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Preschool Children's Development in Number, Geometry, and Executive Function: A Cross-Lagged Examination

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PRESCHOOL CHILDREN'S DEVELOPMENT IN NUMBER, GEOMETRY, AND

EXECUTIVE FUNCTION: A CROSS-LAGGED EXAMINATION

by

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ABSTRACT

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by

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The study herein examined relations between early mathematics and executive function (EF) during the preschool years, with additional considerations for demographic influences. In line with professional recommendations regarding the comprehensive nature of preschool mathematics, measures included the TEAM, an early mathematics measure inclusive of number and geometry. A single measure of EF was used, specifically the Head Toes Knees Shoulders (HTKS), a measure of early EF inclusive of working memory, inhibition, and cognitive shift elements. One hundred eighteen children from both rural and urban communities (based on USDA Rural-Urban Continuum Codes) were included in the study; they were an average of 53 months at the beginning of the preschool year. Children were assessed at the beginning and end of the preschool year; relationships between number, geometry, and EF were examined across that time period, using a cross-lagged panel model. Results suggest that number is a universal contributor to later number, geometry, and EF skills; geometry appears to be a universal recipient, influenced by earlier number, geometry, and EF skills. EF was significantly influenced by number and executive function skills at the beginning of the preschool year, and it also predicted geometry skills at the end of the preschool year. Demographic factors of gender, maternal education, household income, and urbanicity were also examined. Limited influence was noted, including household income associated with number performance and urbanicity associated with EF at the beginning of the preschool year; no significant differences based on these demographic factors were found at the end of the preschool year.

(96 pages)

PUBLIC ABSTRACT

Preschool Children's Development in Number, Geometry, and Executive Function: A Cross-Lagged Examination

Brionne G. Neilson, Doctor of Philosophy

Children develop rapidly during early childhood, and this includes their mathematics and executive function (EF) skills. Past research has focused on connections between early mathematics and EF, but more work was needed to fully understand these relations. In particular, past studies have generally used numeracy-based measures to assess early mathematics, although professional guidelines indicate a more comprehensive construct that includes geometry. The research herein addresses some of the gaps of previous work as it examines unique connections between early number, geometry, and EF. One hundred eighteen preschool children from urban and rural communities, being an average age of 53 months at the beginning of the preschool year, were assessed at both the beginning and end of the preschool year. Using the TEAM, a measure of early mathematics inclusive of number and geometry, and the Head Toes Knees Shoulders (HTKS), a measure of early EF with elements of working memory, inhibition, and cognitive shift, relationships between number, geometry, and EF were examined across the preschool year, using a cross-lagged panel model. Three-way ANOVAs were also used to examine differences based on demographic factors, specifically gender, maternal education, household income, and urbanicity (defined by USDA Rural-Urban Continuum Codes). Findings indicate demographic factors played a limited role; household income was significantly associated with number skills and urbanicity with EF skills at the beginning of the preschool year. No other significant relationships based on demographic variables were found. Number skills at Time 1 universally contributed to number, geometry, and EF performance at Time 2; geometry at Time 2 was universally influenced by number, geometry, and EF at Time 1. EF played a mixed role; Time 1 EF significantly predicted Time 2 geometry, and Time 2 EF was significantly predicted by Time 1 number skills. These findings suggest that geometry is an important area of early mathematics to consider, and the relationship between mathematics and EF may be more nuanced than previously understood.

DEDICATION

I dedicate this dissertation to my husband, Aaron, who stood by my side throughout this journey. We married at the beginning of my doctoral program, and he has been supportive of my work and education from day one. He stuck with me through many late nights, early mornings, and chaotic days in between. I am incredibly grateful for his loyal companionship as we have ridden the intellectual, emotional, and even physical rollercoaster of a doctoral program. May we have many more adventures to come.

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CHAPTER I

INTRODUCTION

During early childhood, mathematics and executive function (EF) skills are predictive of later school success (e.g., Blair & Raver, 2015; Duncan et al., 2007; Ginsburg et al., 2008), and both develop rapidly (Campbell, 2005; Geary et al., 2008; Zelazo & Carlson, 2012). Evidence indicates relations between mathematics and EF change over the course of early childhood as children develop more complex cognitive skills (e.g., Fuhs et al., 2014; Jacob & Parkinson, 2015; Schmitt et al., 2017). Although few, if any, aspects of child development could be considered simplistic, the areas of mathematics and EF are particularly complex. The purpose of this chapter is to discuss current understanding relative to the development of preschool mathematics and EF and outline a research study addressing the connections between mathematics and EF longitudinally for rural and urban children.

Current Insights

The National Council of Teachers of Mathematics (NCTM, 2000) has identified five mathematics content areas for early childhood including the following: number and operations, algebra, geometry, measurement, and data analysis and probability. Likewise, the National Mathematics Advisory Panel recommends attention to children's mathematical development in arithmetic; fractions, decimals, and proportions; estimation; geometry; and algebra during the early years (Geary et al., 2008). In both cases, the foci are considerably wider than the traditional preschool emphasis on numeracy and some geometry (i.e., shapes). A comprehensive focus is essential as early mathematics skills serve as a foundation for later school success; therefore, the more comprehensive our study of early mathematics, the more refined our practice in promoting early development (e.g., Duncan et al., 2007; Jordan et al., 2009; Watts et al., 2015).

Mathematical skill development begins in infancy, undergoes significant development during the early childhood years, and continues through adolescence and adulthood. With such rapid change, longitudinal designs are essential to capture how relations between mathematics and other areas of development may change as children age (Schmitt et al., 2017). Those skills developed at a young age are directly connected with later skill acquisition, including aiding development across mathematical domains (e.g., arithmetic skills aiding in understanding fractions, Geary et al., 2008). Duncan et al. (2007) compiled research from six studies finding that although many skills were predictive of later academic achievement, early math skills were the strongest across all six studies in predicting later success. Additional studies (Jordan et al., 2009; Watts et al., 2015) have also supported the significance of early mathematics in connection with later achievement.

In each of these instances, however, researchers relied on early mathematics measures focused primarily on numbers, basic operations, and, in some cases, shapes. Limited research has targeted other areas of mathematics, such as a study connecting spatial awareness and EF to early number knowledge (Verdine et al., 2014). They found that both early EF and spatial awareness predicted overall mathematics performance. Another study used an intervention with a broad-based mathematics focus targeting numeracy, geometry, and spatial skills (Weiland & Yoshikawa, 2013). They found that post-intervention, children's scores increased significantly in early EF, language and literacy, and mathematics skills. With only limited work including multiple aspects of mathematics (e.g., number and geometry), though, further research is needed to better understand how they relate to one another, as well as to other developmental areas.

Early childhood is a period of qualitative change in regions of the brain underlying complex cognitive processes (Bell et al., 2007), with rapid change demonstrated for the region underlying three aspects of EF: working memory (e.g., Espy & Bull, 2005), inhibitory control (e.g., Wiebe et al., 2012), and shift (e.g., C. A. C. Clark et al., 2013). It has been suggested that during early childhood, EF may progress from undifferentiated to differentiated, becoming more complex as children age (Anderson, 2002; Bardikoff & Sabbagh, 2017; Best & Miller, 2010). This increased complexity occurs as the aspects of EF become coordinated (C. A. C. Clark et al., 2016; Fischer & Rose, 1994) and more efficient (Carlson, 2005). During early childhood, however, these three aspects appear to be either unitary or at least highly correlated (Best & Miller, 2010; Zelazo & Carlson, 2012; Zelazo, Carlson, & Kasek, 2008). Again, this rapid change suggests longitudinal designs may be needed to address how relations between EF and other domains may change as children develop (Schmitt et al., 2017; Best & Miller, 2010; Zelazo et al., 2008). The study of EF is important, especially during early childhood, as it provides foundational support for developing cognitive behaviors (C. A. C. Clark et al., 2016). Additionally, it influences behavior (C. Clark et al., 2002), academic achievement (Shaul & Schwartz, 2014), self-control (Shoda, Mischel, & Peake, 1990), social functioning (Kochanska, Murray, & Harlan, 2000), and many other aspects of life (Diamond, 2013).

Beyond examining mathematics and EF independently, researchers have also investigated the complexities of relations between them over time. For example, Welsh et al. (2010) followed Head Start children longitudinally, finding strong predictive relations between early EF, literacy, and numeracy. Fuhs et al. (2014) as well as Schmitt et al. (2017) also used longitudinal design to examine similar relations across preschool and kindergarten, noting bidirectional relations between aspects of EF and mathematics. In all three studies, however, mathematics was again measured in terms of numeracy, such as counting skills and basic operations. EF, though, was measured in each case using a battery of several measures targeting a combination of all three aforementioned aspects; in each instance, these measures were combined into a single latent variable of children's early EF.

In attempting to understand the complex relations between mathematics and EF in early childhood, it is also essential to consider context, including demographic variation. Existing literature often includes considerations for child gender and socioeconomic status (e.g., Fuhs et al., 2014; Jordan et al., 2009; McClelland et al., 2014; Schmitt et al., 2017); considerations for urbanicity (i.e., geographic location and population density) are less common (Graham & Provost, 2012; Miller & Votruba-Drzal, 2013). Regarding gender, according to past research, preschool-age girls have a modest advantage in latent EF (Wiebe et al., 2008) and perform better on inhibitory control tasks, especially tasks related to delaying gratification (e.g., Bull et al., 2011; Carlson & Moses, 2001;

Matthews et al., 2009; Olson et al., 2005). However, other studies do not support gender differences in EF performance (Brocki & Bohlin, 2004; Deák et al., 2004; Hughes & Ensor, 2005).

Socioeconomic status influences children's cognitive development and academic achievement (e.g., Bradley & Corwyn, 2002; Hackman et al., 2015; Miller et al., 2013). Hackman et al. specifically addressed the connection of socioeconomic status to childhood EF, pointing to the negative influence of sustained stressors on cognitive and brain development. Miller et al. examined the influence of income on early achievement; their results suggested income increases related to improvements in academic performance. Notably, though, this study also emphasized the role of the urban-rural continuum; the researchers explained that most previous work addressing poverty focused on urban samples, although rural and suburban children account for a larger percentage of poor children in the U.S (Miller et al., 2013).

Regarding additional contexts of development, urbanicity has received more limited attention. This may be due, in part, to the many ways in which the term is defined (Cromartie & Bucholtz, 2008). Definitions may focus on geographic location, population density, or land use. One study, utilizing a large public data set, used U.S. Census Bureau data to classify participants as living in urban, suburban, or rural areas (Graham & Provost, 2012); another used U.S. Department of Agriculture (USDA) Rural-Urban Commuting Area (RUCA) codes to classify areas as being either large urban, small urban, suburban, or rural (Miller & Votruba-Drzal, 2013). Other options include using USDA Rural-Urban Continuum Codes (RUCC) or USDA Frontier and Remote (FAR) codes. Cromartie and Bucholtz (2008) mentioned more than two dozen options for defining urbanicity currently used by federal agencies; they advised researchers to consider the scope and focus of their work and clarify the ways in which they define urbanicity for purposes of their studies. Regarding urbanicity's influence on preschool children's performance, research is limited. Miller and Votruba-Drzal (2013) explained that urbanicity might be particularly important to consider, though, because of how it is often connected with availability of resources such as health care, childcare, or libraries. They also indicated that preschool children in rural settings might perform more poorly on academic tasks than children in urban settings (Miller & Votruba-Drzal, 2013), and other research has suggested that this difference can persist across the elementary grades (Graham & Provost, 2012).

Need for More Knowledge

Measurement of early mathematics is an area with variation in how constructs are assessed, and it has been noted by researchers in the field as an area for further work (e.g., Clements et al., 2016; Fuhs et al., 2014, Schmitt et al., 2017). Even though professional work has indicated the complexity of early childhood mathematics (Geary et al., 2008; NCTM, 2000), most of the existing research relies primarily on measures of numeracy such as the Test of Early Mathematics Ability (TEMA-3; Ginsburg & Baroody, 2003) and Woodcock Johnson-III Applied Problems subtest (WJ-III; Woodcock et al., 2001). While more comprehensive measures of early mathematics are available (e.g., Clements & Sarama, 2011b; Klein et al., 2000), they are not commonly used. This study, however, does employ such a measure as a means of capturing multiple aspects of mathematics (i.e., number and geometry).

There are three EF assessment strategies typically used during the preschool years including: a single face-to-face measure (e.g., McClelland et al., 2007), a panel of face-to-face measures (e.g., Bull et al., 2011), or a panel of face-to-face measures and a teacher and/or parent paper-and-pencil measure (e.g., C. A. C. Clark et al., 2010). These research strategies are not without their problems. For example, research has found potentially contradictory evidence regarding which elements of EF are influential during preschool (e.g., Blair & Razza, 2007; Diamond & Taylor, 1996; Espy et al., 2004; McClelland et al., 2007; Purpura et al., 2017). This may be, in part, because of the closely correlated relations between these separate elements in early childhood (Best & Miller, 2010; Zelazo et al., 2008). This indicates a great need for research investigating how associations between early EF and other domains may change over the course of the preschool years.

Recommendations by some scholars (Clements et al., 2016; Geary et al., 2008) note the need for more research to fully understand the unique relations that may exist between individual aspects of mathematics and EF. In their report from the National Mathematics Advisory Panel, Geary et al. (2008) note that foundational skills in one mathematical domain seem to facilitate acquisition of skills in other domains; however, only limited research has attempted to investigate associations between separate mathematical domains in early childhood, let alone link these domains to EF skills (Verdine et al., 2014; Weiland & Yoshikawa, 2013).

As contextual factors can have a significant impact on early EF and mathematics development, it is important to understand what role they play. Although studies have often addressed socioeconomic elements (e.g., McClelland et al., 2014; Schmitt et al., 2017; Welsh et al., 2010), only limited research has addressed urbanicity, finding a gap between some rural and urban children regarding academic skill levels upon school entry (Graham & Provost, 2012; Miller & Votruba-Drzal, 2013). As mathematics and EF are predictive of children's skill level during the preschool years (Duncan et al., 2007), consideration of differences among rural and urban contexts during the preschool year may provide additional information on developmental contexts. Using the USDA RUCC codes, rural and urban areas are delineated based on population density and, in the case of rural areas, distance from an urban center. This translates into a possible indicator of access to resources, both locally and distantly (Cromartie & Bucholtz, 2008; Miller & Votruba-Drzal, 2013). This, in turn, may influence children's academic performance, although with such limited research in this area, more work is needed to thoroughly understand this relationship (Graham & Provost, 2012; Miller & Votruba-Drzal, 2013; Miller et al., 2013).

Purpose of the Study

This study aimed to address several gaps in the literature, specifically a more comprehensive conceptualization of mathematics, inclusive of multiple domains; an examination of how those domains relate to one another; an investigation as to how EF is related to early mathematics; and inclusions of demographic factors, such as gender, socioeconomic status, and urbanicity. The study was also longitudinal in design, with a goal of investigating how the association between these variables may change over time, due to the evidence of rapid development in mathematics and EF during the preschool year. This was accomplished using a broader measure of mathematical performance than has typically been used, along with a single, face-to-face measure of EF designed to capture all three areas, reflecting the close relations between these areas during early childhood. Upon perusing existing literature, it appears this study was among the first longitudinal studies to take such a broad approach in assessing both EF and mathematical performance among preschoolers. Contextual elements were also included in analyses to determine how elements of gender, socioeconomic status, and urbanicity may influence children's mathematics and EF performance. In pursuit of these goals, this study focused on a more comprehensive measure of mathematics to examine the interrelatedness of early number, geometry, and EF skills across time. It addressed several gaps in the existing literature on early childhood EF and mathematics.

Research Questions

With these objectives in mind, the guiding research questions were as follows.

1. Do preschool children's number, geometry, and executive function skills differ significantly based on: (a) child gender, (b) maternal education, (c) household income, and (d) urbanicity?
2. What associations exist among number, geometry, and EF skills from fall to spring of the preschool year?

CHAPTER II

LITERATURE REVIEW

Mathematics in Early Childhood

Mathematics skills develop early in the first five years of life and serve an important role in later academic development (Campbell, 2005; Case & Okamoto, 1996; Duncan et al., 2007). As such, measuring these skills during a period of such rapid growth can be complex. Recommendations from the NCTM (2000) and National Mathematics Advisory Panel (Geary et al., 2008) suggest mathematics during early childhood involves several domains; however, research designs do not always reflect this. Existing assessments of early mathematics include both single-domain (e.g., Ginsburg & Baroody, 2003; Woodcock et al., 2001; Verdine et al., 2014) and multi-domain (e.g., Clements & Sarama, 2011b; Klein et al., 2000) measures. Previous research has relied heavily on measures of number (e.g., Fuhs et al., 2014; McClelland et al., 2007; Schmitt et al., 2017; Welsh et al., 2010), and few studies have attempted to capture multiple domains (Clements & Sarama, 2007; Lee et al., 2012; Verdine et al., 2014; Weiland & Yoshikawa, 2013).

Domains of Mathematics

The National Mathematics Advisory panel has focused on children's mathematics in areas of arithmetic; fractions, decimals, and proportions; estimation; geometry; and algebra (Geary et al., 2008). Their report includes discussion of skill development in each of these areas during the period of early childhood, also noting that development in one area (e.g., arithmetic) may facilitate skill acquisition in another (e.g., fractions). The NCTM (2000) has similarly identified multiple mathematics content areas for early childhood, specifically: number and operations, algebra, geometry, measurement, and data analysis and probability. NCTM curriculum recommendations focus on numbers and operations, geometry, and measurement during the preschool years (NCTM, 2006). Many preschool programs, though, focus mainly on small-number counting and basic shape names and lack the broader, deeper range of content possibilities (Ginsburg et al., 2008). In 2002, the National Association for the Education of Young Children (NAEYC) and NCTM collaborated to produce a joint position statement emphasizing the importance of comprehensive and developmentally appropriate mathematics education for young children. In addition to giving guidance in incorporating a variety of mathematics skills, they also advised connecting math concepts, such as number and geometry, to strengthen further young children's skill levels (NAEYC & NCTM, 2002).

Concepts of Number

Numeracy is arguably the area of mathematics most emphasized in early childhood (e.g., Campbell, 2005; Ginsburg et al., 1998; Sarama & Clements, 2008). Skills in this area include counting, subitizing, basic arithmetic, and comparing numbers, among others (Geary et al., 2008; NCTM, 2000; Sarama & Clements, 2008). Evidence shows children develop numerical abilities as early as infancy (Starkey & Cooper, 1980; Starkey et al., 1990), further developing foundational skills throughout early childhood (Campbell, 2005; Case et al., 1996; Ginsburg et al., 2008). Piaget suggested that children's development of number sense was tightly linked with their development of logical reasoning, with early skills serving as a necessary foundation for later development (Inhelder & Piaget, 1964; Piaget, 1952). Upon entry to preschool, many children can recite rote number words from 1 through 10 and have begun counting small quantities of objects (Geary et al., 2008; NAEYC & NCTM, 2002). Children further solidify understanding of quantity, recognition of numerals, and success with basic arithmetic during the preschool years (Campbell, 2005; Case et al., 1996; Piaget, 1952). These skills provide a foundation for further development leading to abilities for solving more complex mathematical problems in later school years (Case & Okamoto, 1996; Duncan et al., 2007; Geary et al., 2008; Inhelder & Piaget, 1964; NCTM, 2006; Piaget, 1952).

Theorists, researchers, and other professionals have also pointed to connections between numeracy and other areas of mathematics (e.g., Case et al., 1996; Geary et al., 2008; Ginsburg et al., 1998; NCTM, 2006; Sarama & Clements, 2008). For example, the NCTM recommends using number skills to connect with geometry (e.g., counting a shape's sides or vertices) and data analysis (e.g., comparing quantity in sets). The National Mathematics Advisory Panel also points to a variety of connections between numeracy and other mathematics elements such as estimation, fractions, and algebra (Geary et al., 2008). Number and arithmetic development is also supported by other domains, such as geometry (Clements & Sarama, 2011a; NAEYC & NCTM, 2002). Likewise, Piaget et al. (1960), maintaining number sense and spatial awareness as distinctly different constructs, noted that tasks of measurement, particularly those requiring use of metric units, necessitated use of both number and geometry skills.

Concepts of Geometry

The National Mathematics Advisory Panel defines geometry as, "…the branch of mathematics concerned with properties of space, and of figures and shapes in space" (Geary et al., 2008, p. xxi). In early childhood, this includes concepts of two- and three-dimensional shapes, space, and position (Ginsburg et al., 2008; Sarama & Clements, 2008; NCTM 2006). The van Hiele (1986) model is a common guide for understanding how geometric reasoning develops, encompassing five levels of understanding (Clements & Sarama, 2011a; Geary et al., 2008). Children begin with visual recognition of basic shapes and figures (level 0) and may eventually progress to rigorous use of geometric theories and reasoning (level 4), usually during adulthood (Geary et al., 2008). Piaget and Inhelder (1956) proposed that geometric understanding, specifically spatial awareness, begins by noticing attributes of objects (e.g., size) and their location in space. During early childhood, children develop ways of representing these properties; these early skills serve as a foundation for the eventual grasp of plane geometry (Case et al., 1996; Piaget & Inhelder, 1956). As with numeracy skills, children develop broad, foundational geometry skills even before school entry (Geary et al., 2008; Ginsburg et al., 1998, 2008).

Prior to beginning preschool, most children have had informal opportunities to explore basic shapes, patterns, and spatial navigation (NAEYC & NCTM, 2002). Although preschool children most often receive instruction at the most basic level, they may, with high-quality instruction, progress to later levels, where shapes are being recognized and defined by specific properties and components (Clements & Sarama, 2011a). As geometry skills continue to develop throughout the school years; preschool and kindergarten children generally move from manipulating geometric figures in pictures and puzzles to naming and recognizing shapes and further to analyzing specific aspects (i.e., how many sides or angles) of those shapes (Geary et al., 2008; NCTM, 2006). Children may also progress in their representations of objects and shapes in space, including representations presenting objects in relation to other adjacent shapes or objects (Case et al., 1996; Piaget & Inhelder, 1956).

Geometry skills have also been related to other mathematic domains such as number knowledge, arithmetic, algebra, and patterns (Clements & Sarama, 2011a; Geary et al., 2008; NAEYC & NCTM, 2002; Verdine et al., 2014). Historically, Piaget maintained that concepts of geometry were separate from concepts of number, and young children relied instead on their developing spatial understanding for basic geometry tasks (Piaget et al., 1960). These authors also noted, though, that more complex measurement tasks, specifically those using defined metric units, required the combined use of number and geometry concepts. Although numeracy and geometry are clearly unique from one another, there are also mathematical tasks that draw from both, supporting an overarching mathematical construct (Geary et al., 2008; Piaget et al., 1960). More research is needed specifically targeting geometry skills in young children in order to better understand how they may also relate to domains outside of mathematics.

Measuring Early Mathematics

In attempting to capture mathematics development in early childhood, researchers often rely heavily on measures of numeracy. Some of the most common of these measures, such as the Test of Early Mathematics Ability (TEMA-3; Ginsburg &

Baroody, 2003) and Woodcock Johnson-III Applied Problems subtest (WJ-III; Woodcock et al., 2001) are frequently used as the sole indicator of early mathematics performance (e.g., Fuhs et al., 2014; McClelland et al., 2007; Schmitt et al., 2017; Welsh et al., 2010). The TEMA-3 specifically focuses on numbering skills, number-comparison, numeral literacy, number facts, and calculation skills (Ginsburg & Baroody, 2003); the WJ-III Applied Problems subtest similarly targets number concepts and calculations (Woodcock et al., 2001).

Aside from using the van Hiele (1986) model to broadly categorize children's skill level in geometry and Piaget's tasks of children's spatial awareness (Piaget & Inhelder, 1956; Piaget et al., 1960), measures specific to this domain are limited (Polignano & Hojnoski, 2012). One example developed by Verdine et al. (2014) is the Test of Spatial Awareness (TOSA); this measure is designed to specifically measure young children's abilities with spatial arrangements of two- and three-dimensional figures. As it is a newer measure, though, it is not widely used at this time.

Somewhat more commonly used are measures that address a comprehensive set of mathematics skills, including both number and geometry. For example, the Tools for Early Assessment in Math (TEAM; Clements & Sarama, 2011b) includes questions addressing algebra, geometry, measurement, data analyses, and numbers and operations. Likewise, the Child Math Assessment (CMA; Klein et al., 2000) was designed to address number, arithmetic, space/geometry, measurement, patterns, and logical relations. Because of their comprehensive nature and limited availability, these measures entail longer administration times, and they are not as commonly used as other, shorter measures targeting early numeracy.

In summary, mathematics in early childhood consists of many elements, including number and geometry. Traditional measures of preschool mathematics ability, though, are primarily numeracy-based. The present study utilized a comprehensive measure of early mathematics to address gaps in the existing literature. Specifically, this measure allowed for examination of number and geometry separately while also investigating their relationships with one another over the course of the preschool year.

Executive Function in Early Childhood

Other skills found to be highly predictive of academic achievement are those related to EF (Blair & Raver, 2015; Bull & Scerif, 2001; Skibbe et al., 2012). Although consensus is lacking regarding a set definition of which skills fall within the EF umbrella, researchers generally include working memory, involving the ability to hold and manipulate information; cognitive flexibility or shifting, referring to skills of alternating between tasks or mental sets; and inhibitory control, meaning the ability to overcome a predominant response, whether in thought or emotion (e.g., Anderson, 2002; Bardikoff & Sabbagh, 2017; Clements et al., 2016; Garon et al., 2008). It is believed that although EF skills are, at first, very basic (Diamond, 2002), they experience considerable growth during the preschool years (Zelazo et al., 2013; Zelazo & Carlson, 2012; Zelazo et al., 2008), and eventually develop into more complex, coordinated skills typical in adulthood (Garon et al., 2008). Researchers have expressed disagreement regarding how EF is conceptualized in studies of early childhood, with some advocating for a single measure reflective of the unitary nature of EF at this stage of life and others promoting use of multiple measures to capture individual aspects of EF as they emerge and are differentiated during early childhood (Nelson et al., 2016; Wiebe et al., 2008; Zelazo et al., 2008).

Linked with development of the prefrontal cortex, which is understood to reach full maturity in adolescence, EF appears to experience significant development during the early childhood years (e.g., Anderson, 2002; Bardikoff & Sabbagh, 2017; Best & Miller, 2010; Miyake et al., 2000; Zelazo et al., 2013; Zelazo & Carlson, 2012; Zelazo et al., 2008). Zelazo et al. (2008) posited that, although previously thought to be non-functional during childhood, functioning of the prefrontal cortex, and thus executive function skills, likely emerges in infancy. Early working memory and inhibition abilities closely interact to allow for more complex tasks, including those drawing upon cognitive shift skills to navigate multifaceted rules (Best et al., 2011). The development of EF may also be tied with children's development in perspective-taking (Zelazo et al., 2008), a notion suggested by Inhelder and Piaget (1964), although the specific terminology of EF was not yet common in research on early childhood development. For example, they noted that for children to understand correctly that multiple spatial arrangements of objects did not change the actual quantity, they needed first to be able to reject their initial perception (Inhelder & Piaget, 1964); this might now be rephrased as requiring an inhibitory response.

Areas of Executive Function

Like mathematics, rudimentary EF skills develop as early as infancy (Society for

Research in Child Development, 2014; Zelazo et al., 2008), undergoing significant change during the preschool years (C. A. C. Clark et al., 2016; Diamond, 2002; Zelazo et al., 2013). Some researchers posit that it is during these years that EF moves from an undifferentiated skill set to individual, differentiated skills, becoming increasingly complex as children grow to adolescence and adulthood (Anderson, 2002; Bardikoff & Sabbagh, 2017; Best & Miller, 2010; Zelazo et al., 2013). Initially, EF was understood to develop in adolescence (Golden, 1981), and as such, examination in early childhood is a more recent area of interest (Garon et al., 2008). Ongoing research has given rise to questions of whether early EF should be conceptualized as unitary or separate constructs (e.g., Carlson & Moses, 2001; Nelson et al., 2016; Wiebe et al., 2011); however, many agree that even as these skills of working memory, inhibition, and shift become more differentiated, they remain highly correlated in early childhood (Bardikoff & Sabbagh, 2017; Garon et al., 2008; Espy, 2016; Zelazo et al., 2013). Zelazo et al. (2013) noted that these areas of EF were more highly correlated for younger children (3-6 years) than for older children (8-15 year), supporting Best and Miller's (2010) work tying EF to early cognition and the idea that these skills become increasingly differentiated over time.

Working Memory

Working memory, a core component of an information processing framework, consists of four components: the central executive (attentional controller), the phonological loop (storage buffer), the visual-spatial sketchpad (storage buffer), and an episodic buffer that interacts with long-term memory (Baddeley, 2000; Baddeley & Hitch, 1974; Case et al., 1996; Geary et al., 2008). This area of EF develops significantly during the preschool years (e.g., Espy & Bull, 2005; Gathercole, 1998; Zelazo et al., 2013) and has been tied to children's early mathematics performance (e.g., Case et al., 1996; Clements et al., 2016; Geary et al., 2008). Zelazo et al. (2013) noted that development in this area of EF appeared to be most rapid between the ages of 4 and 5, when considering the period between ages 3 and 15 years. Development of working memory in early childhood has been shown in terms of capacity on digit, word, object, and span tasks (e.g., Espy & Bull, 2005; Gathercole, 1998), spatial and object memory (Diamond, 1991), and tracking large numbers of items (Hongwanishkul et al., 2005).

Inhibitory Control

Closely tied with working memory, inhibitory tasks may be classified as simple or complex based on how much working memory input is required (Garon et al., 2008). In preschool, common simple tasks assessing inhibitory control often involve delayed gratification (e.g., Carlson, 2005; Mischel, 1974); more complex tasks involve arbitrary rules used to direct responses requiring inhibition of competing responses (e.g., Carlson, 2005; Garon et al., 2008). As simple tasks require less input from working memory, they may be a better reflection of preschool children's inhibitory control (Best & Miller, 2010). Other researchers have noted the close correlation between inhibition and other EF tasks, particularly working memory, during early childhood, noting particularly rapid development from the ages of 3 to 5 years (Zelazo et al., 2013).

Cognitive Shifting

Working memory and inhibitory control also contribute to cognitive shift abilities, as they require focusing on relevant stimuli, ignoring distractions, and retaining information regarding original and contradictory mental sets; as such, it is arguably the most complex area of EF (Chevalier et al., 2012; Miyake et al., 2000). Tasks of cognitive shift may involve attention shifting, wherein rules changed based on stimuli aspects, or response shifting, wherein motor response selection is influenced (Rushworth et al., 2005). Card sort tasks (e.g., Zelazo, 2006) are often used to assess skills in attention shifting; these tasks require individuals to sort a set of cards by one characteristic (i.e., color) followed by another (i.e., shape) and later by combining these directives. One example of a response shifting task is the Tower of Hanoi (TOH: Klahr, 1978; Simon, 1975) measure, which requires individuals to move a set of disks to match a presented configuration, shifting between goals and rules in the process. Like working memory and inhibition, shifting also undergoes significant growth during the preschool years (Zelazo et al., 2013).

During early childhood, EF aspects are highly correlated (Bardikoff & Sabbagh, 2017; Best & Miller, 2010; Zelazo et al., 2008); differentiation of tasks may start to occur toward the end of early childhood, continuing into adolescence (Best et al., 2011; Zelazo & Carlson, 2012). With such rapid change occurring during the preschool years, measuring EF at this time can be difficult (Zelazo et al., 2013). While the three aspects may be distinctly different, their close ties and interactions, particularly during the early years of development, indicate that the EF construct could be conceptualized as a unitary one, although researchers argue for both approaches (Espy, 2016; Wiebe et al., 2011; Zelazo et al., 2008).

Measuring Early Executive Functioning

Measures of EF, like those of mathematics, may focus on a wide range of skills or may be limited in their scope. Extant literature supports both conceptualizations (e.g., Carlson & Moses, 2001; Wiebe et al., 2011), although individual researchers have disagreed on which is most appropriate during the early years of development (Espy, 2016). These disagreements reflect ongoing efforts to understand how EF functions in early childhood, particularly considering the high correlations between individual areas at this age (Bardikoff & Sabbagh, 2017; Garon et al., 2008; Zelazo et al., 2013).

There are numerous options for assessing EF in early childhood; Garon et al. (2008) reviewed more than thirty face-to-face EF measures used with preschool children, and it still was not a comprehensive list of available face-to-face tools. Additionally, some researchers have chosen a paper and pencil option, such as the Behavior Rating Inventory of Executive Function (BRIEF-P; Gioia et al., 1996), a survey of children's EF inclusive of subscores in inhibition, cognitive shift, emotional control, working memory, and planning and organizing. Other measures, such as the Head Toes Knees Shoulders task (HTKS; McClelland et al., 2014) attempt to capture multiple EF skills with a single face-to-face measure, reflecting the high correlation between these skills in early childhood. Regarding selecting EF measures, some researchers have opted for a battery of measures (e.g., Bull & Scerif, 2001; C. A. C. Clark et al., 2010; Fuhs et al., 2014) while others choose to use a single measure indicative of this construct (e.g., Mazzocco & Kover, 2007; McClelland et al., 2007; Skibbe et al., 2012). In opting for a single measure, it may be advisable to use a measure indicative of multiple EF aspects (e.g., McClelland et al., 2014) as opposed to a single, narrow measure of a solitary EF aspect.

Relationships Between Mathematics and Executive Function

Connections between early mathematics and EF have been of particular interest in recent years (e.g., Clements et al., 2016; Fuhs et al., 2014; Schmitt et al., 2017). Past theorists also noted possible connections between EF types of skills and mathematics (Case et al., 1996; Piaget & Inhelder, 1956), although the language may not have reflected current understandings of EF development and terminology. Current research supports connections between EF and multiple academic areas, with several noting that the constructs appear to be more closely tied for preschool children, becoming more differentiated as they move into elementary grades (Fuhs et al., 2014; Schmitt et al., 2017; Zelazo et al., 2013).

Of the existing research, a majority has emphasized a relationship wherein EF skills are predictive of mathematics performance (e.g., Best et al., 2011; C. A. C. Clark et al., 2010; Jacob & Parkinson, 2015). C. A. C. Clark et al., and Best et al. (2011) each used a longitudinal design to demonstrate this connection; the former demonstrated multiple EF measures during preschool as being highly predictive of later math performance after kindergarten, and the latter suggested close correlations between these constructs into adolescence. Jacob and Parkinson used meta-analytic techniques to determine connections from EF to a variety of academic outcomes. In each case, emphasis was on EF predicting mathematics, along with other academic skills, as the research was not designed to address how mathematics skills might also affect EF development. Clements et al. (2016), though, stressed the need for investigations of multiple pathways between these constructs to fully understand the interactions between early mathematics and EF.

Other literature has pointed to a bidirectional relationship between the constructs of early mathematics and EF (Fuhs et al., 2014; Schmitt et al., 2017; Welsh et al., 2010). Fuhs et al. assessed children at the beginning and end of the prekindergarten year as well as again at the end of the kindergarten year. Their assessment protocol included six measures of EF and five measures of academic achievement, with two of those targeting number concepts. Geometry was not included in these measures. They found that their latent variable of EF predicted gains in all measured academic areas (mathematics, language, and literacy) through kindergarten, and they noted strong bidirectional associations between EF and mathematics during the preschool year. The Schmitt et al. study included an additional time point at the beginning of kindergarten; they likewise found bidirectional associations between mathematics, measured with an assessment focused on numeracy, and EF, measured with four tasks combined into a latent variable, over the preschool year. They noted, though, that these relationships changed in kindergarten, with only EF predicting mathematics. Welsh et al. (2010) also noted relationships for Head Start children during prekindergarten, measuring EF (three measures combined into a single factor) and mathematics (a single measure of numeracy) at the beginning and end of the school year. They found that early numeracy scores predicted later EF and numeracy, and early EF scores predicted later numeracy and EF. In a review of literature regarding mathematics and EF connections, Clements et al.

(2016) strongly recommended further research to investigate multiple pathways between these constructs as well as specific elements of mathematics and EF and how they may be inter-related.

Researchers have also worked to understand which individual aspects of EF relate to children's mathematics performance. For example, McClelland et al. (2007) and Espy et al. (2004) found that higher mathematics performance was predicted by higher working memory and inhibition scores in preschool. Blair and Razza (2007), however, found that inhibitory control and shift were the EF elements connected with preschool mathematics skills. Bull and Scerif (2001) found connections with all three EF aspects, noting that children with lower mathematics scores also scored lower on inhibition and working memory, which further impacted performance on shifting tasks. Research has suggested close correlation between EF aspects during the preschool years (e.g., Bardikoff & Sabbagh, 2017; Garon et al., 2008), and it appears that EF may also be more closely connected with academic performance during this time frame, with increased differentiation between skills as children move into elementary grades (e.g., Fuhs et al., 2014; Schmitt et al., 2017; Zelazo et al., 2013).

In sum, relationships between early mathematics and EF have been of high interest in recent years. Most of the research has suggested a predictive relationship from EF to mathematics, although recent studies suggest a bidirectional relationship may be present, particularly during preschool. Few, if any, studies have addressed mathematical concepts beyond numeracy, despite professional standards indicating young children possess a much broader set of skills prior to kindergarten. As this period of development involves rapid changes in both mathematics and EF skill levels, longitudinal examination of these constructs, including their relationships with one another, is highly valuable.

Contextual Considerations

Existing research regarding early mathematics and EF development frequently includes contextual considerations for age, gender, or socio-economic status (e.g., Fuhs et al., 2014; Jordan et al., 2009; Skibbe et al., 2012). Limited investigations involving urbanicity, often focused on differences in geographic location and population density (Cromartie & Bucholtz, 2008), also suggest differences based on this classification (Graham & Provost, 2012; Miller & Votruba-Drzal, 2013). This may be due, in part, to differences in the availability and quality of valuable resources (Miller & Votruba-Drzal, 2013; Miller et al., 2013). Researchers often stress the importance of including these elements, citing limitations in their own work (e.g., Fuhs et al., 2014; Schmitt et al., 2017; Welsh et al., 2012). For example, Schmitt et al. specifically noted that their study, while providing many valuable insights, might have neglected to capture important contributing factors, such as those related to contextual elements beyond socioeconomic status. As these contextual factors can have a significant impact on early mathematics and EF, it is important to investigate the unique roles they play.

Some studies have indicated that children's development in EF during preschool may exhibit differences by gender. It may be that girls have a slight advantage over boys, particularly regarding inhibitory control (e.g., Bull et al., 2011; Carlson & Moses, 2001; Matthews et al., 2009; Wiebe et al., 2008). Other work, though, does not support these differences (e.g., Brocki & Bohlin, 2004; Deák et al., 2004; Hughes & Ensor, 2005). Additional research in this area would help to clarify any variation based on child gender. Knowing whether EF is inherently different for boys or girls could greatly influence how other relationships, such as those between EF and mathematics, might differ. Such knowledge could also influence practitioners' expectations and education of boys and girls during this period of development.

Children's socio-economic status has also been regularly examined in relation to early development, commonly measured in terms of family income (e.g., Graham & Provost, 2012; Miller et al., 2013; O'Hare & Mather, 2008) and parental education (e.g., Graham & Provost, 2012; Miller & Votruba-Drzal, 2013; Wirt et al., 2004). Considerations of children's socioeconomic status (SES) are often found in studies targeting Head Start programs (e.g., McClelland et al., 2014; Schmitt et al., 2017; Welsh et al., 2010). Lower socio-economic status often negatively influences young children's EF (e.g., Blair et al., 2011; Wiebe et al., 2011) and mathematics (e.g., Graham & Provost, 2012; Miller & Votruba-Drzal, 2013). The quality of the home environment may mediate this effect (Hackman et al., 2015), and other factors may also play a unique role (Miller & Votruba-Drzal, 2013).

One such factor may be urbanicity, which may also influence development in EF and mathematics during early childhood (e.g., Graham & Provost, 2012; Miller & Votruba-Drzal, 2013; Schmitt et al., 2017), a focus that is less prominent in existing research. Although definitions of urbanicity may vary, they generally address elements of geographic location, population density, or land use (Cromartie & Bucholtz, 2008). For example, the U.S. Department of Agriculture (USDA, 2013) has established Rural-Urban Continuum Codes (RUCC) based on both population density and, for rural communities, distance from an urban center. Other federal guidelines may target commuter patterns, community size, or land use (Cromartie & Bucholtz, 2008). Those who have focused on urbanicity (Graham & Provost, 2012; Miller & Votruba-Drzal, 2013) point out that early development and later school success differ by these designations, and they recommend study in these areas would do well to include appropriate considerations. Graham and Provost specifically focus on urbanicity with regard to early mathematics, separating participants into categories of urban, suburban, and rural. They point out that kindergarten mathematics achievement levels as well as increases in mathematics skills across elementary grades both differ significantly by urbanicity categories, with those in suburban areas outperforming their rural and urban counterparts; socioeconomic factors did not account for all the observed differences. Miller and Votruba-Drzal, who also accounted for urbanicity in their study, using categories of large urban, small urban, suburban, and rural, similarly noted that socioeconomic environments did not entirely explain the disparities noted among kindergarten children's early academic skill levels. They similarly found that large urban and rural participants scored lower than their small urban and suburban peers in reading and mathematics. The combined results of such studies strongly suggest that urbanicity is an important context.

Summary

Early mathematics and EF skills, both developing rapidly during the preschool years, are predictive of later school success. Although research has investigated relationships between these constructs in early childhood, there is still much to be learned. For example, past studies have frequently used numeracy-focused measures to capture mathematics performance, with very little consideration for geometry. Very little research to date has included both number and geometry. Past work has also varied regarding measurement of early EF, particularly regarding how EF is best conceptualized during the preschool years. Working memory, inhibition, and shift, highly correlated in early childhood, could arguably be viewed as a unitary construct or as distinctly separate skill sets. Contextual factors, such as gender, SES, and urbanicity, also play a role in the development of skills in mathematics and EF during early childhood; many researchers have advocated for future work to include considerations for these demographic elements to help elucidate their role in academic performance. The subsequent study aimed to address gaps in this knowledge set. Including considerations for multiple demographic factors, this work also utilized a comprehensive measure of mathematics, inclusive of both number and geometry, as well as an established measure of EF designed to capture all three EF areas.

CHAPTER III

METHODS

This chapter outlines the research methods employed for this study. This includes a brief description of the overall goals and objectives of the study, including recruitment procedures. Following this, details are provided regarding study participants. Next, study instruments are explained, followed by a description of the assessment protocol. Finally, a data analysis plan is set forth, inclusive of all research questions.

Goals and Objectives

This study was part of a larger project investigating rural and urban preschool children's mathematics skills, EF, and family and childcare environments. Relevant to this study, the overarching goal was to examine relationships between early mathematics skills and EF over the course of the preschool year, with attention also given to demographic variables. The first objective was to determine normative changes in rural and urban preschoolers' number, geometry, and EF skills between the beginning and end of the preschool year. The second was to determine whether performance in those areas differed based on demographic factors. The third was to determine relationships between number, geometry, and EF over the course of the preschool year, paying particular attention to predictive tendencies and reciprocal relationships among these variables.

Participants

Recruitment entailed selecting possible locations based on RUCCs (USDA, 2013). For sampling in this study, rural participants were in areas categorized as a 7, indicating populations of less than 20,000 not adjacent to a metro area; urban participants were in areas categorized as a 3, indicating a metro area with a population greater than 20,000 and smaller than 250,000. Once a geographic area was selected, local listings were used to identify potential centers for participation. Six rural centers were invited to participate, and four accepted, for a 66.67% acceptance rate. Of these programs, one was a small university lab preschool (capacity ≤ 50), one a mid-sized Head Start program (capacity between 50 and 100), one a large childcare center (between 100 and 300), and one a small childcare center (capacity ≤ 50). The response rate was similar for urban centers, with five programs approached and three opting to participate, for a 60% acceptance rate. Urban centers included a mid-sized university lab preschool (capacity between 50 and 100), a mid-sized university childcare center (capacity between 50 and 100), and a large childcare center (capacity between 100 and 300). Preschool curriculum and activities were provided at all locations, both rural and urban.

After agreeing to participate, center staff worked with research team members to contact families in compliance with each program's privacy policies. For example, some centers would only allow their employees, as opposed to research team members, to interact directly with families prior to obtaining informed consent. Due to these policies, it is unknown how many parents were initially approached, as some programs could only provide information on those families who opted to participate. Once parents agreed to participate, children were primarily assessed at their programs during the normal course of their day. In case a need arose, initial plans included the option to offer evening assessment opportunities; this resulted in two evening assessment opportunities being provided at the rural location to finish data collection in a timely manner and minimize travel for the research team. Children no longer enrolled at their respective centers at Time 2 had assessments completed in their homes.

The final sample was comprised of 118 preschool children (boys = 57), their parents, and teachers. Participants resided in both rural and urban populations (rural = 64 children; boys = 31). Children were an average age of 52.65 months (*SD* = 6.32) at the beginning of the preschool year.

Measures

Measures for this study were selected from a larger battery completed by children, parents/guardians, and teachers. Parents and teachers completed basic demographic surveys. The parent survey (Appendix B), consisting of 25 multiple choice and short-answer items, included questions about things such as gender, ethnicity, language, income, and time in childcare. Teacher surveys (Appendix C), consisting of 15 similarly formatted items, addressed things such as program details and teacher training and experience. Child measures were as follows:

Mathematics, Including Number and Geometry

Mathematics skills were measured using the Tools for Early Assessment in Math (TEAM; Clements & Sarama, 2011b). This measure assesses several elements of mathematics, combining them into two sections focused primarily on number (Part A; e.g., number recognition, sequencing, and comparison; verbal and object counting;

adding and subtracting, etc.) and geometry (Part B; e.g., shape recognition, composition, and decomposition; construction of shapes and patterns; spatial imagery, etc.). Administration time was approximately 10-20 minutes per section. The instrument authors report reliability coefficients ranging from $r = 0.86$ (Part A) to $r = 0.71$ (Part B) (Clements et al., 2008). The Child Math Assessment: Preschool Battery (Klein et al., 2000) was previously used to establish concurrent validity ($r = 0.86$) when evaluating the TEAM as a measure of preschool mathematics achievement (Clements et al., 2008).

Executive Function

EF skills were measured using the Head Toes Knees Shoulders task (HTKS; Ponitz et al., 2009). For this task, children were asked to play a game in which they must do the opposite of what is said by the assessor. For example, the assessor asked the children to touch their head, but children were supposed to do the opposite and touch their toes. The opposite ("touch your toes" prompt to touch their head) was also used. If children passed the head/toes trial, they moved on to a more advanced trial including similar knees/shoulders commands. The HTKS measure, which addresses all three areas of EF, lasted approximately 5-7 minutes, dependent on child proficiency. McClelland et al. (2014) established concurrent validity for this measure with the Dimensional Change Card Sort ($r = 0.56$; DCCS; Frye et al., 1995; Zelazo, 2006) as well as a measure of working memory ($r = 0.60$; Auditory Working Memory; Woodcock et al., 2001).

Assessment Protocol

Measures were administered at the beginning (Fall) and end (Spring) of the school year with approximately six months (*M* = 5.61 months, *SD* = 1.12 months) between waves. Child measures for the entire battery were presented in random order, with a forced juxtaposition between EF and mathematics measures. Trained research assistants administered these measures over two or three sessions at both time points, based on child attention and availability. Assessments were conducted on-site at the child's school with a few exceptions for children who were no longer enrolled in the same program during the second wave; these children were assessed in their homes in the spring.

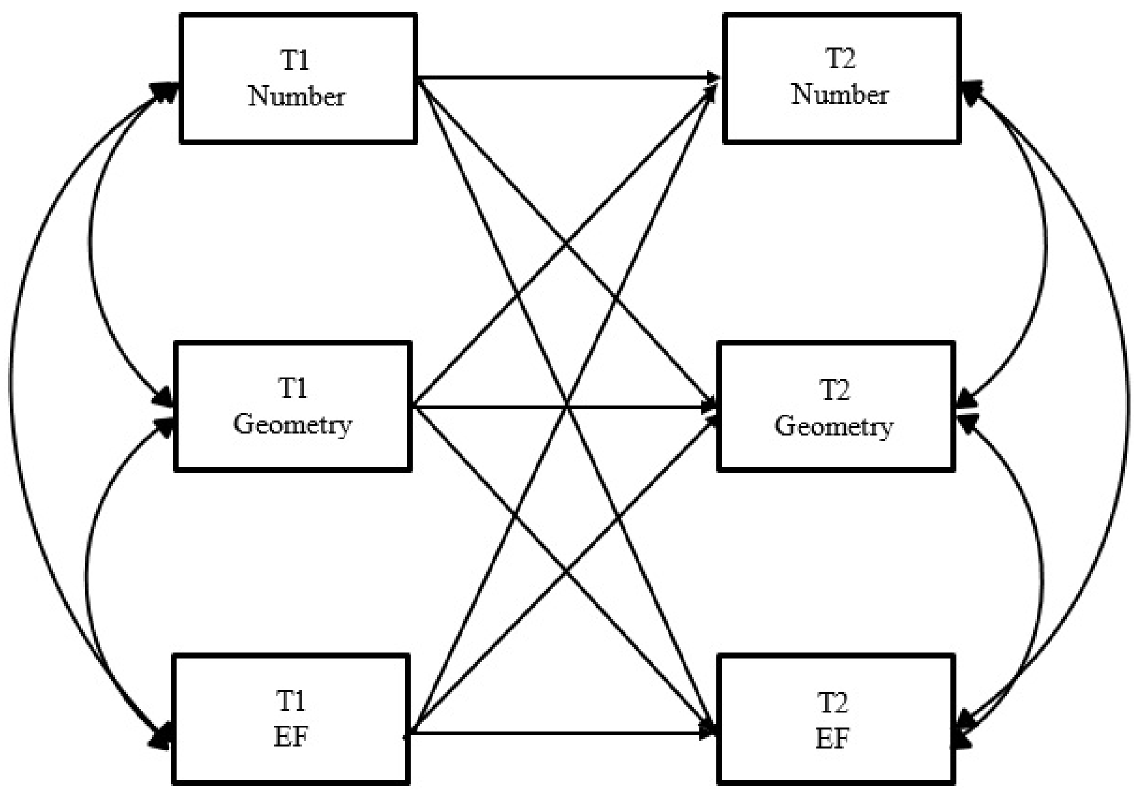
Data Analysis Plan

Data were first examined to ensure necessary assumptions are met for all planned analyses. This included cleaning of data, as well as examining frequencies and tests of normality. Correlational analyses were then run to confirm a priori expectations regarding connections between number (TEAM A), geometry (TEAM B), and EF (HTKS). This analysis also aided in monitoring for potential issues of multicollinearity prior to proceeding with additional analyses. Following this, 3-way ANOVAs were run to examine the possibility for differences based on demographic variables regarding number, geometry, and EF at both time points, thus addressing the first research question. Based on significant results, demographic variables were included in subsequent analyses.

To address the latter research question, a cross-lagged panel model (see Figure 1) was designed to examine autoregressive and cross-lagged effects between number, geometry, and EF at both time points. This model controlled for prior levels of each outcome variable, and it allowed for examination of reciprocal relations between variables (Selig & Little, 2012). Previous work (Fuhs et al., 2014; Schmitt et al., 2017) used similar models in examining these constructs, establishing cross-lagged analysis as an appropriate approach for investigating connections between early mathematics and EF. Initial model fit was sufficient, and no revised models were tested.

Figure 1

Proposed Cross-Lagged Panel Model Examining Number, Geometry, and Executive Function at Two Time Points



CHAPTER IV

RESULTS

In this chapter, descriptive statistics and demographic information are provided followed by analyses addressing each question. Three-way ANOVAs (urbanicity X maternal education X household income) examined for differences between demographic groups, and then a cross-lagged panel model was used in addressing the remaining question regarding relationships between numeracy, geometry, and EF skills across the preschool year. Data for this study were collected using surveys and face-to-face assessments. Data were double entered in Excel using a self-check formula. Once complete, data were transferred into SPSS. Descriptive statistics and ANOVAs were run using SPSS 25; the cross-lagged model was developed and run using AMOS 24.0.0.

Sample Description and Demographics

The total sample included 118 preschool children (boys = 57), along with their parents and teachers. There were 64 children (boys = 31) in rural programs and 54 (boys = 26) in urban programs. Children were an average age of 52.65 months (*SD* = 6.32) at Time 1. Further details on demographic variables can be found in Table 1, including child gender, urbanicity, maternal education, and annual household income. Descriptive statistics for each of the dependent variables (number, geometry, and EF) are shown in Table 2 for Time 1 and Table 3 for Time 2. Correlations between these demographic variables (child gender, urbanicity, maternal education, and annual household income) and dependent variables (number, geometry, and EF) can be found in Table 4. Urbanicity

Table 1

Demographics for Children and Families

	Total sample		Rural		Urban		Male		Female		HS-AS		BS+		$0-$39,999		$40,000-$79,999		$80,000+	
Variables	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Urbanicity (child)																				
Rural	64	54.2					31	54.4	33	54.1	28	73.7	17	32.7	5	35.7	19	59.4	18	40.0
Urban	54	45.8					26	45.6	28	45.9	10	26.3	35	67.3	9	64.3	13	40.6	27	60.0
Child gender																				
Male	57	48.3	31	48.4	26	48.1					18	47.4	25	48.1	3	21.4	15	46.9	26	57.8
Female	61	51.7	33	51.6	28	51.9					20	52.6	27	51.9	11	78.6	17	53.1	19	42.2
Maternal education																				
HS – AS	38	32.2	28	43.8	10	18.5	18	31.6	20	42.6					7	50.0	14	43.8	10	22.2
BS+	52	44.1	17	26.6	35	64.8	25	43.9	27	44.3					7	50.0	16	50.0	29	64.4
Annual household income																				
$0 - $39,999	14	11.9	5	7.8	9	16.7	3	5.3	11	18.0	7	18.4	7	13.5						
$40,000 - $79,999	32	27.1	19	29.7	13	24.1	15	26.3	17	27.9	14	36.8	16	30.8						
$80,000+	45	38.1	18	28.1	27	50.0	26	45.6	19	31.1	10	26.3	29	55.8						

Note. HS – AS = high school diploma up to associate degree; BS+ = bachelor's degree or higher.

Table 2

Means and Standard Deviations for Number, Geometry, and EF at Time 1

	Number		Geometry		EF	
Variables	*M*	*SD*	*M*	*SD*	*M*	*SD*
Total sample	14.86	9.31	7.61	4.88	13.54	12.65
Urbanicity (child)						
Rural	12.05	8.56	7.43	5.35	13.36	13.03
Urban	18.14	9.15	7.82	4.30	13.74	12.32
Child gender						
Male	15.09	10.84	7.18	4.54	12.18	12.42
Female	14.65	7.74	8.02	5.18	14.88	12.84
Maternal education						
HS – AS	13.73	10.41	7.49	4.98	13.94	13.71
BS+	17.73	8.22	8.56	5.41	13.67	12.01
Annual household income						
$0 - $39,999	15.29	964	6.32	4.16	9.54	10.72
$40,000 - $79,999	13.85	9.30	7.14	4.02	11.81	13.30
$80,000+	17.67	8.29	8.81	5.91	16.22	12.34

Note. Number = TEAM Part A; Geometry = TEAM Part B; EF = HTKS

Table 3

Means and Standard Deviations for Number, Geometry, and EF at Time 2

	Number		Geometry		EF	
Variables	*M*	*SD*	*M*	*SD*	*M*	*SD*
Total sample	20.40	10.30	9.92	4.16	20.30	12.96
Urbanicity (child participants)						
Rural	17.90	10.41	9.89	4.47	18.50	13.32
Urban	23.04	9.60	9.95	3.86	22.06	12.48
Child gender						
Male	20.86	12.15	9.52	4.36	20.45	13.08
Female	19.94	8.20	10.30	3.97	20.15	12.98
Maternal education						
HS – AS	19.52	12.93	10.55	4.55	22.75	13.35
BS+	23.02	8.27	10.20	4.05	20.54	12.20
Annual household income						
$0 - $39,999	17.55	11.26	8.40	4.21	16.80	13.48
$40,000 - $79,999	19.14	8.64	10.10	4.16	21.04	12.62
$80,000+	23.18	9.49	10.33	4.23	22.51	12.05

Note. Number = TEAM Part A; Geometry = TEAM Part B; EF = HTKS.

Table 4

Correlations Among All Study Variables

Variables	1.	2.	3.	4.	5.	6.	7.	8.	9.
1. Child gender									
2. Urbanicity	.00								
3. Maternal education	-.01	.41***							
4. Annual income	-.24*	.04	.21						
5. T1 number	-.02	.33***	.21*	.15					
6. T1 geometry	.09	.04	.10	.19	.46***				
7. T1 EF	.11	.02	-.01	.21	.45***	.34***			
8. T2 number	-.05	.25*	.17	.23*	.82***	.50***	.41***		
9. T2 geometry	.10	.01	-.04	.13	.52***	.54***	.47***	.63***	
10. T2 EF	-.01	.14	-.09	.14	.44***	.33**	.42***	.49***	.53***

**p* < .05, ***p* < .01, ****p* < .001.

was noted as rural (1) or urban (2). Maternal education was split into categories of (1) up to and including an associate degree or equivalent, and (2) a bachelor's degree or higher. Household income was split into thirds, with categories being (1) up to $39,999 per year, (2) $40,000 to $79,999 per year, and (3) $80,000 per year and above. In anticipation of further analyses, power analyses were run using G-Power 3.1.9.3. Results indicated that the sample size of 118 participants had 97.7% power to detect an effect size of 0.40 for ANOVA analyses and 93.9% power to detect an effect size of 0.40 for the cross-lagged panel analyses.

Question 1

Do preschool children's mathematics and executive function skills differ significantly based on: (a) child gender, (b) maternal education, (c) household income, and (d) urbanicity? A series of 3-way ANOVAs were then run to look for significant differences in children's performance in number, geometry, and EF based on urbanicity, maternal education, and annual household income. Child gender was not included, as there were no significant correlations with dependent variables.

The main effect of urbanicity was significant for number skills at Time 1, $F(1,70) = 6.90$, $p = .01$, indicating a significant difference between rural ($M = 12.05$, $SD = 8.56$) and urban ($M = 18.14$, $SD = 9.15$) children. Based on this, urban children scored significantly higher than rural children on number skills at the beginning of the preschool year, but this effect is no longer significant at Time 2. The main effect of annual household income was significant for EF skills at Time 1, $F(2,70) = 4.01$, $p = .02$. Children from lower ($M = 9.54$, $SD = 10.72$), middle ($M = 11.81$, $SD = 13.30$), and higher ($M = 16.22$, $SD = 12.34$) income homes were significantly different from each other at the beginning of the preschool year; post-hoc analyses were not statistically significant regarding differences between individual income groups. This effect, though, was also no longer significant at the end of the preschool year. There were no statistically significant differences for scores in geometry at either time point, number at Time 2, or EF at Time 2 based on any of the demographic variables. Full results for all 3-way ANOVAs can be found in Table A-1 (Appendix A).

In summary, only two demographic factors had a statistically significant relationship with children's number and EF skills at the beginning of the preschool year, and no statistically significant relationship was found with geometry. Further analyses included controls for both urbanicity and annual household income based on these results. It also appears that by the end of the preschool year, demographic factors were no longer significantly related to children's scores in number, geometry, or EF.

Question 2

What associations exist between numeracy, geometry, and EF skills between fall and spring of the preschool year? Descriptive statistics for children's performance on these variables are noted previously in Tables 2 and 3, with correlation information noted in Table 4. As expected, children improved in each area between the beginning and end of the preschool year. Measures of children's early number, geometry, and EF skills were significantly correlated with one another at both time points.

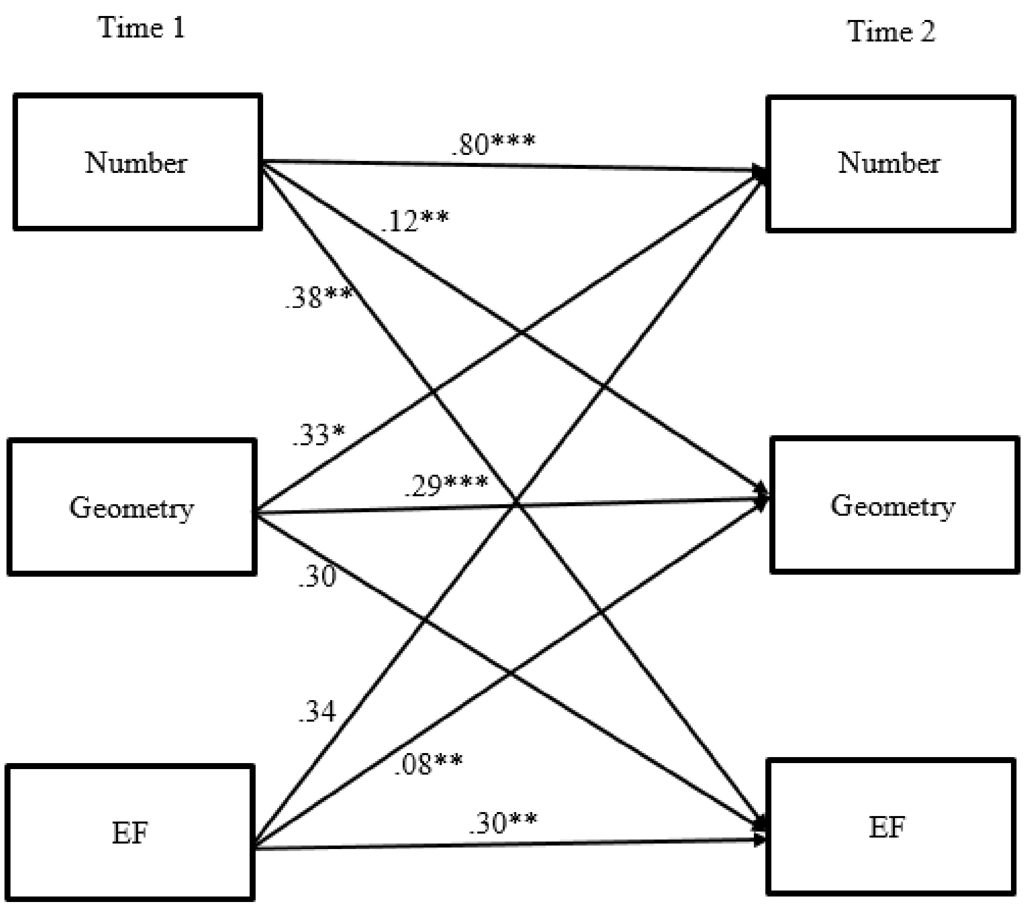
The next set of analyses employed a cross-lagged panel model to examine paths between EF, number, and geometry performance across the two time points. Based on previous analyses, household income and urbanicity were controlled. Figure 2 displays the results for the cross-lagged analyses. Model fit was good, χ^2 (15, N = 118) = 20.79, p = .14; CFI = .98; TLI = .94; RMSEA = .06. Missing data were estimated using full information maximum likelihood. For simplification, covariate estimates are not reported in the figures. See Table 5 for regression details.

Number Associations

Children's number skills at the beginning of the preschool year had a positive effect on their number skills (β = .80, SE = .07, p < .001), geometry skills (β = .12, SE = .04, p < .01), and EF skills (β = .38, SE = .15, p < .01) at the end of the preschool year. End-of-year number skills were significantly influenced by Time 1 number skills

Figure 2

Cross-Lagged Panel Model Examining Number, Geometry, and EF at Two Time Points



Time 1 = fall of preschool; Time 2 = spring of preschool. $N = 118$.
*$p < .05$; **$p < .01$; **$p < .001$.

($\beta = .80$, $SE = .07$, $p < .001$) and Time 1 geometry skills ($\beta = .33$, $SE = .13$, $p < .05$). Time 2 number skills were not significantly influenced by Time 1 EF skills. It appears that early number skills are a significant predictor of all three constructs at the end of preschool; the association with later geometry skills indicates a bidirectional association (i.e., early geometry skills also influenced later number skills). EF results, though, did not support a bidirectional association with number.

Table 5

Regression Weights and Standard Errors for Number, Geometry, and EF in the Cross-Lagged Panel Model

Regression	*b*	*S.E.*
T1 Number		
T2 Number	.80***	.07
T2 Geometry	.12**	.04
T2 EF	.38**	.15
T1 Geometry		
T2 Number	.33*	.13
T2 Geometry	.29***	.07
T2 EF	.30	.26
T1 EF		
T2 Number	.03	.05
T2 Geometry	.08**	.03
T2 EF	.30**	.10

*$p < .05$, **$p < .01$, ***$p < .001$.

T1 Geometry Associations

Children's geometry skills at the beginning of the preschool year positively predicted their number (β = .33, *SE* = .13, $p < .05$) and geometry (β = .30, *SE* = .07, $p < .001$) skills at the end of the preschool year. The influence of Time 1 geometry skills on Time 2 EF skills was not statistically significant. End-of-year geometry skills were significantly influenced by Time 1 number skills (β = .12, *SE* = .04, $p < .01$), Time 1 geometry skills (β = .30, *SE* = .07, $p < .001$), and Time 1 EF skills (β = .08, *SE* = .03, $p < .01$). Here it appears that end-of-year geometry skills are significantly impacted by early scores in all three measured areas. These results suggest a bidirectional association with number skills (i.e., geometry skills predicted later number skills and number skills predicted later geometry skills). This was not the case, though, for geometry and EF skills.

T1 Executive Function Associations

Children's EF skills at the beginning of the preschool year had a positive effect on their geometry skills (β = .08, *SE* = .03, $p < .01$) and EF skills (β = .30, *SE* = .10, $p < .01$) at the end of the preschool year. The influence of Time 1 EF skills on Time 2 number skills was not statistically significant. End-of-year EF skills were significantly influenced by Time 1 number skills (β = .38, *SE* = .15, $p < .01$) and Time 1 EF skills (β = .30, *SE* = .10, $p < .01$). They were not significantly influenced by Time 1 geometry skills. Interestingly, there were not bidirectional associations between EF and either number or geometry; early number skills predicted later EF skills, but early EF skills did not predict later number skills. Likewise, early EF skills predicted later geometry skills, but early geometry skills did not predict later EF skills.

Summary of Associations

In sum, and relevant to the second overarching research questions, it appears that children's early skills in each measured area (number, geometry, EF) significantly influence their later performance on those same skills, respectively. Additionally, number and geometry skills appear to have a bidirectional association, with early performance on one significantly affecting later performance on the other. Bidirectional associations with children's EF, though, were not supported for number or geometry; instead, early EF appears to significantly influence later geometry performance while early number skills influence later EF performance. Notably, each of these pathways indicates significant associations while controlling for all other pathways as well as demographic factors, giving evidence of the unique associations between the respective constructs. It is also of interest to find that early number skills alone are predictive of each end-of-year construct, whereas later geometry is the only variable predicted by all three beginning-of-year measures.

CHAPTER V

DISCUSSION

This concluding chapter focuses on a discussion of the study results relevant to each of the research questions. Following this, study limitations are addressed. Next is a discussion of unique contributions this study contributes to the field, along with mention of associated impacts and future implications. Finally, a general summary of the chapter concludes the discussion.

Question 1

The first question addressed how preschool children's performance in math and EF may differ based on child gender, maternal education, household income, and urbanicity. Although some previous research has indicated the possibility for differences based on child gender (e.g., Carlson & Moses, 2001; Matthews et al., 2009; Wiebe et al., 2008), such differences were not present in this sample, which notably included similar numbers of boys and girls. Results from this study, like other work (e.g., Brocki & Bohlin, 2004; Deák et al., 2004; Hughes & Ensor, 2005), indicate that boys and girls exhibit similar math and EF skills during preschool. It may be that the measures chosen for this study, which were mostly game-like in nature, facilitated similar performance regardless of gender.

Maternal education, one common measure of SES (e.g., Miller & Votruba-Drzal, 2013; Wirt et al., 2004), was significantly correlated with children's number skills at the beginning of the preschool year; however, performance in number did not differ significantly based on this factor when including other demographic variables. Performance in geometry and EF also did not differ based on maternal education. Interestingly, education levels were similar between urban and rural samples, and a significant percentage of the sample were highly educated; it may be that a larger distribution of education levels would reveal more nuanced relationships with early mathematics and EF. Also, perhaps other factors beyond maternal education had a greater impact on children's geometry and EF performance; for example, it may be that the time parents spend at home or the activities and materials in the home have a greater influence than a parent's formal education.

Another common measure of SES, household income (e.g., Graham & Provost, 2012; Miller et al., 2013; O'Hare & Mather, 2008) was significantly associated with children's EF at Time 1. Higher income appears to connect with greater EF skills upon preschool entry. This relationship, though, did not persist at Time 2, nor was household income significantly connected with children's number or geometry at either time point. Perhaps families with higher income have access to additional resources that may facilitate EF development in the earliest years (Hackman et al., 2015); participating in enriching preschool activities may provide a more similar set of resources for children, resulting in less difference at the end of the preschool year. Income levels were relatively high throughout the sample, though, with limited percentages represented in the lowest category. Future work may take into consideration time and activities at home in connection with income levels and child performance.

Aside from socioeconomic factors, this study also accounted for urbanicity, which was significantly associated with differences in number skills at the beginning of the preschool year; urban children scored significantly better than their rural counterparts on Time 1 EF. It is of particular interest to note that this association included considerations for socioeconomic factors that are often associated with different settings of urbanicity. Once more, though, this association was not found at the end of the preschool year. It is possible that rural communities have less access to resources which would contribute to children's number experiences prior to preschool (Cromartie & Bucholtz, 2008); however, these differences may be mitigated by formal preschool experiences which are often intentionally focused on number activities (e.g., Campbell, 2005; Ginsburg et al., 1998; Sarama & Clements, 2008).

Overall, it appears, for this sample, that there are limited differences in children's number and EF skills based at the beginning of the preschool year, based on demographic factors of household income and urbanicity. Even these associations, though, are non-significant at the end of the preschool year. While demographic elements play an important role in children's early development (e.g., Blair et al., 2011; Graham & Provost, 2012; Miller & Votruba-Drzal, 2013; Wiebe et al., 2011), formal preschool activities may provide enriching opportunities that allow children a more similar set of resources to aid in mathematics and EF development. This lends support to the importance of the role played by those who care for and educate children during this period of development.

Question 2

The second question addressed the associations between children's number, geometry, and EF skills across the preschool year. Like the work of Fuhs et al. (2014) and Schmitt et al. (2017), this study employed a cross-lagged panel model to investigate these associations. This allowed control for all outcome variables as well as controlling for demographic factors found to significantly relate to these variables. Like previous research findings (C. A. C. Clark et al., 2010; Fuhs et al., 2014; Schmitt et al., 2017; Welsh et al., 2010), this study also revealed connections between early mathematics and EF. Uniquely, though, this study also addressed geometry. Based on the results, it appears that children's number skills at the beginning of the preschool year contribute to all three measured outcomes at the end of the preschool year. This is in line with past studies suggesting that early preschool number skills are predictive of later number skills as well as later EF skills (e.g., Fuhs et al., 2014; Schmitt et al., 2017; Welsh et al., 2010). The current study, though, did not support these researchers' findings of EF as being predictive of number. This may be due, in part, to the intentional separate considerations for number and geometry, whereas previous work has generally not distinguished between these concepts. Perhaps the use of measures emphasizing number only (e.g., Ginsburg & Baroody, 2003; Woodcock et al., 2001) masked associations between early EF and various aspects of early mathematics. This supports the importance of further investigating mathematics beyond measures of number (Clements & Sarama, 2011a). Future studies specifically emphasizing the role of geometry or other aspects of mathematics would provide valuable guidance in future early childhood curriculum development and teaching.

While early number skills appear to be universally predictive of later performance, geometry appears to be the universal recipient, being significantly impacted by all three measured predictors. This supports previous assertions that number and geometry share connections (e.g., Case et al., 1996; Geary et al., 2008; Piaget et al., 1960). As Piaget et al. noted, it may also be that geometric tasks, particularly as they become more complex, require the use of numeracy skills as well. Although geometry and number are distinctly different concepts, the close relationship between them may make pure measurement of geometry a difficult endeavor. As past research has not emphasized the role of geometry in connection with EF, it is of particular interest to notice the association between these variables. Future work may be well-advised to investigate which specific aspects of EF contribute share stronger connections with geometry, particularly as children enter elementary school and EF skills become more differentiated (Best & Miller, 2010; Zelazo et al., 2013). As previously mentioned, studies focused on geometry could provide important insights that would contribute to future curriculum development efforts.

Children's EF skills were uniquely associated with number and geometry, with later EF skills being predicted by earlier number skills and earlier EF skills predicting later geometry performance. Both associations are supportive of previous work indicating close connections between children's EF and academic performance during preschool (e.g., Fuhs et al., 2014; Schmitt et al., 2017; Zelazo et al., 2013). Noting the directions of these relationships poses interesting questions for future work. It may be that children's number skills allow them to engage in activities that facilitate further development of EF skills; likewise, advanced EF capabilities may allow children to more successfully complete geometry tasks, possibly drawing upon numeracy skills at the same time (Clements et al., 2016). Once more, future work should include multiple elements of early mathematics to understand how these areas relate to one another, as well as to other developmental areas. As children move into elementary school, it may also be of interest to investigate how separate elements of EF uniquely relate to number and geometry.

Clearly the inclusion of geometry in a study of children's early mathematics and EF is a worthwhile effort. Considering the evidence that EF skills predict geometry performance in preschool, it is worth questioning what it is about EF that would facilitate work in geometry. For example, Inhelder and Piaget (1964) posited that children needed to suppress their instinctual perceptions of proximity (which could be seen as an inhibition skill) in order to correctly approach geometric tasks. For tasks such as measurement, shifting between number and geometry strategies might be required for success (Piaget & Inhelder, 1956). Perhaps geometry tasks, by nature, require a combination of higher number and EF skills; additional research is necessary to gain a better understanding of the role of geometry in early childhood.

Limitations

Although this study provides unique results addressing previous gaps in research, it is not without limitation. This was a convenience sample; although rural and urban samples were representative of those classifications throughout the region, they may not be nationally representative of urban and rural characteristics, particularly in terms of levels of maternal education and household income. Future work intentionally addressing urbanicity in diverse regions would help to understand how this element contributes to children's academic performance.

Use of the TEAM as a measure of mathematics allowed for the unique strength of including geometry in this study. As this measure is less well-known than other measures of mathematics (e.g., Ginsburg & Baroody, 2003; Woodcock et al., 2001), comparing results across studies is less simple. It was also outside the scope of this work to include other areas of children's development (i.e., language and literacy), which have previously related to early mathematics and EF (e.g., Fuhs et al., 2014; Schmitt et al., 2017).

Implications and Future Work

One of the unique contributions of this work is the inclusion of geometry as an element of early child development. As professional recommendations have pointed to multiple areas of mathematics (Geary et al., 2008; NAEYC & NCTM, 2002; NCTM, 2000, 2006), this study supports the importance of also structuring research to match those recommendations. Further work investigating children's geometry skills in connection with other developmental areas is of high importance. Considering the unique position of geometry in relation to number and EF, both predictive of geometry performance, future work is especially needed to verify this relationship.

It is also worth noting the many nonsignificant findings regarding demographic variables. Unlike previous work, these results suggest that demographic factors may not always significantly relate to academic performance. It may be that factors outside of these demographic factors have a greater association with preschool children's number, geometry, and EF skills. The unique inclusion of urbanicity is also note-worthy, as it appears to play at least a small role in influencing children's academic performance at the beginning of the preschool year, even when including considerations of socio-economic status. Perhaps the proximity and availability of urban resources and amenities has the potential to impact children's academic performance. Future work is needed to adequately discover such relationships.

Conclusion and Summary

The current study has provided valuable insight regarding relationships between preschool children's number, geometry, and EF skills. While in line with findings from previous research in this area, this work also contributes new insights, particularly regarding the role of geometry during preschool. While clearly related to children's number skills, this concept also shares unique associations with EF, and it may yet be uniquely connected with other areas of children's development. Intentionally accounting for differences in urbanicity was also a contribution of the work at hand. While connections may have been minimal, there nonetheless was a unique place for the element of urbanicity, and it would be wise to investigate this further in future studies.

REFERENCES

Anderson, P. (2002). Assessment and development of executive function (EF) during childhood. *Child Neuropsychology, 82*(2), 71-82. doi:10.1076/chin.8.2.71.8724

Baddeley, A. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences, 4*(11), 417–423. doi:10.1016/S1364–6613(00)01538–2

Baddeley, A. D., & Hitch, G. (1974). Working memory. In G. A. Bower (Ed.), *The psychology of learning and motivation* (Vol. 8, pp. 47–89). Academic Press. doi:10.1016/S0079–7421(08)60452–1

Bardikoff, N., & Sabbagh, M., (2017). The differentiation of executive functioning across development: Insights from developmental cognitive neuroscience. In N. Budwig, E. Turiel, & P. Zelazo (Eds.) *New perspectives on human development* (pp. 47-66). Cambridge University Press.

Bell, M. A., Wolfe, C. D., & Adkins, D. R. (2007). Frontal lobe development during infancy and childhood. In D. J. Coch, K. W. Fischer, & G. Dawson (Eds.), *Human behavior learning, and the developing brain: Typical development* (pp. 247–276). Guilford.

Best, J. R., & Miller, P. H. (2010). A developmental perspective on executive function. *Child Development*, *81*(6), 1641-1660. doi:10.1111/j.1467-8624.2010.01499.x

Best, J. R., Miller, P. H., & Naglieri, J. A. (2011). Relations between executive function and academic achievement from ages 5 to 17 in a large, representative national sample. *Learning and Individual Differences, 2*, 327-336. doi:10.1016/j.lindif.2011.01.007

Blair, C., Granger, D. A., Willoughby, M., Mills-Koonce, R., Cox, M., Greenberg, M. T., Kivlighan, K. T., & Fortunato, C. K. (2011). Salivary cortisol mediates effects of poverty and parenting on executive functions in early childhood. *Child Development, 82*(6), 1970–1984. doi:10.1111/j.1467-8624.2011.01643.x

Blair, C., & Raver, C. C. (2015). School readiness and self-regulation: A developmental psychobiological approach. *Annual Review of Psychology, 66*, 711-731. doi:10.1146/annurev-psych-010814-015221

Blair, C., & Razza, R. P. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child Development, 78,* 647–663. doi:10.1111/j.1467-8624.2007.01019.x

Bradley, R. H., & Corwyn, R. F. (2002). Socioeconomic status and child development. *Annual Review of Psychology*, *53*(1), 371-399. doi:/10.1146/annurev.psych.53. 100901.135233

Brocki, K. C., & Bohlin, G. (2004). Executive functions in children aged 6 to 13: A dimensional and developmental study. *Developmental Neuropsychology, 26*, 571–593. doi:10.1207/s15326942dn2602_3

Bull, R. & Scerif, G. (2001). Executive functioning as a predictor of children's mathematics ability: Inhibition, switching, and working memory. *Developmental Neuropsychology, 19*(3), 273-293. doi:10.1207/S15326942DN1903_3

Bull, R., Espy, K. A., Wiebe, S. A., Sheffield, T. D., & Nelson, J. M. (2011). Using confirmatory factor analysis to understand executive control in preschool children: Sources of variation in emergent mathematic achievement. *Developmental Science*, *14*(4), 679-692. doi:10.1111/j.1467-7687.2010.01012.x

Campbell, J. I. (Ed.). (2005). *Handbook of mathematical cognition.* Psychology Press.

Carlson, S. M. (2005). Developmentally sensitive measures of executive function in preschool children. *Developmental Neuropsychology, 28*(2), 595-616. doi:10.1207/s15326942dn2802_3

Carlson, S. M., & Moses, L. J. (2001). Individual differences in inhibitory control and children's theory of mind. *Child Development, 72*, 1032–1053. doi:10.1111/1467-8624.00333

Case, R., Okamoto, Y., Griffin, S., McKeough, A., Bleiker, C., Henderson, B., Stephenson, K. M., Siegler, R. S., & Keating, D. P. (1996). The role of central conceptual structures in the development of children's thought. *Monographs of the Society for Research in Child Development, 61*(1/2), i-295. doi:10.2307/1166077

Chevalier, N., Sheffield, T. D., Nelson, J. M., Clark, C. A. C., Wiebe, S. A., & Espy, K. A. (2012). Underpinnings of the costs of flexibility in preschool children: The roles of working memory and inhibition. *Developmental Neuropsychology, 37*, 99–118. doi:10.1080/87565641.2011.632458

Clark, C., Prior, M., & Kinsella, G. (2002). The relationship between executive function abilities, adaptive behaviour, and academic achievement in children with externalising behaviour problems. *Journal of Child Psychology and Psychiatry*, *43*(6), 785-796. https://doi.org/10.1111/1469-7610.00084

Clark, C. A. C., Chevalier, N., Nelson, J. M., James, T. D., Garza, J. P., Choi, H. J., & Espy, K. A. (2016). The changing nature of executive control in preschool: I. Executive control in early childhood. *Monographs of the Society for Research in Child Development*, *81*(4), 7-29. doi:10.1111/mono.12268

Clark, C. A. C., Pritchard, V. E., & Woodward, L. J. (2010). Preschool executive functioning abilities predict early mathematics achievement. *Developmental Psychology*, *46*(5), 1176–1191. doi: 10.1037/a0019672

Clark, C. A. C., Sheffield, T. D., Chevalier, N., Nelson, J. M., Wiebe, S. A., & Espy, K. A. (2013). Charting early trajectories of executive control with the shape school. *Developmental Psychology*, *49*(8), 1481-1493. doi:10.1037/a0030578

Clements, D. H., & Sarama, J. (2007). Effects of a preschool mathematics curriculum: Summative research on the Building Blocks project. *Journal for Research in Mathematics Education, 38*(2), 136-163. doi:10.2307/30034954

Clements, D. H., & Sarama, J. (2011a). Early childhood teacher education: The case of geometry. *Journal of Mathematics Teacher Education, 14*(2), 133-148. doi:10.1007/s10857-011-9173-0

Clements, D. H., & Sarama, J. (2011b). *TEAM: Tools for early assessment in math–teachers guide*. McGraw Hill.

Clements, D. H., Sarama, J., & Germeroth, C. (2016). Learning executive function and early mathematics: Directions of causal relations. *Early Childhood Research Quarterly, 36*, 79-90. https://doi.org/10.1016/j.ecresq.2015.12.009

Clements, D. H., Sarama, J., & Liu, X. H. (2008). Development of a measure of early mathematics achievement using the Rasch model: The Research-Based Early Maths Assessment. *Educational Psychology, 28*(4), 457-482. doi: 10.1080/01443410701777272

Cromartie J., & Bucholtz, S. (2008). Defining the “rural” in rural America. *Amber Waves, 6*, 28-34.

Deák, G. O., Rey, S. D., & Pick, A. D. (2004). Effects of age, reminders, and task difficulty on young children’s rule-switching flexibility. *Cognitive Development, 19*, 385–400. doi:10.1016/j.cogdev.2004.05.002

Diamond, A. (1991). Guidelines for the study of brain–behavior relationships during development. In H. Eisenberg (Ed.), *Frontal lobe function and dysfunction* (pp. 339–378). New York University Press.

Diamond, A. (2002). Normal development of prefrontal cortex from birth to young adulthood: Cognitive functions, anatomy, and biochemistry. In D. Stuss & R. Knight (Eds.), *Principles of frontal lobe function* (pp. 466–503). Oxford University Press.

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*, 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Diamond, A., & Taylor, C. (1996). Development of an aspect of executive control: Development of the abilities to remember what I said and to “Do as I say, not as I do.” *Developmental Psychobiology*, *29*(4), 315-334. https://doi.org/10.1002/(SICI)1098-2302(199605)29:4<315::AID-DEV2>3.0.CO;2-T

Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., Pagani, L. S., Feinstein, L., Engel, M., Brooks-Gunn, J., Sexton, H., Duckworth, K., & Japel, C. (2007). School readiness and later achievement. *Developmental Psychology, 43*(6), 1428-1446. doi:10.1037/0012-1649.43.6.1428.supp

Espy, K. A., & Bull, R. (2005). Inhibitory processes in young children and individual variation in short-term memory. *Developmental Neuropsychology, 28,* 669–688. doi:10.1207/s15326942dn2802_6

Espy, K. A., McDiarmid, M. M., Cwik, M. F., Stalets, M. M., Hamby, A., & Senn, T. E. (2004). The contribution of executive functions to emergent mathematic skills in preschool children. *Developmental Neuropsychology, 26*, 465–486. doi:10.1207/s15326942dn2601_6

Fischer, K., & Rose, S. (1994). Dynamic development of coordination of components in brain and behavior: A framework for theory and research. In G. Dawson & K. Fischer (Eds.), *Human behavior and the developing brain* (pp. 3–66). Guilford Press.

Frye, D., Zelazo, P. D., & Palfai, T. (1995). Theory of mind and rule-based reasoning. *Cognitive Development, 10*, 483–527. https://doi.org/10.1016/0885-2014(95)90024-1

Fuhs M. W., Nesbitt K. T., Farran D. C., & Dong N. (2014). Longitudinal associations between executive functioning and academic skills across content areas. *Developmental Psychology, 50*(6), 1698-1709. doi:10.1037/a0036633

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: A review using an integrative framework. *Psychological Bulletin, 134*(1), 31-60. doi: 10.1037/0033-2909.134.1.31

Gathercole, S. E. (1998). The development of memory. *The Journal of Child Psychology and Psychiatry and Allied Disciplines*, *39*(1), 3-27. doi:10.1111/1469-7610.00301

Geary, D. C., Boykin, A. W., Embretson, S., Reyna, V., Siegler, R., Berch, D. B., & Graban, J. (2008). Chapter 4: Report of the task group on learning processes. In *National Mathematics Advisory Panel, Foundations for success: The final report of the National Mathematics Advisory Panel* (pp. i-221). U.S. Department of Education.

Ginsburg, H. P., & Baroody, A. (2003). *TEMA-3 examiners manual* (3rd ed.). PRO-ED.

Ginsburg, H. P., Klein, A., & Starkey, P. (1998). The development of children's mathematical thinking: Connecting research with practice. In I. E. Sigel, K. A. Renninger (Vol. Eds.), & W. Damon (Series Ed.), *Handbook of child psychology: Vol. 4. Child psychology in practice* (5th ed., pp. 401–476). Wiley.

Ginsburg, H. P., Lee, J. S., & Boyd, J. S. (2008). Mathematics education for young children: What it is and how to promote it. *Social Policy Report of the Society for Research in Child Development, 22*(1), 3-22.

Gioia, G. A., Andrwes, K., & Isquith, P. K. (1996). *Behavior rating inventory of executive function-preschool version (BRIEF-P).* Psychological Assessment Resources.

Golden, C. J. (1981). The Luria-Nebraska Children's Battery: Theory and formulation. In G. W. Hybd & G. E. Obrzut (Eds.), *Neuropsychological assessment and the school-aged child* (pp. 277-302). Grune & Stratton.

Graham, S. E., & Provost, L. E. (2012). Mathematics achievement gaps between suburban students and their rural and urban peers increase over time. *Carsey Institute Issue Brief*, 52, 1-8.

Hackman, D. A., Gallop, R., Evans, G. W., & Farah, M. J. (2015). Socioeconomic status and executive function: developmental trajectories and mediation. *Developmental Science*, *18*(5), 686-702. doi:10.1111/desc.12246

Hongwanishkul, D., Happaney, K. R., Lee, W. S., & Zelazo, P. D. (2005). Assessment of hot and cool executive function in young children: Age-related changes and individual differences. *Developmental Neuropsychology*, *28*(2), 617-644. doi:10.1207/s15326942dn2802_4

Hughes, C., & Ensor, R. (2005). Executive function and theory of mind in 2 year olds: A family affair? *Developmental Neuropsychology, 28,* 645–668. doi:10.1207/ s15326942dn2802_5

Inhelder, B., & Piaget, J. (1964). *The early growth of logic in the child* (E. A. Lunzer & D. Papert, Trans.). London: Routledge.

Jacob, R. & Parkinson, J. (2015). The potential for school-based interventions that target executive function to improve academic achievement: A review. *Review of Educational Research, 85*(4), 512-552. doi:10.3102/0034654314561338

Jordan, N. C., Kaplan, D., Ramineni, C., & Locuniak, M. M. (2009). Early math matters: Kindergarten number competence and later mathematics outcomes. *Developmental Psychology, 45*(3), 850-867. doi:10.1037/a0014939

Klahr, D. (1978). Goal formation, planning, and learning by preschool problem solvers or: 'My socks are in the dryer.' In R. Siegler (Ed.), *Children's thinking: What develops?* (pp. 181–211). Erlbaum.

Klein, A., Starkey, P., & Wakeley, A. (2000). *Child math assessment: Preschool battery (cma).* University of California, Berkeley.

Kochanska, G., Murray, K. T., & Harlan, E. T. (2000). Effortful control in early childhood: Continuity and change, antecedents, and implications for social development. *Developmental Psychology, 36*, 220–232. https://doi.org/ 10.1037/0012-1649.36.2.220

Lee, K., Ng, S. F., Pe, M.L., Ang, S.Y., Hasshim, M. N. A. M., & Bull, R. (2012). The cognitive underpinnings of emerging mathematical skills: Executive functioning, patterns, numeracy, and arithmetic. *British Journal of Educational Psychology, 82*, 82-99. doi:10.111/j.2044-8279.2010.02016.x

Matthews, J. S., Ponitz, C. C., & Morrison, F. J. (2009). Early gender differences in self-regulation and academic achievement. *Journal of Educational Psychology, 101*(3), 689-704. doi:10.1037/a0014240

Mazzocco, M. M. M., & Kover, S. T. (2007). A longitudinal assessment of executive function skills and their association with math performance. *Child Neuropsychology, 1*, 18-45. doi: 10.1080/09297040600611346

McClelland, M. M., Cameron, C. E., Connor, C. M., Farris, C. L., Jewkes, A. M., & Morrison, F. J. (2007). Links between behavioral regulation and preschoolers' literacy, vocabulary, and math skills. *Developmental Psychology*, *43*(4), 947–959. doi:10.1037/0012-1649.43.4.947

McClelland, M. M., Cameron, C. E., Duncan, R., Bowles, R. P., Acock, A. C., Miao, A., & Pratt, M. E. (2014). Predictors of early growth in academic achievement: The head-toes-knees-shoulders task. *Frontiers in Psychology, 5*(599), 1-14. doi:10.3389/fpsyg.2014.00599

Miller, P., & Votruba-Drzal, E. (2013). Early academic skills and childhood experiences across the urban-rural continuum. *Early Childhood Research Quarterly, 28*, 234-248. doi:10.1016/j.ecresq.2012.12.005

Miller, P., Votruba-Drzal, E., & Setodji, C. M. (2013). Family income and early achievement across the urban–rural continuum. *Developmental Psychology, 49*(8), 1452-1465. doi:10.1037/a0030244

Mischel, W. (1974). Processes in delay of gratification. In L. Berkowitz (Ed.), *Advances in experimental social psychology* (Vol. 7, pp. 249– 292). Academic Press.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*, *41*, 49-100. doi:10.1006/cogp.1999.0734

National Association for the Education of Young Children and National Council of Teachers of Mathematics. (2002). *Early childhood mathematics: Promoting good beginnings.* Joint position statement. Author.

National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics.* Author.

National Council of Teachers of Mathematics. (2006). *Curriculum focal points for prekindergarten through grade 8 mathematics: A quest for coherence.* Author.

Nelson, J. M., James, T. D., Chevalier, N., Clark, C. A. C., & Espy, K. A. (2016). *Structure, measurement, and development of preschool executive function.* In J. A. Griffin, P. McCardle, & L. S. Freund (Eds.), *Executive function in preschool-age children: Integrating measurement, neurodevelopment, and translational research* (p. 65-89). American Psychological Association. https://doi.org/10.1037/14797-004

O'Hare, W., & Mather, M. (2008). Child poverty is highest in rural counties in US. *Population Reference Bureau.* https://www.prb.org/Publications/Articles/2008/childpoverty.aspx

Olson, S. L., Sameroff, A. J., Kerr, D. C. R., Lopez, N. L., & Wellman, H. M. (2005). Developmental foundations of externalizing problems in young children: The role of effortful control. *Development and Psychopathology, 17*, 25–45. doi:10.10170S0954579405050029

Piaget, J. (1952). *The child's conception of number* (C. Gattegno & F. M. Hodgson, Trans.). Routledge.

Piaget, J., & Inhelder, B. (1956). *The child's conception of space* (J. Langdon & J. L. Lunzer, Trans.). Routledge.

Piaget, J., Inhelder, B., & Szeminska, A. (1960). *The child's conception of geometry* (E. A. Lunzer, Trans.). Routledge.

Polignano, J. C., & Hojnoski, R. L. (2012). Preliminary evidence of the technical adequacy of additional curriculum-based measures for preschool mathematics. *Assessment for Effective Intervention, 37*(2), 70-83. doi:10.1177/15345084 11430323

Ponitz, C. C., McClelland, M. M., Matthews, J. S., & Morrison, F. J. (2009). A structured observation of behavioral self-regulation and its contribution to kindergarten outcomes. *Developmental Psychology*, *45*(3), 605-619. https://doi.org/10.1037/a0015365

Purpura, D. J., Schmitt, S. A., & Ganley, C. M. (2017). Foundations of mathematics and literacy: The role of executive functioning components. *Journal of Experimental Child Psychology*, *153*, 15-34. doi:10.1016/j.jecp.2016.08.010

Rushworth, M. F. S., Passingham, R. E., & Nobre, A. C. (2005). Components of attentional set-switching. *Experimental Psychology, 52,* 83–98. https://doi.org/10.1027/1618-3169.52.2.83

Sarama, J., & Clements, D. H. (2008). Mathematics in early childhood. In O. N. Saracho & B. Spodek (Eds.) *Contemporary Perspectives on Mathematics in Early Childhood Education* (pp. 67-94). Information Age Publishing.

Schmitt S. A., Geldhof G. J., Purpura D. J., Duncan R., & McClelland M. M. (2017). Examining the relations between executive function, math, and literacy during the transition to kindergarten: A multi-analytic approach. *Journal of Educational Psychology,* 109(8), 1120-1140. doi:10.1037/edu0000193

Selig, J. P., & Little, T. D. (2012). Autoregressive and cross-lagged panel analysis for longitudinal data. In B. Laursen, T. D. Little, & N. A. Card (Eds.), *Handbook of developmental research methods* (pp. 265–278). Guilford Press.

Shaul, S., & Schwartz, M. (2014). The role of the executive functions in school readiness among preschool-age children. *Reading and Writing*, *27*(4), 749-768. doi:10.1007/s11145-013-9470-3

Shoda, Y., Mischel, W., & Peake, P. K. (1990). Predicting adolescent cognitive and social competence from preschool delay of gratification: Identifying diagnostic conditions. *Developmental Psychology, 26*, 978–986. https://doi.org/10.1037/0012-1649.26.6.978

Simon, H. A. (1975). The functional equivalence of problem solving skills. *Cognitive Psychology, 7*(2), 268-288. doi:10.1016/0010-0285(75)90012-2

Skibbe, L. E., Phillips, B. M., Day, S. L., Brophy-Herb, H. E., & Connor, C. M. (2012). Children's early literacy growth in relation to classmates' self-regulation*. Journal of Educational Psychology, 104*(3), 541-553. doi: 10.1037/a0029153

Society for Research in Child Development. (2014). The emergence of executive function. *Monographs of the Society for Research in Child Development, 79*(2), 1–11. doi:10.1002/mono.12095

Starkey, P., & Cooper, R. (1980). Perception of numbers by human infants. *Science, 210*(4473), 1033-1035.

Starkey, P., Spelke, E. S., & Gelman, R. (1990). Numerical abstraction by human infants. *Cognition, 36*(2), 97-127. doi:10.1016/0010-0277(90)90001-Z

U.S. Department of Agriculture (USDA) (2013). *Rural-urban continuum codes.* https://www.ers.usda.gov/data-products/rural-urbancontinuum-codes/

van Hiele, P. M. (1986). *Structure and insight: A theory of mathematics education.* Academic Press.

Verdine, B. N., Golinkoff, R. M., Hirsh-Pasek, K., Newcombe, N. S., Filipowicz, A. T., & Chang, A. (2014). Deconstructing building blocks: Preschoolers' spatial assembly performance relates to early mathematical skills. *Child Development 85*(3), 1062-1076. doi:10.111/cdev.12165

Verdine, B. N., Irwin, C. M., Golinkoff, R. M., & Hirsh-Pasek, K. (2014). Contributions of executive function and spatial skills to preschool mathematics achievement. *Journal of Experimental Child Psychology, 126*, 37–51. http://dx.doi.org/10.1016/j.jecp.2014.02.012

Watts, T. W., Duncan, G. J., Chen, M., Claessens, Al, Davis-Kean, P. E., Duckworth, K. Engel, M., Siegler, R. & Susperreguy, M. I. (2015). The role of mediators in the development of longitudinal mathematics achievement associations. *Child Development, 86*(6), 1892-1907. doi:10.1111/cdev.12416

Weiland, C., & Yoshikawa, H. (2013). Impacts of a prekindergarten program on children's mathematics, language, literacy, executive function, and emotional skills. *Child Development, 84*(6), 2112-2130. doi:10.111/cdev.12099

Welsh, J. A., Nix, R. L., Blair, C., Bierman, K. L., & Nelson, K. E. (2010). The development of cognitive skills and gains in academic school readiness for children from low-income families. *Journal of Educational Psychology, 102*(1), 43-53. doi:10.1037/a0016738

Wiebe, S. A., Espy, K. A., & Charak, D. (2008). Using confirmatory factor analysis to understand executive control in preschool children: I. Latent structure. *Developmental Psychology, 44*(2), 575–587. doi:10.1037/0012-1649.44.2.575

Wiebe, S. A., Sheffield, T. D., & Espy, K. A. (2012). Separating the fish from the sharks: A longitudinal study of preschool response inhibition. *Child Development, 83*(4), 1245–1261. doi:10.1111/j.1467-8624.2012.01765.x

Wiebe, S. A., Sheffield, T., Nelson, J. M., Clark, C. A., Chevalier, N., & Espy, K. A. (2011). The structure of executive function in 3-year-olds. *Journal of Experimental Child Psychology, 108*(3), 436-452. doi:10.1016/j.jecp.2010.08.008

Wirt, J., Choy, S., Rooney, P., Provasnik, S., Sen, A., & Tobin, R. (2004). *The condition of education 2004* (NCES No. 2004-077)..S. Department of Education, National Center for Education Statistics.

Woodcock, R. W., McGrew, K. S., & Mather, N. (2001). *Woodcock-Johnson III Tests of Cognitive Abilities*. Riverside Publishing.

Zelazo, P. D. (2006). The Dimensional Change Card Sort: A method of assessing executive function in children. *Nature Protocols,* 1, 297–301. https://doi.org/10.1038/nprot.2006.46

Zelazo, P. D., Anderson, J. E., Richler, J., Wallner-Allen, K., Beaumont, J. L., & Weintraub, S. (2013). II. NIH Toolbox Cognition Battery (CB): Measuring executive function and attention. *Monographs of the Society for Research in Child Development, 78*(4), 16-33.

Zelazo, P. D., & Carlson, S. M. (2012). Hot and cool executive function in childhood and adolescence: Development and plasticity. *Child Development Perspectives*, *6*(4), 354-360. doi:10.1111/j.1750-8606.2012.00246.x

Zelazo, P. D., Carlson, S. M., & Kesek, A. (2008). The development of executive function in childhood. In C. A. Nelson & M. Luciana (Eds.), *Developmental cognitive neuroscience. Handbook of developmental cognitive neuroscience* (pp. 553-574). MIT Press.

APPENDICES

Appendix A

3-Way ANOVA Results

Table A1

Results of 3-Way ANOVAs for Number, Geometry, and EF Comparing Based on Urbanicity, Maternal Education, and Annual Household Income

Variables	*F*	*df*
Dependent Variable: T1 Number		
Urbanicity	6.90*	1, 70
Maternal Education	2.53	1, 70
Annual Household Income	1.74	2, 70
Urbanicity X Maternal Education	.00	1, 70
Urbanicity X Annual Household Income	1.28	2, 70
Maternal Education X Annual Household Income	2.12	2, 70
Urbanicity X Maternal Education X Annual Household Income	1.37	2, 70
Dependent Variable: T2 Number		
Urbanicity	2.50	1, 61
Maternal Education	2.96	1, 61
Annual Household Income	2.18	2, 61
Urbanicity X Maternal Education	.23	1, 61
Urbanicity X Annual Household Income	.64	2, 61
Maternal Education X Annual Household Income	1.64	2, 61
Urbanicity X Maternal Education X Annual Household Income	.38	1, 61
Dependent Variable: T1 Geometry		
Urbanicity	.03	1, 71
Maternal Education	1.88	1, 71
Annual Household Income	1.31	2, 71
Urbanicity X Maternal Education	.12	1, 71
Urbanicity X Annual Household Income	.96	2, 71
Maternal Education X Annual Household Income	.85	2, 71
Urbanicity X Maternal Education X Annual Household Income	.95	2, 71
Dependent Variable: T2 Geometry		
Urbanicity	.09	1, 61
Maternal Education	.07	1, 61
Annual Household Income	1.22	2, 61
Urbanicity X Maternal Education	.09	1, 61
Urbanicity X Annual Household Income	.01	2, 61
Maternal Education X Annual Household Income	.52	2, 61
Urbanicity X Maternal Education X Annual Household Income	.24	1, 61

(*table continues*)

Variables	*F*	*df*
Dependent Variable: T1 EF		
Urbanicity	.07	1, 70
Maternal Education	.04	1, 70
Annual Household Income	4.01*	2, 70
Urbanicity X Maternal Education	.46	1, 70
Urbanicity X Annual Household Income	1.23	2, 70
Maternal Education X Annual Household Income	2.37	2, 70
Urbanicity X Maternal Education X Annual Household Income	1.34	2, 70
Dependent Variable: T2 EF		
Urbanicity	2.38	1, 62
Maternal Education	1.34	1, 62
Annual Household Income	2.21	2, 62
Urbanicity X Maternal Education	.34	1, 62
Urbanicity X Annual Household Income	.37	2, 62
Maternal Education X Annual Household Income	.46	2, 62
Urbanicity X Maternal Education X Annual Household Income	.95	1, 62

*$p < .05$.

Appendix B

Parent Demographic Questionnaire

Your Name: ______________________________ Center: ________________________ Child's Name: ______________________________

Parent Demographics Questionnaire

1. What is today's date? ___________________________

2. What is your relationship with the child?
   a. Mother
   b. Father
   c. Stepmother
   d. Stepfather
   e. Grandmother
   f. Grandfather
   g. Aunt/Uncle
   h. Legal Guardian
   i. Other ___________________________

3. What year were you born? ___________________________

4. What is your marital status?
   a. Married/Partnered
   b. Never Married/Partnered
   c. Divorced
   d. Widowed
   e. Other ___________________________

5. What is your spouse's/partner's relationship to the child (if applicable)?
   a. Mother
   b. Father
   c. Stepmother
   d. Stepfather
   e. Other ___________________________

6. What year was your spouse/partner born (if applicable)? ___________________________

7. How many years have you been in your current relationship with your spouse/partner (if applicable)? ___________________________

8. What is your child's birth date?

   Month _____________________ Day ________________ Year ________________

9. Was your child born prematurely (earlier than 37 weeks)?

Yes _______________ No _______________

10. How many children under the age of 18 live in your household? _______________

11. Mark your highest level of education obtained:
   a. Some high school
   b. High school diploma/GED
   c. Technical/Vocational school training
   d. Some college
   e. Technical/Vocational certificate
   f. Associate's degree (2 year degree)
   g. Bachelor's degree
   h. Master's degree or equivalent
   i. Ph.D. or other higher education (MD, DDS, etc.)
   j. Other __________________________
   k. Prefer not to respond

12. Mark the highest level of education obtained for your spouse/partner (if applicable):
   a. Some high school
   b. High school diploma/GED
   c. Technical/Vocational school training
   d. Some college
   e. Technical/Vocational certificate
   f. Associate's degree (2 year degree)
   g. Bachelor's degree
   h. Master's degree or equivalent
   i. Ph.D. or other higher education (MD, DDS, etc.)
   j. Other __________________________
   k. Prefer not to respond

13. What is your child's ethnicity?
   a. White/Anglo/Caucasian
   b. African American/Black
   c. Asian/Pacific Islander
   d. Latino/Hispanic
   e. American Indian/Alaskan Native
   f. Other
   g. Prefer not to respond

14. What is your ethnicity?
    a. White/Anglo/Caucasian
    b. African American/Black
    c. Asian/Pacific Islander
    d. Latino/Hispanic
    e. American Indian/Alaskan Native
    f. Other
    g. Prefer not to respond

15. What is your spouse's/partner's ethnicity (if applicable)?
    a. White/Anglo/Caucasian
    b. African American/Black
    c. Asian/Pacific Islander
    d. Latino/Hispanic
    e. American Indian/Alaskan Native
    f. Other
    g. Prefer not to respond

16. On average, how many waking hours a week do you spend with your child? __________

17. On average, how many waking hours a week does your spouse/partner spend with your child (if applicable)? __________

18. On average, how many hours a week do you work outside of the home? __________

19. On average, how many hours a week does your spouse/partner work outside of the home (if applicable)? __________

20. On average, how many hours a week does your child spend in childcare? __________

21. What is the main language spoken in your home?
    a. English
    b. Spanish
    c. French
    d. Tongan
    e. Chinese
    f. Other _________________________

22. What is your **household** income before taxes?
    a. Less than $10,000
    b. $10,001 to $20,000
    c. $20,001 to $30,000
    d. $30,001 to $40,000
    e. $40,001 to $50,000
    f. $50,001 to $60,000
    g. $60,001 to $70,000
    h. $70,001 to $80,000
    i. $80,001 or more
    j. Prefer not to respond

23. What is your occupation? ____
    ____

24. What is your spouse's/partner's occupation (if applicable)? _____________________
    ____

25. Is there any other information you wish to share? ____________________________
    ____
    ____

Appendix C

Child Care Provider Demographic Questionnaire

Your Name: ______________________________ Center: ______________________________

Child Care Provider Demographics Questionnaire

Please circle answer or fill in the blank.

1. What is today's date? __________________________

2. What year were you born? __________________________

3. What is your gender?
   a. Male
   b. Female

4. What is your ethnicity?
   a. White/Anglo/Caucasian
   b. African American/Black
   c. Asian/Pacific Islander
   d. Latino/Hispanic
   e. American Indian/Alaskan Native
   f. Other

5. What is the main language spoken at the center?
   a. English
   b. Spanish
   c. French
   d. Tongan
   e. Chinese
   f. Other __________________________

6. What type of program do you have?
   a. Family Child Care Home
   b. Family Child Care Group
   c. Child Care Center
   d. Other __________________________

7. Are you accredited?
   a. Yes
   b. No

8. How many children are currently enrolled in your program or classroom? ____________

9. What is your program or classroom capacity? _______________

10. How many children receive state subsidy funds? _______________

11. How many years have you been providing child care? _______________

12. How many training activities have you participated in during the past 6 months? ______

13. Mark your highest level of education obtained:
    a. High school/GED
    b. Associates/2-year degree
    c. Technical degree
    d. 4-year degree
    e. Masters degree
    f. Ph.D
    g. Professional degree (i.e. law, dental, etc.)
    h. Other _________________________

14. Mark your current career ladder level:
    a. 0
    b. 1
    c. 2
    d. 3
    e. 4
    f. 5
    g. 6
    h. 7
    i. 8
    j. 9
    k. 10

15. Is there any other information you wish to share?

CURRICULUM VITAE

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Education

2013-2018 **Doctor of Philosophy (Ph.D.)** – Utah State University
Major: Family and Human Development
Emphasis: Infancy & Childhood
Dissertation: Preschool Children's Development in Number, Geometry, and Executive Function: A Cross-Lagged Examination

2007-2009 **Master of Education (M.Ed.)** – Utah State University
Major: Elementary Education
Emphasis: Level I Reading Endorsement

2003-2006 **Bachelor of Science (B.S.)** – Utah State University
Dual Major: Early Childhood Education & Elementary Education
Emphasis: Language Arts
Honors: Summa Cum Laude

1999-2001 **Associate of Science (A.S.)** – College of Eastern Utah
Major: Early Childhood Education
Honors: Academic & Service Learning

Research Interests

Preschool Mathematics and Executive Function: Relationships between elements of mathematics and executive function; spatial awareness; early number line; parent and teacher perceptions in relation to direct child observations; home numeracy environment

Childcare Quality: Quality Rating and Improvement Systems (QRIS), Environment

Rating Scales (ERS), childcare subsidies; elements of higher/lower quality programs; impact on families

Women's Leadership: Theories of leadership development; inter-disciplinary lenses; leadership among child care directors; teacher self-efficacy

Research Experience:

2014-Present **Project: Theories of Women's Leadership**
Role: Collaborative Researcher

2015-2018 **Project: SUNBEAM (Studying Urban and Non-Urban Behaviors, Environments, Attitudes, and Mathematics)**
Role: Project Co-Manager
Supervising Professor: Ann M. Berghout Austin, PhD – Family, Consumer, and Human Development, Utah State University

2013-2018 **Projects: Children's Numeracy; Utah QRIS Validation; Early Childhood Leadership**
Role: Graduate Research Assistant
Supervising Professor: Ann M. Berghout Austin, PhD – Family, Consumer, and Human Development, Utah State University

Teaching Experience:

2018-Present **Assistant Professor** – Family Life & Human Development; Southern Utah University

Courses:
FLHD 1500 – Human Development Through the Lifespan
FLHD 3200 – Child Development: Infancy Through Twelve
FLHD 3610 – Play & Advanced Guidance
FLHD 3700 – Principles of Effective Parenting
FLHD 4880 – Child Care Teaching Practicum
EDRG 4120 – Integrated Studies of Children's Literature

2012-Present **Trainer** – Care About Childcare

Courses: Guidance and Emotional Wellness, The Power of Development and Guidance, School Age, Theories and Best Practices, School Readiness Standards, The Director's Toolbox, Training for ASQ and ASQ-SE, Marketing Strategies, Learning in the Early Years, What Do You Do With the Mad That You Feel?, Medication Administration, Infant & Toddler Development, All About Twos, Ages & Stages

2014-2018 **Graduate Instructor** – Family, Consumer, and Human Development; Utah State University

Courses: WGS 3010 – Women and Leadership
FCHD 2660 – Parenting and Child Guidance

2016 **Teacher Mentor and Consultant** - Dolores Doré Eccles Center for Early Care and Education; Utah State University

2013-2014 **Teaching Assistant** – Family, Consumer, and Human Development; Utah State University

Courses: FCHD 3570 – Youth and Adolescence

2010-2013 **Lead Teacher** – Dolores Doré Eccles Center for Early Care and Education; Utah State University

2012 **Interim Program Administrator** – Dolores Doré Eccles Center for Early Care and Education; Utah State University

2009-2010 **Instructor** – Family, Consumer, and Human Development; Utah State University

Courses: FCHD 2600 – Seminar in Early Childhood Education
FCHD 2630 – Practicum in Early Childhood Education

2007-2010 **Lead Teacher/Coordinator** – Children's House; Utah State University

2006-2007 **Apprentice Teacher** – Wellsville Elementary (2nd Grade); Wellsville, Utah
Utah State University Mentor-Apprentice Collaboration Program

Invited Lectures:

2017 Utah State University - FCHD 6910/7910 – Parenting
Topic: Parenting and social-emotional development in early childhood.

2014 Utah State University - FCHD 2660 – Parenting and Child Guidance
Topic: Promoting self-esteem in children using positive guidance techniques.

Publications

Published:

Book Chapters:

Egan, C., Shollen, S. L., Campbell, C., Longman, K. A., Fisher, K., Fox-Kirk, W., & Neilson, B. G. (2017). Capacious model of leadership identities construction. In Storberg-Walker, J. & Haber-Curran, P. (Eds), *Theorizing Women and Leadership: New Insights and Contributions From Multiple Perspectives*, Women and Leadership: Research, Theory, and Practice Book Series. Charlotte, NC: International Leadership Association (ILA) & Information Age Publishing (IAP).

Esplin, J. A., Neilson, B. G., Austin, A. M. B., Blevins-Knabe, B., Hendershot, S., & Loesch, L. (2016). Number line skills and home numeracy activities for preschoolers in center-based and family-based child care. In Blevins-Knabe, B. Austin, A. M. B. (Eds), *Early Childhood Mathematics Skill Development in the Home Environment.* New York, NY: Springer.

In Preparation/Review:

Peer-Reviewed Journal Articles:

Esplin, J. A., Neilson, B.G., Austin, A. M. B., & Fronk, A. (*Under Revision*). Assessing the validity of Utah's self-report QRIS (Care About Childcare) with subsidy rate and center capacity as intervening factors.

Campbell, C. R., Shollen, S. L., Egan, C., & Neilson, B. G. (*Under Revision*). The capacious model and leader identity: An integrative framework.

Neilson, B. G., Esplin, J. A., Austin, A. M. B., Corwyn, R. F., & Blevins-Knabe, B. (TBD). Preschool children's development in number, geometry, and executive function: A cross-lagged examination.

Esplin, J. A., Neilson, B. G., Corwyn, R. F., Austin, A. M. B., & Blevins-Knabe, B. (TBD). Measuring preschool children's executive function.

Olson, T. L., Bradford, K., & Neilson, B. G. (TBD). Beyond parenting: Family stress in caring for children with autism spectrum disorder.

Practitioner Journal Articles:

Neilson, B. G., Austin, A. M. B., & Blevins-Knabe, B. (TBD). Encouraging

preschool children's mathematics development.

Presentations

Campbell, C., Shollen, S. L., Egan, C., & Neilson, B. G. (2018, October). Integrated capacious model of leadership identities construction: Self-assessment tool and program design template for leaders. Half-day, preconference workshop for the International Leadership Association (ILA) Annual Global Conference, West Palm Beach, FL.

Neilson, B. G., Esplin, J. A., Austin, A. M. B., Blevins-Knabe, B., & Corwyn, R. (2018, March). Mathematics, including geometry, and executive function skills at two points in time. Presented as part of a research paper symposium regarding measurement of children's mathematics at the Society for Research in Human Development (SRHD) Bi-Annual Conference, Plano, TX.

Campbell, C., Shollen, S. L., Egan, C., Longman, K., & Neilson, B. G. (2017, May). The capacious model: An integrative linchpin for leader identity theories. Presented at the 2nd Interdisciplinary Perspectives on Leadership Symposium, Mykonos, Greece.

Neilson, B. G., Blevins-Knabe, B., Austin, A. M. B., Esplin, J. A., & Loesch, L. A. (2017, April). Children's early mathematical development in a rural home numeracy environment. Presented at a poster symposium at the Society for Research in Child Development (SRCD) Biennial Meeting, Austin, TX.

Esplin, J. A., Neilson, B. G., Austin, A. M. B., Blevins-Knabe, B. & Loesch, L. A., (2016, April). Parent and teacher ratings of child executive functioning. Poster presented at the Society for Research in Human Development (SRHD) Bi-Annual Conference, Denver, CO.

Esplin, J. A., Neilson, B. G., Austin, A. M. B., Blevins-Knabe, B. & Loesch, L. A., (2016, April). Parent and teacher ratings of child executive functioning. Poster presented at the Utah State Student Research Symposium, Logan, UT. (Duplicate presentation were accepted/encouraged).

Neilson, B. G. (2015, October). Incorporating the state early learning standards in developmentally appropriate and fun ways: Mathematics standards. Invited presentation for the Utah Association for the Education of Young Children (UAEYC) playshop in Roosevelt, UT.

Egan, C. & Neilson, B. G. (2015, October). The capacious model of leadership identities construction: The five interconnected systems. Presented in a symposium at the Annual International Leadership Association Global

Conference, Barcelona, Spain.

Fox Kirk, W., Neilson, B. G. (2015, June). Understanding women's leadership identities: An ecological approach. Presented at International Leadership Association Women & Leadership Affinity Group Conference, Asilomar, CA.

Loesch, L., Neilson, B.G., Austin, A.M.B., Blevins-Knabe, B., Hendershot, S., & Esplin, J. (2015, March). Home numeracy and executive functioning. Presented at the Society for Research in Child Development (SRCD) Biennial Meeting, Philadelphia, PA.

Neilson, B.G. (2014, November). Improving emotional IQ: Effective listening & problem solving skills. Invited presentation for the Logan 1st Ward, Logan, UT.

Storberg-Walker, J. B., Madsen, S. R., Austin, A. M. B., & Longman, K. A. (2014, October) Listed in "other presenters" as Neilson, B. G. Presented with group at the ILA Pre-Conference session: Advancing Theories of Women & Leadership, San Diego, CA.

Neilson, B.G. & Olson, T. L. (2014, April). Beyond parenting: Family stress in caring for children with autism spectrum disorder. Poster presented at the Utah State Inclusive Excellence Symposium and Graduate Research Symposium, Logan, UT. (Invited to present same research at both symposia.)

Neilson, B.G. (2014, April). Standards and sanity: You can have both! Invited keynote address at UAEYC Mini Conference, Wasatch Christian School, Ogden, UT.

Thompson, B.G., Esplin, J., Blevins-Knabe, B., Austin, A.M.B., & Hendershot, S.M., (2014, March). Correlations of children's home numeracy and cognitive abilities. Poster presented at the Society for Research in Human Development (SRHD) Bi-Annual Conference, Austin, TX.

Thompson, B.G., Swindell, J.L., & Strader, W.H. (2013, November). Nurturing future leaders in early childhood student clubs and organizations. Presented at NAEYC Annual Conference & Expo, Washington, DC.

Thompson, B.G. (2013, April) Home, school, and community: Making meaningful connections. Presented at Utah Early Childhood Conference, Salt Lake City, UT and at Northern Utah Early Childhood Conference, Logan, UT (2012, October).

Hudson, H.D. & Thompson, B.G. (2013, April) Healthy food programs for children. Presented at Utah Early Childhood Conference, Salt Lake City, UT.

Thompson, B.G. & Swindell, J.L. (2012, November). Creating a student early childhood club or organization: We are the future of NAEYC. Presented at NAEYC Annual Conference & Expo, Atlanta, GA.

Martin, A.M. & Thompson, B.G. (2012, April). Poetry in preschool. Presented at Utah Early Childhood Conference, Orem, UT.

Martin, A.M. & Thompson, B.G. (2011, November). Teaching poetry to primary grade students. Presented at NAEYC Annual Conference & Expo, Orlando, FL.

Strader, W.H., Johnson, K., Swindell, J.L., Thompson, B.G., & Jamsek, M. (2011, November). Future leaders in early childhood panel: New directions for early childhood clubs and organizations on college and university campuses. Presented at NAEYC Annual Conference & Expo, Orlando, FL.

Rich, K., Eller, K., & Thompson, B.G. (2011, April). Preschool nutrition education and influences on food neophobia. Presented at Utah Early Childhood Conference, Orem, UT.

Strader, W.H., Swindell, J.L., & Thompson, B.G. (2010, November). College and university early childhood clubs and organizations: Constructing opportunities for meaningful student leadership. Presented at NAEYC Annual Conference & Expo, Anaheim, CA.

External Funding

2018 **Graduate Student Travel Award** - $300

2017 **Graduate Student Travel Award** - $300

2016-2017 **Grant-Writing Seminar**

2014-2015 **Graduate Grant-Writing Experience**
Co-Authored, with Dr. Ann M. Berghout Austin, the following grants:

2015 – Utah Agriculture Experiment Station (AES) - $24,186 grant for the Studying Urban and Non-Urban Behaviors, Environments, Attitudes, and Mathematics (SUNBEAM) research project.

2014 – C. Charles Jackson Foundation – $5,000 grant for the Advancing Theories of Women's Leadership (ATWL) Colloquium.

Professional Service

2014-2017	**Conference Proposal Reviewer** for the following: Society for Research in Child Development (SRCD) Society for Research in Human Development (SRHD) Women and Leadership Affinity Group (WLAG) National Association for the Education of Young Children (NAEYC)
2007-2017	**Board Member** Utah Association for the Education of Young Children (UAEYC) Positions Held: Past-President, President, Secretary, Affiliate Liaison, Student Liaison, Student Representative
2010-2016	**Interest Forum Facilitator** Student Interest Forum of the National Association for the Education of Young Children (NAEYC)

<u>Membership in Professional Organizations:</u>

2014-Present	Society for Research in Child Development (SRCD)
2014-Present	Society for Research in Human Development (SRHD)
2014-Present	International Leadership Association (ILA)
2008-Present	National Association for the Education of Young Children (NAEYC)
2008-Present	Utah Association for the Education of Young Children (UAEYC)
2014-2015	National Women's Studies Association (NWSA)

Awards & Recognition

2017	**Certificate of Appreciation and Recognition** Utah Association for the Education of Young Children Presented as acknowledgement and gratitude for 10 consecutive years of board service
2016	**Scholarship Recipient** - $1,000 William H. and Stella Young Griffiths Scholarship

Utah State University – Department of Family, Consumer, and Human Development

2015 **Scholarship Recipient** - $1,750
Ferne Page West Scholarship
Utah State University – Dean's Office; Emma Eccles Jones College of Education and Human Services

2015 **Scholarship Recipient** - $2,000
Harriet Ann Richards Rasmussen Scholarship
Utah State University – Department of Family, Consumer, and Human Development

2007 **Undergraduate Scholar of the Year**
Utah State University – Elementary Education Department

2006 **Scholarship Recipient** - $1,000
College Scholarship
Utah State University – College of Education & Human Services

2006 **Distinguished Service Award**
Associated Students of Utah State University (ASUSU)
Awarded for service project work with the College of Education and Human Services (CEHS) student council.