Towards an understanding of early childhood mathematics education: A systematic review of the literature focusing on practicing and prospective teachers

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Abstract
This article presents the results of a literature review spanning 15 years (2000–2015), identifying empirical research relating to early childhood mathematics education. A total of 1141 articles were identified and examined in order to determine the current state of research in terms of location, participants, research questions, and the research methodology commonly used in this body of literature. Following a discussion of the overarching view of the literature, the authors present an analysis of a subsection of the literature, focusing on practicing and prospective teachers’ practice.

Keywords
Early childhood, literature review, mathematics, teacher practice

The growing field of early childhood mathematics has gained international attention, as seen in increased funding for initiatives such as curriculum development (Clements and Sarama, 2007), improving teacher quality (Thornton et al., 2009), and examining young children’s capacity to engage in mathematical thinking (Baroody et al., 2008, 2009). In addition, current legislation promoting early intervention and school readiness (e.g. the Every Student Succeeds Act and the Early Years Learning Framework for Australia) has a particular focus on young children being cognitively prepared in multiple domains, including mathematics. Further, education organizations have cited the importance of early childhood mathematics in promoting the development of the cognitive domain for young children (e.g. Australian Association, 2006; National Association, 2002;
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National Council, 2013). Studies have identified mathematics ability or understanding at age three
or four as a predictor of success in both mathematics (Wolfgang et al., 2003) and literacy (Hanline
et al., 2010) in kindergarten and as children progress through school. There are varying and some-
times oppositional perspectives on what mathematics young children can or should learn, how this
content should be implemented in classroom settings, how we should assess or evaluate mathematic-
s understanding, and what role, if any, play should take in early childhood mathematics. Some
identify current early childhood instructional practices as push-down approaches where increased
expectations for content are seen as developmentally inappropriate (Wilson, 2009). Others view
play-based experiences as a method of increasing exposure to mathematical content for young
children in a positive way (Van Oers, 2010). With this increased emphasis on the role of mathemat-
s in early childhood education, it is critical to better understand the growing body of research and,
in particular, the role that schooling can or should play in promoting young children’s dispositions
towards and understandings of mathematics.

Questions emerge when making conjectures about early childhood research as to whether find-
ings from formal schooling contexts are generalizable to informal contexts (i.e. preschool or infant
and toddler settings) prior to kindergarten (in the USA). In addition, it is unclear how increased
emphasis on early childhood mathematics is influencing teachers and children in traditionally mar-
ginalized settings. When considering the role of mathematical content knowledge and beliefs about
teaching mathematics in promoting progressive pedagogical practices in mathematics, what are the
implications for early childhood teachers who often display higher levels of mathematical anxiety
(Gresham, 2007), lower levels of content knowledge (Perry et al., 2007), and more traditional
beliefs (Chang-Kredl and Kingsley, 2014) about teaching mathematics? These questions and more
are relevant for international contexts and point to the need for a critical analysis of the types of
research being disseminated, the topics of focus, and the relevant implications. To that end, we
completed an extensive review of the research literature related to early childhood mathematics
over the past 15 years. Although literature reviews exist relating to mathematics education (e.g.
Carbonneau et al., 2013), there are few extensive reviews of the research literature that primarily
focus on early childhood education (birth through age eight). This article provides an overarching
view of the areas of focus related to early childhood mathematics emerging from the research iden-
tified through this review. Additionally, while all areas of early childhood mathematics were
included in this comprehensive review (professional development, instructional practice, student
achievement, student knowledge and dispositions, curriculum development, etc.), this article syn-
thetizes only a subportion of the identified areas, focusing on topics related to teachers (i.e. instruc-
tional practice and practicing and prospective teacher development). Future articles will synthesize
findings from other areas identified in this literature review.

Findings from similar reviews
In a cursory examination of current literature reviews, syntheses, or meta-analyses related to math-
ematics education, we determined that there were very few articles that presented an overarching
view of the literature in early childhood mathematics. In fact, only three literature reviews related
specifically to early childhood mathematics were identified (Anthony and Walshaw, 2009; Fox and
Diezmann, 2007; Linder et al., 2013). In an effort to move towards a better understanding of this
body of work, we also examined alternative reviews of literature related to either the cognitive
domain of early childhood education or, specifically, elementary mathematics education, as the
parameters for these searches often included kindergarten (age five) through third grade (age
eight). Specifically, we examined three additional large-scale literature reviews—two in early
childhood education and one in elementary mathematics education (Carbonneau et al., 2013; Horm
et al., 2013; Matthews, 2013). While reviews examining middle and secondary mathematics education have been published, we chose to limit our examination of these areas because they were not tangentially related to the early childhood years in terms of development, standards for learning and practice, or connections to external influencers such as home and community environments. These articles informed the framework for the selection criteria used in the present study and provided insight towards building an understanding of mathematics in early childhood as a subdomain of these literature reviews.

In 2009, Anthony and Walshaw examined literature related to early childhood mathematics in volume 10 of *Contemporary Issues in Early Childhood*. In this review of the literature, the authors identified a lack of research related to the early childhood years as a confounding factor when making conjectures based on the research literature regarding the development of young children’s identity related to mathematics. In addition, the authors cautioned that a barrier seemed to exist between research focusing on the preschool years and research focusing on the older early childhood years (ages five to eight), which needed to be addressed in order to truly understand mathematics development in young children. Further, the authors posited that young children will learn most effectively when learning opportunities are connected to their own contexts and a balance is struck between teacher-initiated and play-focused activities. Linder et al. (2013) discussed potential predictors of success related to school readiness in mathematics and literacy, or the successful transition from informal schooling (prior to kindergarten in the USA) to formal schooling (kindergarten and beyond). In their results, the authors identified seven themes related to factors that may be associated with increased school readiness. These themes ranged from environmental (e.g. high-quality childcare, home environments, health, and socio-economic status) to personal and interactional (family structure and parenting, social behavior), to learning opportunities (mathematically based tasks). This review of the literature focused mainly on the point of view of the child and did not address issues such as teacher quality and preparation, professional development, assessment, or curricula in early childhood mathematics. Fox and Diezmann (2007), on the other hand, looked specifically at early childhood mathematics through a review of 208 articles published between 2000 and 2005. They provided an overview of the types of journals where this research was published, the age range of participants, and the types of topics that were present in each of the identified articles. The findings from this review indicate that the majority of early childhood mathematics-education research between 2000 and 2005 focused on kindergarten through third grade, and did not adequately address the birth-to-five context. In addition, the authors identified a lack of focus on problem-solving and the use of technology in early childhood settings.

In terms of more general mathematics-education literature reviews, Carbonneau et al. (2013) conducted a meta-analysis of 55 studies that examined mathematics teachers’ self-efficacy related to using concrete manipulatives with their students of varying grade levels (kindergarten to undergraduate education). As they were dealing with a broad range of ages, the authors divided the studies into three categories based on Piaget’s stages of development (preoperational, concrete operational, and formal operational). The findings from this review indicate that providing manipulatives to children at the concrete-operational stage (ages 7–11) can have a positive impact on their ability to construct meaning through mathematical representations. However, the authors also reported that providing manipulatives for young children (ages three to six, or the preoperational stage) did not provide the same impact. The reasons for this discrepancy were not described within the context of this review, and it was unclear what percentage of the 55 articles included in this review pertained to the early childhood years as compared to upper-elementary, middle, and secondary. Also focusing on the role of the teacher, Matthews (2013) reported on a literature review of how the framework for pedagogical content knowledge has influenced the field of mathematics education. Matthews placed an emphasis on pedagogical content knowledge at the elementary
level, or what is assumed to be kindergarten through fifth grade (although this is never explicitly stated).

In the field of early childhood, literature reviews are often centered around domains of development (e.g. cognitive, social/emotional, physical, language). In 2013, Horm et al. used three different domains, “addressing the needs of young children with disabilities; understanding and working effectively with infants and toddlers; and building young children’s competence and interest in mathematics” (97), when conducting a large-scale review of research in early childhood education. The rationale for these three domains was that they are all generally underinvestigated in the research literature. Although demographic information about the number and types of studies included in this review was unclear, the findings from the domain relating to early childhood mathematics indicated that, in terms of pre-service preparation, an emphasis on literacy coursework over mathematics coursework is prevalent in most undergraduate early childhood programs. In addition, field experiences directly related to early mathematics are limited. The research gaps identified by Horm et al. (2013) include the need for an examination of the impact of the Common Core State Standards in relation to early childhood mathematics.

The present study complements and extends these literature reviews by expanding the time period of analysis and by examining all areas of early childhood mathematics, moving past a singular focus on a particular topic or sample. We aim to provide a breadth of understanding as to the types of research that predominate in the field, and then a depth of understanding as to the implications for one particular area of research (relating to practicing and prospective teachers) for both theory and practice.

Methods

Using the approaches from similar literature reviews in early childhood and mathematics education as a guide, we established a set of parameters for this extensive search of the literature. Articles were included in this review if they met the following criteria: (1) they were empirical research published in peer-reviewed journals between 2000 and 2015; (2) they were written in English; (3) they focused on mathematics within the early childhood years (birth through age eight) (longitudinal studies extending beyond third grade were included if the research questions were relevant to early childhood mathematics); and (4) they were situated in a classroom context (studies focusing on family home environments were excluded). In addition, we excluded articles examining connections between health-related concerns (i.e. obesity) and mathematical outcomes in young children as the independent variable (health-related concern) was external to classroom settings. The rationale for including articles published in 2000 or beyond is strengthened by a study conducted by Lubienski and Bowen (2000) in which they were only able to identify a total of 2 articles out of over 3000 published research studies between 1982 and 1998 that were germane to early childhood mathematics. Articles were identified through electronic searches in a variety of social science databases (e.g. Academic Search Complete, Education Resources Information Center (ERIC), Education Research Complete, SocINDEX, PsycINFO, and Professional Development Collection) over the course of three months between January 2015 and March 2015. Table 1 outlines the search terms that were used to identify articles. The majority of the articles that were extracted using these search terms were non-empirical in nature. Those that met the set criteria were downloaded and stored in a cloud-based system housed at Clemson University, and we used both Excel and SPSS to organize and analyze each article as it was identified.

This search was then updated again in January 2016 in order to determine if additional publications should be included. All of the articles were then cross-referenced with a sampling of previously published literature reviews (Anthony and Walshaw, 2009; Carbonneau et al., 2013; Linder
et al., 2013; MacDonald et al., 2012, 2016; Perry et al., 2008; Raghubar et al., 2010; Zaslow et al., 2010) in addition to a sample of highly cited articles published in top-tier early childhood or mathematics-focused journals (Camilli et al., 2010; Chang-Kredl and Kingsley, 2014; Duncan et al., 2007; Howes et al., 2008; McClelland et al., 2006; Magnuson et al., 2007).

A total of 1141 articles were included for review. Once a pool of articles was established, we conducted in-depth readings of each article to identify the following information: (1) the location of the research; (2) the age group or grade level of focus; (3) the mathematical content of focus; (4) the research questions and methodology; (5) the overarching purpose of the research; and (6) the findings and implications. Once this information was ascertained for each article, we quantitized (Sandelowski et al., 2009; Tashakkori and Teddlie, 1998) the overarching demographic information (i.e. location of research, age group or grade level, content of focus, and type of research methodology) to provide a holistic view of the types of research that have been conducted in early childhood mathematics over the past 15 years.

Following this analysis, we conducted a qualitative analysis of the research purpose, findings, and implications for the 1141 articles using a constant comparative method (Corbin and Strauss, 2008). We examined the methods, results, and implications sections of each article and identified the dependent variable of focus and the independent variable(s) of focus, if applicable. For example, in a study examining a professional development intervention on kindergarten teachers’ mathematics instruction, the dependent variable was teacher practice and the independent variable was a professional development intervention. The dependent variables identified were those that related primarily to children, teachers, or the classroom environment. With this framework, the articles had the potential to be clustered under more than one category—for example, an article might focus on how a specific intervention could influence both teacher practice and student achievement (e.g. Cankoy, 2011). The majority of the articles focused on research questions relating to children’s achievement in mathematics (70%). In addition, articles examining teacher practices and dispositions towards and understandings of early childhood mathematics were also prevalent in the research (21%). Table 2 outlines the overall topics emerging from the analysis.

Table 1. Search terms for identifying articles.

<table>
<thead>
<tr>
<th>Search terms</th>
<th>Number of articles relevant to early childhood mathematics</th>
<th>Quantitative</th>
<th>Qualitative</th>
<th>Mixed</th>
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<tbody>
<tr>
<td>“early childhood” and “mathematics”</td>
<td>380 out of 1388</td>
<td>250</td>
<td>78</td>
<td>52</td>
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<td>“early childhood” and “math*”</td>
<td>125 out of 1890</td>
<td>99</td>
<td>19</td>
<td>7</td>
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<tr>
<td>“child care*” and “math*”</td>
<td>13 out of 745</td>
<td>13</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>“young children” and “math*”</td>
<td>109 out of 1359</td>
<td>79</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>“infant*” and “toddler*” and “math*”</td>
<td>1 out of 89</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>“prekindergarten” and “math*”</td>
<td>9 out of 114</td>
<td>6</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>“preschool*” and “math*”</td>
<td>88 out of 1345</td>
<td>77</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>“kindergarten*” and “math*”</td>
<td>70 out of 1227</td>
<td>60</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>“grade 1” or “first grade” and “math*”</td>
<td>54 out of 5017</td>
<td>41</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>“grade 2” or “second grade” and “math*”</td>
<td>58 out of 2100</td>
<td>41</td>
<td>13</td>
<td>4</td>
</tr>
<tr>
<td>“grade 3” or “third grade” and “math*”</td>
<td>72 out of 11,935</td>
<td>51</td>
<td>14</td>
<td>7</td>
</tr>
<tr>
<td>“elementary*” and “math”</td>
<td>143 out of 9252</td>
<td>94</td>
<td>24</td>
<td>25</td>
</tr>
<tr>
<td>Cross-referencing</td>
<td>19 additional</td>
<td>16</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: * indicates similar wording—for example, “math*” could mean “mathematics” or “maths.”
Following this primary analysis, we clustered articles according to the dependent variables and treated each cluster as an independent data set. For each cluster, we used the independent variables as categories, and open-ended coding strategies to identify emerging themes within each category (Saldaña, 2013).

Findings

In what follows, we first discuss general descriptive information regarding the overall literature review in terms of where and with whom research in early childhood mathematics is being conducted, and the type of methodology commonly used in this research. We then focus on a discussion of findings specifically related to a subsection of the articles identified in the entire review: scholarly research involving practicing and prospective early childhood mathematics teachers. The results of the teacher-practice subsection of the literature are described through four themes that were identified by a qualitative analysis of the articles: content, disposition, practice, and transformation. Because of the overall size of the literature and the many topics identified within it, we are focusing this article on findings related to teachers. Studies relating to alternative topics (e.g. student achievement or dispositions towards mathematics, curriculum implementation) will be reported in separate articles. We chose to begin with this subsection of articles rather than those related to student achievement (the largest proportion of the identified articles) because oftentimes the independent variables for articles focusing on student achievement were related to teacher practice. Having a better understanding of the research related to teacher practice will allow us to make comparisons when analyzing the student-achievement subsection of the articles in a future study.

Descriptive information

The inclusion of 1141 articles in this review is a significant finding in and of itself. When Fox and Diezmann (2007) published findings from a similar literature review examining early childhood mathematics between 2000 and 2005, only 208 articles met the criteria for inclusion. In just over a decade (between 2005 and 2015), research in early childhood mathematics has grown at a tremendous rate. This research is being published in a variety of peer-reviewed journals, ranging from those focused on early childhood education to those focused on assessment and evaluation. Of the 1141 articles identified through this study, 23% were published in journals specific to psychology;
19% in journals specific to early childhood education; 13% in journals specific to mathematics education; 10% in journals specific to cognition and learning; 10% in technology-focused journals; 9% in general educational research journals; 7% in journals related to special and gifted education; 2% in journals focused on teacher education; 2% in assessment-and-evaluation-focused journals; 1% in journals related to elementary education; and 2% in journals categorized as “Other.”

In terms of methodology, the majority of the studies used a quantitative approach (77%). When examining specific quantitative designs, we found that only 11% of the articles used an experimental or quasi-experimental approach. More often, the studies used a descriptive (30%) or correlational (27%) approach. In contrast, 15% of the studies included for review used a qualitative approach, with the majority classifying their design as a case study (27%). While 8% of the articles self-identified as mixed-methods research, often there was little to no discussion of how the data was mixed in the studies and, oftentimes, the actual description of methods was heavily quantitative (a survey with one or two open-ended questions) or heavily qualitative (using some descriptive data to support qualitative findings), and did not use mixed-methods-centric terminology for sampling, validity, or mixing.

When examining the results as a whole, we identified a significant lack of research occurring in preschool (age four) or below. While early childhood spans the age range from birth to eight, only 5% of the included research focuses on the infant and toddler or birth-to-two age span. The overwhelming majority of research (88%) in early childhood mathematics focuses on formal schooling, defined as kindergarten through grade three in the USA. It is unclear why this trend towards conducting research in formal school settings (what is considered kindergarten, or age five, and beyond in the USA) as opposed to informal settings (public and private childcare, home-based childcare) has emerged. It could potentially be related to the abundance of confounding factors that could be present when conducting research in informal settings. It is clear, however, that based on this finding alone, making conjectures that are grounded in research about early childhood mathematics for preschool and below can be difficult, if not impossible.

A similar finding was identified related to the mathematical content of focus within this literature. While research focused on concepts related to number and operations was prevalent (44%), research relating to other mathematical content areas was limited: algebra (4%), geometry (7%), measurement (4%), data analysis (2%). This lack of focus on other content areas within early childhood mathematics is concerning when considering that developing number sense is often cited as an indicator of school readiness (e.g. Le Corre et al., 2006; Manfra et al., 2014), and that number concepts pervade assessments in early childhood education, while other content areas are far less represented. Increased research relating to content areas other than number and operations is critical to better understand how each influences mathematical development in young children.

In terms of demographics, the overwhelming majority of studies took place in settings within the USA (57%), followed by Australia (5%), England (4%), Belgium (4%), the Netherlands (3%), and Finland (3%). Sample sizes ranged from very small (between 1 and 30 participants) to very large (between 5000 and 10,000 participants) and were mainly dependent on the methodology used in the study. Specifically, 22% of the 1141 studies had 30 or less participants; 32% of the studies had between 31 and 99 participants; 29% had between 100 and 499 participants; and 14% had above 500 participants.

**Practicing and prospective early childhood teachers**

Of the 1141 studies included in this review, 164, or approximately 14% of the total sample, included a dependent variable specific to practicing and/or prospective teachers; specifically, 126 studies examined practicing teachers (77%), 33 studies examined prospective teachers (20%), and 5 studies
examined both practicing and prospective teachers (3%). Through our analysis, we categorized the independent variables as content, disposition, adapted practice, and transformation. Figure 1 displays the percentage of studies per category, which accounted for studies investigating more than one independent variable, such as content and disposition. Figure 1 also presents the percentage of studies examining practicing or prospective teachers within each category (Dark is for prospective and light is for practicing).

In studies categorized as “content,” the researchers were interested in a variety of content, including mathematical content knowledge and/or domains within the Mathematical Knowledge for Teaching (MKT) framework (Hill et al., 2008). Studies in which the researchers were concerned with practicing and prospective teachers’ beliefs, attitudes, and/or perceptions about mathematics, teaching mathematics to young children, their role as a teacher, and self were categorized as “disposition.” The category of “adapted practice” included studies examining the implementation of various instructional methods, typically within the moment of teaching itself, such as the use of manipulatives, extending children’s mathematical thinking, or orchestrating a productive discussion. Other studies included within this category were self-reported data of instructional practices integrated as part of instruction. The last category, “transformation,” included studies in which the researchers were interested in examining a change in practicing and prospective teachers’ content, disposition, and/or practice due to an intervention such as a professional development project, a workshop, a course, or a task. Table 3 lists the studies included in this review by country. The percentage does not add up to 100 as a few of the studies included more than one country.

When examining the number of publications per year for the scholarly work included in this subsection of the literature review, we identified a trend of increasing numbers of publications focusing on teacher practice from 2003 (only 2 articles were published during this year) to 2007 (with 13 articles published this year). This trend continued upwards until 2013, with 26 articles published during that year, and then began to decrease in 2014–2015 with totals ranging from 15 to 20 articles per year. Below, we describe in more detail each of the categories emerging from this analysis (content, disposition, adapted practice, transformation). Due to space limitations and the amount of research studies synthesized in this article, not every article is cited but is accounted for within general statements. In the reference list, each study from the review cited in this article is indicated with an asterisk (*).1

**Content.** As noted in Figure 1, studies investigating early childhood practicing and prospective teachers’ content knowledge of mathematics were the least common, accounting for 15% of the total studies in this area. Of these, 56% of the studies examined the content knowledge of prospective teachers, while 44% examined the content knowledge of practicing teachers. Yet there was an apparent difference in the types of content knowledge being investigated between the two groups, as many of the studies involving prospective teachers examined their mathematical content knowledge; on the other hand, those involving practicing teachers often investigated the domains of MKT, particularly pedagogical content knowledge.

Based on a specific mathematical concept (e.g. fractions, proportional reasoning, multiplication) and the manner in which it was assessed (e.g. course grade, standardized test, task-based assessment), the results regarding prospective teachers’ content knowledge in mathematics varied. Bates et al. (2011), for example, found the 89 early childhood participants in their study to have a strong mathematical foundation (mean: 257.44 out of 300). On the other hand, the majority of the research suggests that prospective teachers are lacking procedural and conceptual understandings in certain content areas, such as polygons (Canturk-Gunhan and Cetingoz, 2013; Erdogan and Dur, 2014), proportional reasoning (Pitta-Pantazi and Christou, 2011), variables and equations (Tanisli and Kose, 2013), and multiplication of two 3-digit numbers (Maher and Muir, 2013). Limited
research suggests that no differences in mathematical performance were due to a person’s gender (Duru, 2011) or cognitive learning style (Pitta-Pantazi and Christou, 2009).

Moreover, research suggests that prospective teachers have difficulty in evaluating and understanding students’ explanations and misconceptions (Canturk-Gunhan and Cetingoz, 2013; Fernández et al., 2013; Jacobs et al., 2010; Maher and Muir, 2013; Morris, 2007; Tanisli and Kose, 2013), and responding through appropriate strategies and questions (Maher and Muir, 2013; Tanisli and Kose, 2013). But studies including practicing teachers suggest that such skills and understandings can be developed with time or years of experience (Foote, 2009; Jacobs et al., 2010; Lee, 2010; Warfield, 2001) and, as argued by Cengiz et al. (2011), it may depend on practicing teachers’ proficiency in all three domains of MKT. By way of example, Jacobs et al. (2010) noted how one’s ability to attend to, interpret, and respond to children’s mathematical thinking develops with expertise in the field. Beyond any differences based on experience, Zhou et al. (2006) concluded that

Figure 1. Percentage of studies by category and participants.
teachers in the USA are significantly underdeveloped in certain areas of subject matter knowledge and pedagogical content knowledge compared with Chinese teachers.

**Disposition.** Thirty-one or 19% of the studies examined practicing and prospective teachers’ dispositions regarding mathematics and how they influence instruction—namely, beliefs and attitudes about mathematics, mathematics teaching and learning, and developmentally appropriate mathematics for young children, and self-perceptions regarding mathematics ability and their role as a teacher of mathematics. Unlike the studies discussed in the content category, there was no clear distinction of what disposition was examined between groups and, in general, the results are inconclusive. In considering practicing and prospective teachers’ dispositions, there seem to be other factors influencing or shaping their beliefs and attitudes about mathematics and self. These include, but are not limited to, previous experiences with mathematics as a student (Hodgen and Askew, 2007; Lake and Kelly, 2014; McCulloch et al., 2013; Zacharos et al., 2007), mathematics anxiety (Isiksal et al., 2009), the student body (Lee and Ginsburg, 2007b), and “official” requirements and accountability (Gujarati, 2013; Hanley and Jones, 2007; Vernaza, 2012).

The studies suggest that, more often than not, practicing and prospective teachers have a positive outlook on their ability to teach mathematics to young children (Bates et al., 2011; Brown, 2005; Chen et al., 2014; Dunphy, 2009; Ertekin, 2010; Paparistodemou et al., 2014; Thronsden and Turmo, 2013; Yavuz et al., 2013), and view certain mathematical tools, such as virtual and physical manipulatives (Akkan, 2012), and computers or mobile learning devices (Doğan, 2012), to be beneficial instructional tools. As an example of the former, in a study with 346 preschool teachers, Chen et al. (2013) found that 86% were confident in their ability to observe what preschoolers knew about mathematics, 84% in their ability to plan activities, and 67% in their ability to make sense of preschoolers’ confusion.

Moreover, practicing teachers expressed the belief that teaching mathematics should be child-centered and implemented within a safe and playful environment free of stress (Benz, 2012; Franzén, 2014; Herron, 2010; Hunting et al., 2012; Jung and Reifel, 2011; Lee, 2005; Lee and Ginsburg, 2007b; Siraj-Blatchford and Nah, 2014). Hunting et al. (2012), for instance, found that 64 preschool teachers from rural areas of Australia discussed child-centered mathematical

<table>
<thead>
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<th>Country</th>
<th>Percentage</th>
<th>Country</th>
<th>Percentage</th>
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<tr>
<td>Australia</td>
<td>7.9</td>
<td>Lesotho</td>
<td>0.6</td>
</tr>
<tr>
<td>Botswana</td>
<td>0.6</td>
<td>Netherlands</td>
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<td>Canada</td>
<td>1.8</td>
<td>New Zealand</td>
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</tr>
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<td>Norway</td>
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<td>Samoa</td>
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</table>

**Table 3.** Percentage of studies by country.
practices as, among other things, encouraging children to ask questions; providing a choice of activities and open-ended play experiences; building off prior knowledge; and teaching without forcing the pace. There are a few instances in which practicing and prospective teachers’ beliefs were more teacher-centered, such as considering children’s results more than their process (Dunphy, 2009; Ertekin, 2010; Throndsen and Turmo, 2013), which may be due to their experience in the field (Thiel, 2010).

For some, there was the belief that mathematics should be, and was, incorporated within the daily classroom routines, such as setting the table for lunch (Benz, 2012; Ertekin, 2010; Lee and Ginsburg, 2007a). On the other hand, a few studies noted how teachers who work with young children prior to kindergarten do not always value mathematics over other skills such as social-emotional and explicit language skills (Simpson & Linder, 2014; Blevins-Knabe et al., 2000; Kowalski et al., 2001), and view mathematics as a static body of knowledge to be learned (Zacharos et al., 2007). Also, in considering some of the literature regarding practicing and prospective teachers’ dispositions, it seems as if they are negotiating between their identity as a mathematics teacher and prior experiences versus their identity as a teacher of young children (Gujarati, 2013; Hodgen and Askew, 2007; McCulloch et al., 2013), or between beliefs in their own mathematics ability and their role in teaching mathematics (Bates et al., 2011; Chen et al., 2014; Lee, 2005; Olander and Nyberg, 2014), or between their beliefs in teaching mathematics and their approaches to mathematical instruction (Brown, 2005; Doğan, 2012; Olander and Nyberg, 2014; Throndsen and Turmo, 2013). As an example of this back-and-forth interplay, Gujarati (2013) concluded that for three early career third-grade teachers, there was an inverse relationship between their negative personal beliefs regarding their abilities in mathematics and the amount of effort they put into being a mathematics teacher so as to ensure that their students had positive mathematical experiences.

Adapted practice. Of the 164 studies in this literature review, approximately 39% or 64 studies examined practicing teachers’ (97%) adapted practices within the classroom environment—in other words, practices as they unfolded naturally in the classroom as a result of an intervention, such as the implementation of techniques, materials, or strategies that were different or in addition to their typical instructional practice. The majority of these studies can be further categorized as investigating practicing teachers’ implementation of curricular material, mathematical content, and standards (26%); general instructional strategies and methods (32%); and classroom discourse and communication (28%). There was a relatively smaller number of studies (14%) focused on specific content practices and strategies such as counting (Guha, 2006), place value (McGuire and Kinzie, 2013), metacognition (Whitebread and Coltman, 2010), and the utilization of books (Carlsen, 2013).

The mathematical content implemented by practicing teachers in their classroom seemed to vary depending on their country. In the USA, counting was emphasized more often than measurement and telling the time (Blevins-Knabe et al., 2000; Gonzales and Paik, 2011; Hindman, 2013; Parks and Bridges-Rhoads, 2012; Rowan et al., 2004). For example, Rowan et al. (2004) noted how 509 practicing teachers across 53 schools focused on number concepts for 24% to 32% of the days over a year, and operations were taught for about 40% of the days over a year. In South Africa, geometry ranked the highest and data analysis the lowest (Botha et al., 2005). In Taiwan, teachers more often focused on shapes and, in Peru, the focus was on telling the time (Gonzales and Paik, 2011).

Additionally, in attempts to target lesson objectives and standards, as well as implement a new mathematical curriculum, research suggests that practicing teachers have difficulties in enacting and integrating lessons and the curriculum as intended (Brown et al., 2009; Moloi et al., 2008; Zacharos et al., 2014), which may be mediated by an over-reliance on textbooks (Henry and Brown, 2008), inadequate resources (Hu et al., 2014), or a lack of evidence-based strategies (Phillips and...
Morse, 2011). On the other hand, in a study conducted by Stein and Kaufman (2010), the findings indicated that practicing teachers’ implementation of the *Investigations* (textbook series) afforded them opportunities to maintain high cognitive demand, attend to students’ thinking and reasoning, and plan lessons with big mathematical ideas in mind when compared to practicing teachers’ implementation of the *Everyday Mathematics* (textbook series).

The implementation of mathematics content and curriculum in a classroom setting has also been studied by examining the general instructional strategies and methods employed by practicing teachers. The results from this literature review highlight the competing discourse between, and the implementation of, traditional teaching practices (e.g. teacher-centered worksheets) and non-traditional or reform-based teaching practices (e.g. child-centered, open-ended tasks). On the one hand, practicing teachers were noted as utilizing open-ended and/or meaningful tasks (Cahnnmann and Remillard, 2002; Frid and Sparrow, 2009; Papademetri-Kachrimani, 2015), relevant manipulatives and technology (Frid and Sparrow, 2009; Lee, 2005), different solution paths (Frid and Sparrow, 2009; McClain and Cobb, 2001), and collaborative groups (Georges, 2009). On the other hand, practicing teachers are still prone to employ teacher-led demonstrations (Gonzales and Paik, 2011; Meijnen et al., 2003) and worksheets (Feza, 2014), which may be due to a lack of resources (Feza, 2014) or years of teaching experience (Meijnen et al., 2003). Moreover, it seemed as if some teachers were still grappling with the transition from a prospective to a practicing teacher (Towers, 2010), from reported self-perceptions to observed practices (Brown, 2005), or from the use of a student’s home language to an official school language (Kasule and Mapolelo, 2005). For example, Towers (2010) described not only a novice teacher’s struggle to enact inquiry-based teaching practices, but also his inability to articulate his understandings of inquiry-based teaching to others, which led to problems around collaboration and administrative evaluations.

The scholarship in this study regarding classroom discourse and communication includes both verbal (e.g. Boonen et al., 2011) and non-verbal communication (e.g. Flevares and Perry, 2001). Practicing teachers seem to employ various mathematical talk moves or communication strategies, such as, among others, questions and dialogue to check for student understanding (Wiebe Berry and Kim, 2008), intentional pauses (Cohrssen et al., 2014) and listening (Fleener et al., 2004), encouraging and using appropriate mathematical terms (Cooke and Buchholz, 2005; Rudd et al., 2008), and eliciting students’ mathematical thinking and justifications (Björklund and Pramling-Samuelsson, 2013; Tatsis et al., 2008; Warren and Cooper, 2005). These may be accounted for within the developmental trajectory of building a Math-Talk Learning Community, as developed by Hufferd-Ackles et al. (2004). These communicative practices seem to influence various student outcomes, such as their confidence in learning mathematics (Jung and Reifel, 2011), willingness to participate and collaborate as a mathematics student (Björklund and Pramling-Samuelsson, 2013; Cohrssen et al., 2014; Jung and Reifel, 2011; Kaartinen and Kumpulainen, 2012), and growth of mathematical knowledge over the course of a year (Klibanoff et al., 2006). Yet, as noted throughout the findings, these communicative acts may be hindered by various external factors, such as standards and the discourse of play (Jung and Reifel, 2011; Thomas et al., 2011).

**Transformation.** Broadly speaking, professional development opportunities for educators vary in content, form, and duration. For example, Linder and colleagues (2016) established that across a south-eastern state in the USA, professional development in mathematics for early childhood educators is provided second to literacy and, regardless of content, was typically provided in one- to two-hour brief workshop settings. In addition, the focus of these professional development workshops was typically based on a content strand, as opposed to emphasizing the processes of learning and teaching mathematics. In the results of this literature review, the articles categorized as transformation studies included professional development opportunities lasting anywhere from a
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semester course to a three-year ongoing program, with a few studies including the influence of a particular assignment or task. This time duration is desirable because, as stated in a joint position paper in the USA by the National Association of Young Children and the National Council for Teachers of Mathematics: “Inservice professional development needs to move beyond the one-time workshop to deeper exploration of key mathematical topics as they connect with young children’s thinking and with classroom practices” (National Association for the Education of Young Children, 2002: 6). There also seems to be promise for professional development that involves co-teaching (e.g. Jao, 2013), mentorship (Wang and Paine, 2001), or coaching (Rudd et al., 2008) models. For example, Rudd et al. (2008) found that through professional development, 11 practicing teachers’ mathematics-mediated language increased by 56% during the observed sessions, but that those who took part in the coaching model increased their mathematical language by an additional 39%.

Of the 164 studies within this cluster of the overall literature review, 27% or 44 studies were categorized as transformation and examined changes in practicing and prospective teachers’ professional knowledge (20%), disposition (36%), and practice (44%) due to a professional development program, intervention, course, and/or task. The majority of these studies were conducted with practicing teachers (72%) as opposed to prospective teachers (18%). In general, across these studies, the changes examined by the researchers seem to be more positive than negative—in other words, educators exhibited improvements in a particular area of focus. For example, over a year-long program, Polly, Neale and Pugalee (2014) noticed an increase in practicing teachers’ MKT scores, implementation of student-centered pedagogies, and view of mathematics as discovery-oriented as opposed to transmission-oriented. Yet this does not apply to every study categorized as professional development. Piasta et al. (2015), for instance, did not observe an increase in the time allotted for preschool-aged children (aged three to five) to engage in mathematical learning opportunities at the conclusion of professional development. There are also studies in which the short-term impacts are examined, such as 18 months after completion of engagement in professional development (e.g. Warren, 2009). However, the longer-term impacts of these professional development opportunities are unclear, specifically with regard to sustaining changes in content knowledge, dispositions, and practices.

Improvements in practicing and prospective teachers’ content knowledge included an increase in MKT (Hart, 2009; Polly, Margerison and Piel, 2014; Tirosh et al., 2013; Warren, 2009), general mathematics content knowledge (Bailey, 2010; Hooks and Duarte, 2005; Tirosh et al., 2013), and specific content knowledge, including understanding place value (Bussi, 2011; Cady et al., 2014), patterns and algebra (Warren, 2009), and spatial ability (Kurtulus, 2013). For example, Tirosh et al. (2013) found that weekly meetings with preschool teachers around challenging mathematical tasks shifted the manner in which the teachers discussed the existence of multiple solutions to solve a problem and the impact of changing the parameters of a task. As another example, six Year One teachers, who engaged in professional development to support implementation of a “pattern and algebra” strand (i.e. patterns, equivalence and equations, and functions), self-reported an increase in both mathematics content knowledge and mathematical language specific to this strand (Warren, 2009). On the other hand, Polly, Neale and Pugalee (2014) could not claim that a year-long professional development program provided to 15 kindergarten teachers was successful in increasing teachers’ mathematical content knowledge, as there were both increases and decreases in scores from the beginning to the end of the professional development.

Additionally, there is evidence to suggest that professional development has a positive influence on practicing and prospective teachers’ beliefs about and attitudes towards mathematics (Afamasaga-Fuata’i and Sooaemalelagi, 2014; Erfjord et al., 2012; Graue et al., 2015; Palmer, 2009; Perry et al., 2007; Perry and MacDonald, 2015), and confidence in their ability to teach
mathematics to young children (Afamasaga-Fuata’i and Sooaemalelagi, 2014; Arnold et al., 2002; Bintas, 2008; Palmer, 2009; Stavroula et al., 2015). For example, after a 10-week alternative mathematics course aimed at challenging prospective teachers’ gendered attitudes to mathematics, as well as their own subjectivity, Palmer (2009) noted a positive shift in students’ attitude about mathematics and an increase in approximately 50% of the 75 students in their confidence to teach mathematics. In addition, these prospective teachers recognized how the course changed their understandings of their personal mathematical subjectivity—in other words, what it means to be a “maths-person.” Through using a pair-dialogue approach to instruction, Tsamir et al. (2014) noted a positive change in practicing teachers’ self-efficacy related to students’ knowledge, which seemed to diminish the negative correlation between self-efficacy for teaching and student knowledge present at the beginning of the professional development. Moreover, at the conclusion of a mathematics methods course, Saçkes et al. (2012) noted an increase in prospective teachers’ efficacy beliefs for integrating science and mathematics, while Gresham (2007) found a decrease in prospective teachers’ mathematics anxiety.

Lastly, professional development has been shown to transform practicing and prospective teachers’ mathematical practices, such as their mathematical language (Rudd et al., 2008; Warren et al., 2011) and planning of lessons (Björklund, 2012; Muñoz-Catalán et al., 2010; Piasta et al., 2015). For instance, Muñoz-Catalán et al. (2010) gained an understanding of how an early career practicing teacher involved in professional development became more flexible in her planning to teach mathematics—namely, by considering her students’ difficulties, which appeared to be influenced through her joint reflection with others and through her personal reflections. Furthermore, studies have shown a change in practicing and prospective teachers’ mathematical practices to become more child-centered and include research-based strategies (Kretlow et al., 2012; Polly, Margerison and Piel, 2014; Polly, Neale and Pugalee, 2014; Thornton et al., 2009). As a specific example, professional development has been shown to increase early childhood educators’ questions—questions that invoke student thinking, exploration, and justification (Lin, 2006; Warren et al., 2011).

Discussion

This article provides an overview of an extensive literature review related to early childhood mathematics and a more in-depth analysis of one subsection of this literature—research relating to prospective and practicing teachers in early childhood mathematics. In terms of research focusing specifically on early childhood teacher practice related to mathematics, increased research is necessary to fully understand the impact that previous mathematics experiences, current knowledge related to mathematics, or specific curricular or professional development interventions can have on current or prospective teachers’ practice. With only 164 articles published on these topics in the past 15 years, an average of less than 20 articles published annually over the past 5 years, and an average of less than 10 articles published annually from 2000–2009, we have a very limited scope of understanding of how to best prepare future early childhood educators to teach mathematics to young children. This scope is even smaller when considering that the majority of this research occurs in settings for children aged five to eight, and does not often occur in infant, toddler, or preschool settings. It should be noted, however, that this review was conducted for articles published through 2015 and does not include articles published over the past couple of years. Considering the increase in publications from 2010–2015, we can assume that research related to early childhood mathematics will continue to trend upward, and that future literature reviews should be conducted to further our understanding of the work in this area.

In relation to content knowledge, practicing and prospective early childhood teachers seem to lack foundational mathematics content knowledge and MKT. However, these issues can be
developed with experience. It is clear that mathematics content and methods for teaching should be a priority for prospective teacher preparation and professional development efforts. Surprisingly, the literature indicates that practicing and prospective early childhood teachers have a positive outlook towards their own abilities related to mathematics and their ability to teach mathematics. In addition, much of the research literature in this area pointed to teachers’ ability to describe developmentally appropriate methods for mathematics instruction (i.e. play-centric, open-ended tasks incorporated into informal routines). In comparison, some research points to teachers’ view of mathematics as being a static body of knowledge, and a disequilibrium between negotiating how they learned mathematics as a child and how to envision their current role as an early childhood mathematics educator. This subsection of the literature requires continued exploration in order to examine shifts in dispositions over time.

There are clear distinctions between teachers’ practices when comparing between countries. An overwhelming emphasis is placed on counting in the USA. However, these findings are skewed because of the large proportion of research being conducted in the USA (46.6%). In addition, even though research points to teacher beliefs about mathematics being more progressively oriented, research relating to curriculum implementation and teacher practice indicates that both prospective and pre-service teachers struggle with the enactment of progressive practices, and particularly with an over-reliance on textbooks (which may not provide effective strategies for teaching). Further research is necessary in this area to better understand the teaching trajectory for current and prospective early childhood teachers as they grapple with changing standards, increased evaluation expectations, and new curricula, and to determine the malleable effects of these initiatives and more on instructional practice.

Finally, in terms of professional development, early childhood teachers seem to experience a wide variety of lengths, formats, and topics. The majority of the limited research published related to teacher transformation as a result of professional development shows positive results. While most research focusing on professional development examines teacher changes in terms of content knowledge or MKT, there is a growing body of research that is also examining early childhood mathematics beliefs and attitude shifts as a result of professional development interventions. However, much of this research focuses on the particular time period when the professional development intervention occurs and immediately following, and does not often examine the sustainability of professional development efforts over time, which is likely the reason why the results are positive. Further research is necessary to better develop a framework for professional development related to early childhood mathematics.

**Recommendations**

The current body of research in early childhood mathematics is well established, as seen in the sheer number of articles identified to be part of this review (1141). However, questions emerged when examining the methodological structures and topics of focus within this body of research. While quantitative research is the dominating methodology, these studies were often descriptive or correlational. While this research is important, a need exists for studies using quasi-experimental or experimental designs in this field. In addition, many do not take a longitudinal approach. Further, while mixed-methods research is becoming increasingly more commonplace, we have not yet seen the full emergence of mixed-methods methodology being used in relation to early childhood mathematics.

When examining the age range of the participants in the articles included for review, it is clear that a substantial gap is present for research examining early childhood mathematics for children from birth to age five. The majority of the research focuses on kindergarten and beyond—a finding
that is similar to what Fox and Diezmann identified in their 2007 review of early childhood mathematics literature. Seemingly, we have not responded effectively to the recommendation made by Fox and Diezmann (2007) and Anthony and Walshaw (2009) to expand research in the birth-to-five domain, as the proportion of research conducted in birth-to-five settings identified in this study is similar to what was reported almost a decade ago. Further, the overwhelming majority of research examines early childhood mathematics in terms of numbers and operations, leaving out a wealth of mathematics content that is relevant to young children. Finally, early childhood education is heavily influenced by international contexts (e.g. Reggio Emilia, Montessori). However, the majority of research in early childhood mathematics has focused on settings within the USA. An increased international focus on early childhood mathematics is important in order to understand fully the implications for research and practice.

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Note
1. Interested parties can email the corresponding author for a full citation list of the 1141 articles included for review.

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