thinking. Symbolic and relationally-based play would provide useful foundations for both reading and mathematics at the same time, rather than requiring separate activities for the separate domains. Instead of drilling children on letter identification and numeral identification, activities could focus on developing their symbolic thinking through symbolic and pretend play and through games asking children to learn to associate different symbols with different referents. Games could promote relational thinking as well, by asking children to make comparisons, identify patterns, and construct and deconstruct parts and whole.

In conclusion, as we seek to better leverage early childhood education to improve outcomes for children, research must play a pivotal role in elucidating which learning experiences and skills are most essential for success. The present study provided initial evidence of the potential value of symbolic mapping and relational thinking for young children's learning. Future research should further explore the development, predictive validity, and malleability of these constructs to better understand their roles in early learning.

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Appendices

Appendix A

Descriptive Statistics by Age in Years

		Mean (SD)		
Task	**Score Type**	**3-year-olds**	**4-year-olds**	**5-year-olds**
PPVT-IV	Raw Score (Ceiling Item- Errors)	78.24 (18.75)	97.05 (19.80)	104.33 (23.61)
Symbolic Mapping				
Animal Coding	Raw Score: (Number Correct- Number Incorrect)	14.59 (9.29)	19.44 (10.82)	26.28 (13.41)
Rapid Object Naming	Raw Score (Number of Seconds to Complete)	63.43 (19.80)	55.12 (16.80)	51.16 (19.01)
Relational Thinking				
Object Assembly	Raw Score (Total correctly joined pieces)	13.34 (6.10)	20.76 (6.39)	24.56 (6.28)
Odd-One-Out	Number Correct (Max = 26)	14.89 (4.51)	19.79 (3.92)	21.28 (2.63)
Reading Measures				
Letter Identification	Number Correct (Max = 26)	15.86 (8.91)	21.56 (5.93)	23.50 (2.92)
Letter Sound	Number Correct (Max = 26)	8.45 (6.76)	11.59 (6.87)	16.50 (7.58)
Rhyming	Number Correct (Max = 16)	10.28 (2.81)	12.64 (2.71)	13.22 (3.06)
Blending & Elision	Blending Raw Score	5.17 (3.96)	8.85 (5.26)	11.83 (4.45)
	Elision Raw Score	3.24 (4.22)	6.49 (4.52)	10.06 (4.68)
	Mean of Standardized Raw Scores	-0.59 (0.70)	0.08 (0.80)	0.70 (0.78)
Math Measures				
Numeral Identification	Number Correct (Max = 15)	9.34 (4.47)	11.10 (3.79)	12.72 (2.99)
Give-N	Number Correct (Max	6.97 (4.12)	11.36 (3.79)	12.39 (2.89)

	= 15)			
Magnitude Comparison	Number Correct – Number Incorrect	19.72 (16.81)	39.13 (17.16)	48.72 (17.61)
Non-symbolic Arithmetic	Number Correct (Max = 12)	4.45 (3.08)	7.90 (2.72)	7.78 (2.76)

Appendix B
Bivariate and Partial Correlation Matrix, Controlling for Age and Verbal Intelligence

	Age	PPVT	AnCo	RON	OA	Odd	LettID	LettSD	Rhyme	Phon	NumID	GiveN	Mag Comp	NSA
Age														
PPVT	.48***													
AnCo	.42***	.46***		-0.24*	0.05	0.15	0.19	0.35**	0.26*	0.34**	0.28**	0.20	0.52***	0.34**
RON	-.31**	-.39***	-.40***		-0.05	-0.07	-0.38***	-0.25*	-0.27*	-0.09	-0.30**	-0.40***	-0.26*	-0.35**
OA	.53***	.38***	.30**	-.24*		0.17	0.18	0.16	0.22*	0.18	0.17	0.31**	0.11	0.20
Odd	.60***	.52***	.43***	-.31**	.46***		0.18	0.12	0.19	0.21	0.26**	0.38***	0.43***	0.39***
LettID	.38***	.33**	.36**	-.48***	.37**	.40***		0.57***	0.24*	0.29**	0.69***	0.51***	0.37**	0.34**
LettSD	.39***	.46***	.52***	-.40***	.36**	.40***	.65***		0.29**	0.50***	0.53***	0.30**	0.44***	0.15
Rhyme	.39***	.43***	.44***	-.41***	.41***	.44***	.39***	.46***		.52***	0.29**	0.50***	0.39***	0.38***
Phon	.59***	.56***	.56***	-.33**	.47***	.56***	.47***	.65***	0.31**		0.32**	0.33**	0.39***	0.19
NumID	.34**	.34**	.42***	-.41***	.34**	.44***	.74***	.62***	.42***	.48***		0.58***	0.49***	0.41***
GiveN	.52***	.46***	.42***	-.52***	.52***	.61***	.62***	.49***	.63***	.58***	.66***		0.53***	0.58***
MagComp	.60***	.55***	.67***	-.45***	.42***	.68***	.53***	.61***	.57***	.66***	.59***	.70***		.66***
NSA	.50***	.43***	.52***	-.48***	.43***	.60***	.48***	.37***	.53***	.48***	.53***	.71***	0.48***	

Note: Values below the diagonal reflect bivariate Pearson correlations (df = 84), while values above the diagonal reflect partial correlations, controlling for age and verbal intelligence (df = 82).
*** Correlation is significant at the 0.001 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
AnCo = Animal Coding
RON = Rapid Object Naming
OA = Object Assembly
Odd = Odd-One-Out
LettID = Letter Identification
LettSD= Letter Sound
Phon = Phonological Operations
NumID = Numeral Identification
MagComp = Magnitude Comparison
NSA = Non-symbolic Arithmetic

Appendix C

Parent Questionnaire

Frequency of Learning Activities

In the past month, how often did you and your child engage in the following activities? Circle 0 if the activity did not occur, 1 if it occurred less than once a week, but a few times a month (1-3 times), 2 if it occurred about once a week, 3 if it occurred a few times a week (2-4 times), or 4 if it occurred almost daily.

	0 Never	1 Less than once a week, but a few times a month	2 About once a week	3 A few times per week (2-4)	4 Almost daily
1.Reading/reciting stories and poems that rhyme	0	1	2	3	4
2. Identifying names of written numbers	0	1	2	3	4
3. Playing with number and letter blocks, magnets, etc.	0	1	2	3	4
4. Telling bedtime stories	0	1	2	3	4
5. Sorting things by size, color or shape	0	1	2	3	4
6. Counting down (10, 9, 8, 7. . .)	0	1	2	3	4
7. Learning sums (e.g., 1+1=2)	0	1	2	3	4
8. Printing numbers	0	1	2	3	4
9. Going to the library	0	1	2	3	4
10. Singing songs (e.g., Itsy Bitsy Spider)	0	1	2	3	4
11. Playing "store" or "teacher"	0	1	2	3	4
12. Making general comparisons (e.g., Which is longer? Who is taller?)	0	1	2	3	4
13. Counting objects	0	1	2	3	4
14. Counting without objects	0	1	2	3	4
15. Talking about street signs or traffic lights	0	1	2	3	4
16. Measuring ingredients when cooking	0	1	2	3	4
17. Identifying names of written alphabet letters	0	1	2	3	4
18. Identifying sounds of alphabet letters	0	1	2	3	4
19. Talking about analogies (e.g., a bird's nest is like a house)	0	1	2	3	4
20. Playing with puzzles	0	1	2	3	4
21. Using maps (e.g., subway or street maps, treasure hunts)	0	1	2	3	4

	0 Neve r	1 Less than once a week, but a few times a month	2 About once a week	3 A few times per week (2-4)	4 Almo st daily
22. Reading prices while shopping (e.g. how much does this cost?)	0	1	2	3	4
23. Comparing prices while shopping (e.g. which costs more?)	0	1	2	3	4
24. Watching educational TV shows	0	1	2	3	4
25. Identifying icons on apps or computer software	0	1	2	3	4
26. Practicing sharing fairly (e.g., splitting cookies evenly)	0	1	2	3	4
27. Building Legos or with other blocks	0	1	2	3	4
28. Singing the ABCs	0	1	2	3	4
29. Comparing numbers of objects (e.g., are there more cars or boats?)	0	1	2	3	4
30. Comparing written numbers (e.g., which is more, 5 or 4?)	0	1	2	3	4
31. Playing with “Play-Doh” or clay	0	1	2	3	4
32. Recognizing and creating patterns with objects, colors, etc.	0	1	2	3	4
33. Learning/recognizing shapes	0	1	2	3	4
34. Playing card games with numbers or letters	0	1	2	3	4
35. Identifying colors	0	1	2	3	4
36. Comparing characters in books (e.g., who is faster, the tortoise or the hare?)	0	1	2	3	4
37. Matching written numbers with groups of objects (e.g., 2 with two stars)	0	1	2	3	4
38. Requesting a number of objects (e.g., “Can you hand me four plates?”)	0	1	2	3	4
39. Playing board games with die or spinner	0	1	2	3	4
40. Identifying words that rhyme or sound similar	0	1	2	3	4
41. Reading picture books	0	1	2	3	4
42. Printing letters	0	1	2	3	4
43. Identifying brand logos (e.g., Nike swoosh, McDonald’s M)	0	1	2	3	4
44. Identifying names of coins (penny, etc.)	0	1	2	3	4
45. Talking about values of coins (e.g., a penny is worth 1 cent)	0	1	2	3	4

Benchmarks

In your opinion, how important is it for children to reach the following benchmarks prior to entering kindergarten? (Circle 0 if not important and 4 if very important.)

	0 Not Important	1	2 Somewhat important	3	4 Very Important
Count to 10	0	1	2	3	4
Count to 100	0	1	2	3	4
Identify/recognize written numbers	0	1	2	3	4
Simple sums (*ex.* 2 + 1 = 3)	0	1	2	3	4
Rehearse the alphabet	0	1	2	3	4
Identify/recognize alphabet letters	0	1	2	3	4
Print name	0	1	2	3	4
Print alphabet letters	0	1	2	3	4

Family Background Information

What is the primary language you speak at home? ________________________________

Do you speak any other languages at home? ________________________________

What is your present marital or relationship status? (check one)

- ☐ Single
- ☐ Married
- ☐ Separated
- ☐ Divorced
- ☐ Live-in Partner
- ☐ Widowed

How would you describe the ethnicity of your preschooler?

- ☐ Asian American
- ☐ African American/Black
- ☐ Caucasian/White
- ☐ Hispanic/Latino(a)
- ☐ Native American
- ☐ Biracial/Multiracial (explain) ____________________________
- ☐ Other: ____________________________

What is your job? (e.g., full-time home maker, carpenter, sales manager)__________________

____

What is the <u>child's other parent's</u> job (if applicable)?________________________________

What is your highest academic degree?

- ☐ No degree earned
- ☐ GED
- ☐ Technical High School Diploma
- ☐ High School Diploma
- ☐ Professional Certification (type: ________________________________)
- ☐ Associate's Degree
- ☐ Bachelor's Degree
- ☐ Master's Degree
- ☐ Professional Higher Degree (J.D., M.D., Ph.D., etc.)

What is the child's other parent's highest academic degree? (if applicable)

- ☐ No degree earned
- ☐ GED
- ☐ Technical High School Diploma
- ☐ High School Diploma
- ☐ Professional Certification (type: ________________________________)
- ☐ Associate's Degree
- ☐ Bachelor's Degree
- ☐ Master's Degree
- ☐ Professional Higher Degree (J.D., M.D., Ph.D., etc.)

Family income can come from a variety of sources including work, federal and state assistance programs (like social security and TANF), child support, disability benefits, unemployment benefits, and other investments. What do you estimate your total yearly household income from all sources is?

☐ Less than 7,500	☐ 37,501 – 45,000	☐ 75,001 – 82,500	☐ 112,501 – 120,000
☐ 7,501 – 15,000	☐ 45,001 – 52,500	☐ 82,501 – 90,000	☐ 120,001 – 127,500
☐ 15,001 – 22,500	☐ 52,501 – 60,000	☐ 90,001 – 97,500	☐ 127,501 – 135,000
☐ 22,501 – 30,000	☐ 60,001 – 67,500	☐ 97,501 – 105,000	☐ 135,001 – 142,500
☐ 30,001 – 37,500	☐ 67,501 – 75,000	☐ 105,001 – 112,500	☐ 142,501 or above

How many people are being supported by your total family income? ______________________

How many of these people supported by your total family income are children? ______________

Appendix D

Descriptive Statistics for All 45 Learning Activities

	Mean (SD)	Min	Max
Telling bedtime stories	3.56 (0.95)	0	4
Reading picture books	3.54 (0.81)	0	4
Reading/reciting stories and poems that rhyme	3.47 (1.01)	0	4
Counting objects	3.45 (0.76)	1	4
Identifying colors *(dropped)*	3.35 (0.94)	0	4
Singing songs *(dropped)*	3.34 (0.99)	0	4
Counting without objects	3.27 (0.85)	1	4
Identifying names of written alphabet letters	3.09 (0.97)	0	4
Identifying sounds of alphabet letters	2.99 (0.93)	0	4
Practicing sharing fairly	2.93 (1.27)	0	4
Building Legos or with other blocks	2.93 (0.99)	0	4
Identifying names of written numbers	2.89 (1.08)	0	4
Singing the ABCs	2.84 (1.18)	0	4
Making general comparisons	2.81 (1.03)	0	4
Learning/recognizing shapes *(dropped)*	2.67 (1.05)	0	4
Watching educational TV *(dropped)*	2.65 (1.25)	0	4
Playing with puzzles	2.62 (1.04)	0	4
Talking about street signs or traffic lights	2.60 (1.18)	0	4
Requesting a number of objects	2.60 (1.20)	0	4
Printing letters	2.55 (1.41)	0	4
Counting down	2.42 (1.40)	0	4
Identifying words that rhyme or sound similar	2.35 (1.29)	0	4
Sorting things by size, color or shape	2.32 (1.14)	0	4

Recognizing and creating patterns with objects, colors, etc.	2.30 (1.23)	0	4
Comparing characters in books	2.21 (1.21)	0	4
Identifying icons on apps or computer software	2.13 (1.31)	0	4
Comparing numbers of objects	2.13 (0.98)	0	4
Matching written numbers with groups of objects	2.09 (1.32)	0	4
Playing "store" or "teacher"	2.08 (1.37)	0	4
Talking about analogies	2.08 (1.22)	0	4
Learning sums	2.00 (1.32)	0	4
Playing with number and letter blocks, magnets, etc.	1.95 (1.20)	0	4
Playing with "Play-Doh" or clay *(dropped)*	1.82 (1.05)	0	4
Measuring ingredients when cooking	1.65 (1.00)	0	4
Comparing written numbers	1.64 (1.29)	0	4
Printing numbers	1.61 (1.33)	0	4
Playing card games with numbers or letters	1.54 (1.06)	0	4
Identifying brand logos	1.49 (1.39)	0	4
Playing board games with die or spinner	1.44 (1.18)	0	4
Going to the library	1.22 (0.87)	0	4
Identifying names of coins	1.21 (1.20)	0	4
Using maps	1.09 (1.06)	0	4
Talking about values of coins	1.04 (1.07)	0	4
Reading prices while shopping	0.91 (1.01)	0	4
Comparing prices while shopping *(dropped)*	0.56 (0.81)	0	3

Appendix E

Standardized OLS Regression Coefficients for Parental Beliefs about Importance of Reading and Math for Kindergarten Readiness Predicting Reading and Math in Children, Controlling for Reading and Math Activities

	Model 1a		*Model 2a*	
	β	*t*	β	*t*
Reading				
Age	0.38***	4.11	0.43***	4.19
Verbal Intelligence	0.35**	3.53	0.35**	3.40
Reading Importance Beliefs	-0.05	-0.40	-0.10	-0.82
Math Importance Beliefs	0.24*	2.16	0.28*	2.24
Reading Activities			-0.08	-0.36
Math Activities			-0.50	-1.52
Total Activities			0.55	1.19
R^2	0.48		0.50	
F	17.06***		10.12***	

	Model 1b		*Model 2b*	
	β	*t*	β	*t*
Math				
Age	0.44***	4.53	0.45***	4.28
Verbal Intelligence	0.29**	2.81	0.32**	3.02
Reading Importance Beliefs	-0.07	-0.60	-0.12	-0.95

Math Importance Beliefs	0.19	1.66	0.31*	2.37
Reading Activities			-0.21	-0.84
Math Activities			-0.55	-1.63
Total Activities			0.55	1.15
R^2	0.43		0.46	
F	14.14***		8.85***	

t $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$