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Predicting Third-Grade Mathematics Achievement: A Longitudinal Investigation of the Role of Early Numeracy Skills

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Abstract

Despite the vast research on the early predictors of mathematics achievement, little research has investigated the predictors of various domains of mathematics (e.g., geometry, statistics). The purpose of the present study was to examine the predictive relationship between first-grade early numeracy and computation skills and third-grade mathematics achievement as measured by a state test. Further, we explored the relations between these measures for students who were Below Proficient and Proficient. Findings suggest that proficiency level matters when examining the relation between mathematics skills. Also, there are different patterns of significant predictors depending on the domain of later mathematics achievement and whether or not reading achievement was considered. Findings are discussed in the context of mathematics learning for students with mathematics difficulty.

Keywords: mathematics, numeracy, longitudinal, mathematics difficulty, achievement

In response to the level of low academic achievement in mathematics, research related to mathematics difficulties (MD) is of primary concern in the United States. Despite the increase in the study of mathematics curricula, instruction, and assessment over the past 50 years and recent initiatives that focus on improving achievement, national achievement trends and research underscore the fact that mathematics achievement gaps are not closing for students with disabilities or those who struggle (National Council of Teachers of Mathematics [NCTM], 2006; National Governors Association Center for Best Practices & Council of Chief State School Officers [NGA & CCSSO], 2010). Early numeracy skills – such as counting, understanding of number relationships, and number combinations – have gained recognition as necessary prerequisite skills for students to develop in order to master more complex mathematics skills (e.g., multi-digit computation). Perhaps this is why so many studies in recent years have examined the relation between early numeracy skills and other areas of mathematics up to several grade levels later including broad mathematics achievement (Jordan, Kaplan, Ramineni, & Locuniak, 2009; Missall, Martínez, & Casebeer, 2012), computation (Locuniak & Jordan, 2008; Stock, Desoete, & Roeyers, 2009), and whole number skills (Navarro et al., 2012). The results and implications of these studies provide practitioners and researchers with invaluable information regarding the importance of early numeracy for developing mathematics competences broadly; in contrast, a gap in the literature exists for the relation between early numeracy and other domains of mathematics such as geometry, measurement, and data analysis. We intend to address this gap in the current study and provide recommendations for understanding and supporting students with learning difficulties and disabilities.

We conducted a longitudinal study to explore the relation between first-grade early mathematics skills and third-grade mathematics achievement as measured by a state test. While state tests are often used for accountability purposes, they are also used as an indicator of risk to identify students who may benefit from interventions and who may have learning disabilities. In this introduction, we briefly discuss the importance of developing early mathematics skills, provide a review of longitudinal studies of mathematics achievement, and explain the importance of developing mathematics competences in all domains. We also identify typical characteristics of students identified as at-risk for MD, and factors that may influence longitudinal mathematics achievement, including socio-economic status and reading achievement. Finally, we discuss the purpose and the research questions guiding the current study.

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Importance of Developing Early Numeracy Skills

Children have many opportunities to learn and develop understanding of mathematics prior to formal instruction. Mathematics skills that develop early are typically referred to as early numeracy skills and these skills are heavily emphasized in preschool through first grade standards and recommendations (NGA & CCSSO, 2010; NCTM, 2006; National Research Council [NRC], 2009). Common examples of early numeracy skills include counting, cardinality, numeral identification, magnitude or set comparisons, number sequencing, composing, and simple arithmetic (NRC, 2009). Mastery of whole number understanding becomes increasingly important as students develop later skills such as problem solving, operations with rational numbers, and algebra (Fuchs et al., 2014).

The results of longitudinal research also underscore the power of specific early numeracy skills measured in preschool through first grade to predict later mathematics achievement (Desoete, Stock, Schepens, Baeyens, & Roeyers, 2009; Geary, Hoard, Nugent, & Bailey, 2013; Krajewski & Schneider, 2009; Locuniak & Jordan, 2008; Nguyen et al., 2016). For example, advanced counting skills (i.e., cardinality, counting forward and backward from a given number) measured in preschool was the strongest predictor of broad mathematics achievement measured in fifth grade (Nguyen et al., 2016), and in another study, first-grade counting skills accounted for nearly 30% of variance in early arithmetic scores (Desoete et al., 2009). Kindergarten scores on missing number and quantity discrimination tasks were significant predictors of third-grade mathematics achievement (Missall et al., 2012), and first-grade number system knowledge significantly predicted seventh-grade functional numeracy scores when controlling for IQ, working memory, and attention (Geary et al., 2013).

Long-term Consequences of Mathematics Achievement

From preschool on, national standards, organizations, and experts have recommended an instructional balance across mathematics domains (NCTM, 2006; NRC, 2009). The NRC identifies two areas of mathematics that are especially important for young children, including (1) whole number understanding, relations, and operations, and (2) geometry, spatial thinking, and measurement. Young preschool students use their skills in geometry, spatial thinking, and measurement as they notice differences such as height, shape, and placement of objects. They may also transfer these skills to early use of data analysis as they sort items according attributes (Ginsburg, Lee, & Boyd, 2008). By the end of third grade, students are also expected to analyze and compare properties of shapes and use data analysis skills to solve problems. By the end of sixth grade, students should use geometry to solve real life problems involving angles, surface area, and volume (NCTM, 2006; NGA & CCSSO, 2010).

It is imperative that students develop skills in domains other than numbers and operations solely, because according to recent high school graduation requirements the majority of states now require three or four mathematics courses for high school students. Many of the courses students will take in high school address content in geometry and probability and statistics (Education Commission of the States, 2018). In turn, mathematics achievement in high school influences several long-term outcomes including enrollment in and completion of post-secondary school, preparedness for college coursework and the workforce, and employment outlook and hourly earnings in adulthood (Parsons & Bynner, 1997; Spielhagen, 2006). Proficiency with skills in domains of mathematics such as geometry, measurement, and data analysis are required for successful employment in a variety of fields such as geography, architecture, construction, graphic design, and engineering.

Although it is crucial that all students master mathematics content throughout school for positive post-secondary outcomes, many students struggle with mathematics concepts as early as preschool (Jordan & Hanich, 2003; Vukovic, 2012). Often, initial achievement gaps for low achieving students remain over time due to slower or parallel growth for students with MD. For example, in one study, gaps that existed between typically achieving students and students with MD on mathematics concepts and number series in kindergarten still existed in third grade, with gaps increasing on average each year (Vukovic, 2012). Another study reported that significant group differences that were evident at the beginning of first grade remained in fifth grade on a measure of composing and decomposing between typically achieving, low achieving, and students identified as having a mathematics learning disability (Geary et al., 2012). Although a considerable amount of research has examined how early numeracy skills relate later achievement in the domains of numbers and operations and mathematics achievement broadly, very little attention has been paid to other domains of mathematics including geometry, measurement, and data analysis. In order to be successful in mathematics across grade levels, students must establish mathematics skills across all domains. Thus, it is important to identify

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where students may have gaps in understanding across mathematics domains, and to identify student level factors that may contribute to these gaps including overall difficulty with learning mathematics, reading achievement, and environmental factors such as socio-economic status.

Characteristics of Students with Mathematics Difficulty

Most students follow a typical timeline for learning mathematics; however, some students struggle to learn concepts and have chronic low mathematics achievement. In fact, according to the most recent national data, approximately 56% of students without disabilities in fourth grade scored At or Below Basic in mathematics (NAEP, 2015). We often identify students as having MD when they when they struggle with chronic low mathematics achievement without a diagnosis of disability. Typical criteria for identifying MD ranges from restrictive cut-offs of performance below the 10th percentile to less restrictive criteria of performance below the 25th percentile (Nelson & Powell, 2017). Though other researchers may use a less stringent cut-off of performance at or below the 40th percentile to identify students at-risk for academic failure and in need of supplemental supports or intervention (e.g., Miller & Kaffar, 2011). Higher cut-offs such as the 40th percentile are often used by school professionals and published assessment systems in aims of identifying more students with potential risk (e.g., Fastbridge Learning, 2017; NWEA, 2015). It is valuable to consider this 40^{th} percentile in practice as that is what many schools apply in their decision making processes.

Common characteristics of students with MD include failure to detect counting errors, use of less efficient counting and computation strategies, difficulty performing multi-step procedures, poor basic fact retrieval, and difficulty with problem solving (Chong & Siegel, 2008; Geary, 2004). In addition, students with MD may display weaknesses with working memory and spatial representations of numbers (Geary, 2004). Many students that have learning difficulty in mathematics also display difficulty with reading (RD). Estimates for students who have combined MD+RD are variable and contingent on the criteria used to identified MD and RD (e.g., Morgan, Farkas, & Wu, 2009). Students with combined MD+RD may present with a unique set of learning needs, as over time, these students have slower growth in mathematics especially in mathematics as related to language, such as word problem solving, compared to peers who exhibit only MD (Jordan & Hanich, 2003; Vukovic, 2012). Research also indicates that students from low-SES backgrounds have difficulty related to mathematics. The most recent NAEP results reported that a larger proportion of students who were eligible for free and reduced price lunch (FRL) scored at Basic (48%) and below Basic (28%), compared to peers who were not eligible for FRL (35% and 8%, respectively), meaning that only 24% of students eligible for FRL scored at Proficient or Advanced. Morgan et al. (2009) also found that students from lower SES families had lower initial mathematics performance and growth over 5 years compared to students from higher SES families. Difficulties in mathematics persist over time, leading to widened achievement gaps for students with MD, MD+RD, and low SES. Thus, it is important to better understand the predictors of later achievement in specific mathematics domains to facilitate early intervention and early identification of students with learning disabilities.

Limitations of Previous Research

This study will address limitations of previous studies that examined the relationship between early numeracy skills and broad mathematics achievement measured at a later time point. First, previous longitudinal studies have limited the focus of examining the predictive nature of early numeracy with later early numeracy skills, computation or fact retrieval, and broad mathematics achievement (Desoete, Ceulemans, De Weerdt, & Pieters, 2012; Krajewski, & Schneider, 2009; Locuniak & Jordan, 2008). Other areas of mathematics achievement, such as data analysis, geometry, and measurement have largely been less observed with regard to the influence of early numeracy skill development. Missall et al. (2012) examined the relationship between kindergarten and first-grade numeracy skills and third-grade mathematics achievement as measured by a state test; however, the authors only examined overall performance in mathematics, specific mathematics domains (e.g., geometry) were not evaluated in terms of their relationship with early numeracy skill development. Similarly, VanDerHeyden, Codding, and Martin (2017) examined the decision accuracy of mathematics screening tools for predicting performance on a state test but did not examine separate domains of mathematics measured on the state test. Research has examined the ability of screening to predict performance in a broad subject area, such as mathematics, but knowing that a student is at risk in a particular content area (e.g.. math) does not provide teachers with direction of what to do instructionally to support that student. In addition, other research has examined the relation between fluency based mathematics computation skill and performance on state tests (e.g., Cormier, Yeo, Christ, Offrey, & Pratt, 2016); however, conceptual early numeracy skills are also critical for the development of later mathematics. This is a significant gap in the literature because the

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expectation to learn and master mathematics skills in areas such as geometry and measurement begins as early as kindergarten in national and state standards (NCTM, 2006; NGA & CCSSO, 2010) and continues through middle and high school, with early skills providing the foundation to build subsequent skills.

Second, this study seeks to predict MD as measured by performance on a mathematics state test. Few longitudinal studies have used performance on an end of year state test to identify students as having MD (Nelson & Powell, 2017); yet, state tests are an important indicator of academic progress from year to year. Schools and teachers use the results of state tests to measure student progress, as well as overall effectiveness of curricula and intervention programs. How students are categorized as having MD may have significant implications for schools in their allocation of resources and support; at the end of an academic year, many schools identify students who may need intervention the following school year using end of year state test data. It is important for practitioners to understand how data collected with formative assessments in early years relate to student performance on assessments that may be used to identify later intervention needs. In this regard, knowing the extent to which formative assessment results predict later scores on specific domains may suggest which skills are important for later math development which occurs in multiple domains and dimensions. We also explore the role that reading achievement plays in the predictive power of early mathematics skills to later mathematics achievement.

Purpose and Research Questions

The purpose of the present study was to examine the predictive relationship between first-grade early numeracy and computation skills and third-grade mathematics achievement. For the continuation of this paper we refer to the combination of early numeracy skills and computation skills collectively as *early mathematics skills.* The present work extends previous work that examines the predictive nature of these skills (e.g., Desoete et al., 2009; Geary et al., 2013; Krajewski & Schneider, 2009; Locuniak & Jordan, 2008; Missall et al., 2012) by exploring their role in the development of other skills such as data analysis, geometry, and measurement. A secondary focus of this study is to examine how early numeracy skills predict to mathematics domains across different subgroups of students, including students who are at-risk for MD and students from low socio-economic status. This study considers achievement as measured by a state test in order to advance practitioners' and researchers' understanding of how foundational early mathematics skills influence later grade-level achievement. This study was guided by the following research questions:

1. What is the relation between first-grade early mathematics skills and third-grade mathematics achievement as measured by a state test? Does this relation vary between students' level of proficiency on the state test?
2. To what degree do first-grade early mathematics skills accurately predict mathematics difficulty as measured by performance on a third-grade state test of mathematics?
3. Which early mathematics skills measured in first grade are most predictive of later achievement in Number and Operations, Algebra, Data Analysis and Probability, and Geometry and Measurement as measured by a state test? To what extent are these predictors significant when controlling for reading ability and socio-economic status?

Method

Participants and Setting

This longitudinal study included participants from two suburban school districts in the Midwest. School administrators opted into this study, and the assessments were administered to students in the participating schools as part of school-wide initiatives. Of the 239 first-grade students (sampled from 14 classrooms) who participated in the first year of the study, 175 students remained in the district in third grade and took a state test, yielding a 27% attrition rate. The final sample was approximately 49% female. The majority of the sample was White (84%) with 6% of students identifying as Black, 5% Hispanic, 5% Asian, and 1% American Indian. These ethnicity categories were used based on how the state in which the study was conducted reports student demographics. Twenty-nine percent of the participants were eligible for free and reduced lunch (FRL) and 12% were eligible to receive special education services, though none of these students were identified as having a significant intellectual disability. The first- and third-grade samples did not vary significantly by gender ($\chi^2 = .001$, $p = .97$), FRL ($\chi^2 = 1.657$, $p = .20$), or special education status ($\chi^2 = .601$, $p = .43$).

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Measures

We examined two types of measures in this study, including a broad mathematics measure and skill specific measures. We also considered a broad reading measure and socioeconomic status in our regression analyses. The Minnesota Comprehensive Assessment (MCA-III) served as the measure of third-grade mathematics achievement. At the time of data collection, each of the early numeracy domain specific measures and the measure of written computation were experimental researcher-developed measures. After this study, the early numeracy measures underwent a series of modifications and modified versions are now included as subtests in the published [removed for review] measure [citation removed for review].

State test. The MCA-III are state accountability tests in reading, mathematics and science that aim to measure student achievement and proficiency based on academic standards. In this study, we used MCA-III scores in mathematics and reading. The MCA-III is a computer based test that is group administered. The MCA-III is based on Minnesota Academic Standards (2007) and items were developed to align with instructional goals and benchmarks by using a clear blueprint and item specifications. In mathematics, the test yields a total scaled score as well as subscale scores for four strands: Number and Operations, Algebra, Geometry and Measurement, and Data Analysis and Probability. In reading, the test yields a total scaled score, which includes content in the areas of: Literature and Informational Text. Scores categorize students into four categories: does not meet standards, partially meets standards, meets standards, and exceeds standards. In the current study, the groups were collapsed: Below Proficient (does not meet standards, partially meets standards) and Proficient (meets standards, exceeds standards). Marginal reliability estimates were high for the Total Score (r = .95) and moderate to high for each strands (r = .69 to .87*; Mdn* r = .74; Minnesota Department of Education, 2017).

Early mathematics skills. Researchers administered a series of skill-specific measures to target early mathematics skills. The measures were developed based on state and national academic standards in first grade.

Decomposing. The Decomposing measure assessed students' ability to compose and decompose numerals and set representations. Students were presented with a target number (the whole) presented as a numeral between 5 and 20 at the top of the page, and three numbers (the part) below target number on the same page. Each "part" was represented by a numeral or set of dots, and an empty box represented the missing "part." Students were instructed to tell the examiner what number went in the box to make the target number and were timed for 1 min. The publisher reported reliability coefficients (i.e., test-retest, inter-rater, alternate form, coefficient alpha, split-half) ranging from .79 to 1.00 [citation removed for review].

Number Sequence. Students' knowledge of the mental number line was measured with the Number Sequence measure. This measure was untimed and students were orally asked questions regarding counting forward, backward, number before, number after, and number between. Reported reliability coefficients (i.e., test-retest, inter-rater, coefficient alpha, split-half) range from .71 to 1.00 [citation removed for review].

Numeral Identification. The Numeral Identification measure assessed students' ability to fluently name numerals between 0 and 120. Students had 1 min to correctly name as many numerals as possible from a page of 96 total numerals. The measure consisted of 16 rows with 6 randomly ordered numerals. The publisher reported reliability coefficients (i.e., test-retest, inter-rater, split-half, alternate form, coefficient alpha) ranging from .85 to .98 [citation removed for review].

Place Value. Students' understanding of base-ten representation of numbers was measured with the Place Value test. This test was administered in a whole class format and students provided written responses on paper to two types of items. For one type, students were shown a base-10 block representation of a number and wrote the numeral that represented the number of blocks. The second type of item showed a picture of 99 blocks (9 rods and 9 units in a standardized configuration) and students were instructed to circle the correct number of blocks to represent the numeral provided. Students were provided with 2 min to answer as many questions as they could and scores were reflected by the number of items answered correctly. The publisher reported reliability coefficients (i.e., test-retest, inter-scorer, alternate form, coefficient alpha, split half) ranging from .77 to 1.00 [citation removed for review].

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Verbal Addition. The Verbal Addition measure assessed students' skills with answering verbally-presented single-digit addition problems. Students were not provided with a visual representation of the problem and had 30 s to answer problems. The examiner asked the students questions such as, "What is 1 plus 2?" Test-retest reliability for the sample was .79.

Verbal Subtraction. The Verbal Subtraction measure assessed students' skills with answering verbally-presented single-digit subtraction problems. Students were not provided a visual representation of the problem and they had 30 s to answer problems. The examiner asked questions such as, "What is 7 minus 2?" Test-retest reliability for the current sample was .72.

Story Problems. Students' understanding of story problems and sign representation was assessed using the Story Problems measure. There were two types of items in this assessment. For the first type, the examiner read a story problem that was represented by a picture, and students were prompted to select the correct expression (i.e., proper numerical notation; e.g., 2+3). Students selected from four options, and each option was comprised of two positive integers and an addition or subtraction symbol. Then, addition and subtraction story problems were also presented verbally and students responded with the answer to the story problem. The publisher reported reliability coefficients ranging from .77 to 1.00 [citation removed for review].

Computation. Students' basic computation fluency was assessed with a timed measure of single-digit addition and subtraction. Students were provided with a page of addition and subtraction problems. The measure was administered in a whole group format and students were instructed to answer as many problems as they could in 2 min. Students were reminded to watch the sign (i.e., +, –) and put an "X" over any problems that they wanted to skip. The test yielded a score of items correct per 2 min. Coefficient alpha reliability for the current sample was .93.

Procedure

Measures. The skill-specific mathematics measures were administered individually (except for Place Value and Computation) to students in the spring of first grade (2014) and testing occurred in a quiet room, the back of a classroom, or the hallway. Examiners included school staff and trained data collectors with experience in standardized assessments and curriculum based measures. Each examiner attended a 2-hour training that reviewed administration, directions, and scoring procedures. All examiners passed a procedural fidelity check prior to data collection. The raw scores for assessments were calculated by the examiner and checked for accuracy by other raters. Any discrepancies were double-checked and resolved. School staff administered the MCA-III when participants were in third grade (spring 2016) and administration was based on standardized protocols of the state.

Data analysis. Means, standard deviations and Pearson correlations were calculated. We utilized classification accuracy analyses to identify which early mathematics skills were the best predictors of later mathematics achievement on the state test. We coded MCA-III proficiency levels as 0 = does not meet or partially meets standards (Below Proficient); and 1 = meets or exceed standards (Proficient). Each early mathematics subtest was coded as 0 if performance was at or below the 40th percentile or 1 if above the 40th percentile. We selected the 40th percentile as it is often used in schools to identify students at-risk for difficulties in mathematics and in need of intervention services. For each subtest we reported the sensitivity, specificity, and accuracy. Sensitivity is the proportion of students identified as being at risk in mathematics who were also found to be at risk on the third-grade MCA-III. Specificity is the proportion of students who were identified as being not-at risk in mathematics in first grade who were also found to be proficient in mathematics at the end of third grade. Sensitivity and specificity is a balance that has varying consequences. For example, a school district may choose to aim for higher sensitivity in order to identify as many students as possible and provide early intervention services, however that is at the cost of providing interventions and resources to students who may not need it. We also provided the overall correct classification accuracy rate, which suggests that overall number of students who were correctly identified.

We also conducted linear regression in SPSS to identify the best predictors of student performance on four strands of the MCA-III: Number and Operations, Algebra, Data Analysis and Probability, and Geometry and Measurement. Although students were nested within 14 classrooms, we conducted a sensitivity analysis and confirmed that the intraclass correlations (*ICC*) for the unconditional models were all below 10%. These results indicated that students nested within classes/teachers did not account for unique variance in the MCA-III; therefore, simple multiple regression was sufficient to model the data (i.e., rather than a hierarchical model; Raudenbush & Bryk, 2002). Outcome variables were standardized for the analysis. Further, previous research is not clear as to the early skills that are predictors of specific domains of mathematics (e.g., data analysis). First, we conducted the regression with only the early mathematics measures as predictors. Next, we added control measures: FRL status (coded as: 0 = not eligible; 1 = eligible for reduced or FRL) and student performance on the spring Reading MCA-III. For both models, all predictors were entered at the same time.

Results

Descriptive Statistics

Descriptive statistics are reported in Tables 1 and 2. Table 1 provides the *M*, *SD*, minimum and maximum scores for the MCA-III. About 25% of the current sample was below the proficiency level provided by the state test. Table 2 includes means and standard deviations for students who did and did not meet proficiency on the third-grade MCA-III. For both groups, distributions of all numeracy measures, the written computation measure and the MCA-III were distributed normally (i.e., *z-score* > |1.96| or kurtosis > 3). We conducted a series of *t*-tests on each early mathematics measure between students who were Below Proficient and Proficient. We found that there was a significant difference between early mathematics skills in the spring of first grade based on student's level of meeting state standards in the spring of third grade ($p < .01$). Hedges' *g* ranged from .56 and 1.04 across the measures. This result suggests student performance on early mathematics measures in first grade significantly differentiated between those who were Below Proficient or Proficient by the end of third grade.

Relationship between Numeracy Skills and MCA-III

Pearson correlations were calculated to assess the relationship between the early mathematics measures and third-grade mathematics achievement as measured by the MCA-III. Table 3 provides these correlations for the total sample, students Below Proficient and students Proficient on the third-grade MCA-III. When correlations were examined for the total sample all were significant (p <. 01; Table 3). The Decomposing and Number Sequence subtests showed the strongest correlations across all strands (r =.35 to .55 and r = .40 to .56, respectively) . For the overall MCA-III score, all early mathematics measures were significantly correlated in the Proficient group, while only five measures were significantly correlated for the Below Proficient group (i.e., Numeral Identification [r = .42], Decomposing [r = .43], Number Sequence [r = .55], Verbal Subtraction [r = .44] and Story Problems [r = .50]). This pattern was consistent across the MCA-III strand subscores, such that the magnitude of the relation between the measures were stronger for the Proficient group compared to the Below Proficient group. Interestingly, these measures across groups were inconsistent. For example, in regards to the Algebra strand, in the Below Proficient group, Numeral Identification, Number Sequence, Story Problems and Computation were all significantly related (r = .31, 39, .44, .38, respectively), but in the Proficient group, Decomposing, Number Sequence, Verbal Addition, Verbal Subtraction, Story Problems and Computation were significant (r = .31, .26, .18, .22, .19, .19, respectively). The Number Sequence measure appeared to be the most consistently correlated with each of the scores provided by the MCA-III. Further, the Data Analysis strand was the only aspect of the state test that produced negative correlations. These relations are examined in more depth in the regression analyses.

Prediction of Proficiency Level on Third Grade State Test

Table 4 displays the results of the classification accuracy and prediction of proficiency level on the MCA-III. In the current sample, the Numeral Identification task in first grade had the highest accuracy in identifying student proficiency level in third grade (74%). Specifically, if using the measure to predict third grade proficiency on the statewide test, scores would accurately identify 74% of students as at-risk or not at-risk. The next highest performing mathematics skills were Number Sequence (69%) and Computation (69%). We also found that early mathematics measures varied widely on their levels of sensitivity and specificity. For example, Numeral Identification and Computation had the highest levels of sensitivity, which indicates that they most accurately identified students who were truly at-risk, (.83 and .75 respectively), while Verbal Addition and Verbal Subtraction had the highest levels of specificity which indicates that they most accurately identified students who were truly not at-risk (.91 and .86 respectively). We also reported Positive Predictive Value (PPV; proportion of students identified at risk and actually at-risk compared to all students identified at risk) and Negative Predictive Value (NPV; proportion of students identified not at-risk and actually not at-risk compared to all students identified as not at-risk). Overall, all early mathematics measures had a higher PPV than a NPV suggesting that the measures were more accurate at identifying students Below Proficient compared to identifying students who were Proficient (range = .79 – .95).

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Best Predictors of Different Third-Grade Mathematics Strands

The results of the step-wise regression analysis are provided in Table 5. The first-grade early mathematics skills explained 41% of the variation in performance on the Number and Operation strand and this variation was best explained by the Decomposing, Number Sequence and Verbal Subtraction measures. When Reading and FRL were added into the model, an additional 25% of variation in scores was explained and it was explained by Decomposing and Reading scores. Free and reduced lunch status was a significant predictor at the .10 level. In regard to Algebra, early mathematics skills explained 33% of the variation in performance and this variation was best explained by Number Sequence and Computation measures. When Reading and FRL were added to the regression model; Computation remained significant but Reading was a stronger predictor of scores than the Number Sequence measure, which remained significant only at the .10 level. On the Data Analysis and Probability strand, the early math measures explained 25% of the variance in scores. Specifically, Number Sequence was significant ($p < .05$). Verbal Subtraction and Story Problems were significant at a lower level ($p < .10$). When Reading and FRL were considered in the model none of the previous subtests were significant predictors of Data Analysis and Probability and instead Reading and FRL status were significant and all predictors together explained 49% of the variance. Finally, on the Geometry and Measurement strand; Decomposing, Number Sequence, Story Problems and Place Value were significant predictors and the math only model explained a total of 43% of the variation in scores. In the second model, an additional 17% of variance was explained and the significant measures were Decomposing, Place Value and Reading.

Discussion

The purpose of this study was to examine the predictive relationship between first-grade early numeracy and written computation skills and third-grade mathematics achievement as measured by a state test within the context of identification of students with MD. The present work extends previous work that examines the predictive nature of early numeracy skills (e.g., Desoete et al., 2009; Geary et al., 2013; Krajewski & Schneider, 2009; Locuniak & Jordan, 2008; Missall et al., 2012) by exploring their role in the development of other mathematics skills such as data analysis, geometry, and measurement. This study also extended the literature on the prediction of state test outcomes (e.g., Cormier et al., 2016; Missall et al., 2012; VanDerHeyden et al., 2017) with a unique set of early numeracy measures. In this discussion we highlight key findings as well as discuss limitations and recommendations for practitioners and future research.

A primary finding was that different early mathematics skills were important for predicting later performance on different mathematics domains. Understanding predictors of later performance and help support early identification of learning disabilities or difficulties and can help inform what early skills may be vital in developing later mathematical skills. Exploring mathematics domains may yield improved instructional practices and these domains may provide more information about what students can and cannot do in comparison to broad scores. It was also observed that students in the Below Proficient and the Proficient groups demonstrated significantly distinct scores on all early mathematics measures significantly. This suggests that student level of performance on brief early math measures in first grade distinguished them on their performance on a broad statewide test two years later. Further, the early math measures identified students at-risk two years later with reasonable levels of accuracy (58% to 74%). These along with related results and implications are discussed in detail below.

The Relation Between Early Mathematics and Later Achievement is Complex

In our first research question, we examined the relation between first-grade early mathematics skills and third-grade mathematics achievement and found the level of robustness of the relation varied as a function of the students' proficiency level on the state test (i.e., MCA-III). Next, we conducted a series of *t*-tests and found that all early mathematics measures significantly discriminated between the Below Proficient and the Proficient groups of students on the third-grade state test. Specifically, students who did not meet proficiency standards in third grade had significantly lower scores on average across all of the first-grade early mathematics skills assessed in this study. For example, students who were Proficient on the statewide test in third grade answered about 3 more decomposing questions per minute correctly in first grade than students who were Below Proficient in third grade. Specifically, the difference in performance was 1 standard deviation. The largest standardized differences (i.e., Hedge's g) were between the following skills: Decomposing, Number Sequence and Computation. Results from previous studies report that students with MD use decomposing strategies less often than typically developing peers when solving simple addition and subtraction problem (Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007), and students with MD use automatic retrieval of basic facts less often and with less accuracy than typically developing peers (Geary, Hamson,

& Hoard, 2000). Decomposing, Number Sequence and Computation all included a component of relations and operations between numbers, which suggests that these may be important skills for educators to provide early intervention. This is consistent with previous findings that Missing Number and Quantity Discrimination tasks are more robust predictors of later performance compared to skills such as Number Identification and Counting, which are more related to the Number domain of numeracy (Missall et al., 2012). The Missing Number and Quantity Discrimination tasks are also targeted to measure relations based mathematics skills in compared to Number Identification for example which focused on the Number domain of early numeracy. Based on these consistent findings, perhaps educators should focus instructional strategies on understanding relations of numbers as those skills appear to be predictor of later mathematics performance in this study and those skills have been found to be predictive in other studies (e.g., Purpura & Lonigan, 2013).

We also examined Pearson correlations between all measures for students in the Below Proficiency and the Proficient groups. Here, we found that there were different patterns of which measures were most important for the two groups of students. More of the first-grade measures were significantly correlated to the MCA-III scores for the Proficient group compared to the Below Proficient group. This is consistent with recent findings of Cormier et al. (2016) who reported different patterns in academic performance across students in varying proficiency groups on the MCA-III. We also found different patterns across the different MCA-III outcome scores. For example, only four measures were significantly correlated with the Data Analysis and Probability strand score in the Proficient group and only one measure (i.e., Story Problems) was significantly correlated with this score in the Below Proficient group. Interestingly, Data Analysis and Probability was the only strand that yielded negative correlations, perhaps suggesting that early mathematics skills are not as foundational for the development of this aspect of mathematics achievement. It appears that different foundational mathematics skills are related to performance in different areas of broad mathematics. When considering educational implications, specific skills may be related in different ways depending on the student level of proficiency. We recommend that educators focus on developmental trajectories to ensure that they are targeting the correct skills for their students, including those who may have learning disabilities. Previous research suggests that mathematics skills tend to build upon each other overtime and that is one reason why students can develop math difficulties from a young age.

The goal of our second research question was to examine the predictive utility of first-grade early mathematics skills in regard to a state test of broad mathematics skills at the end of third grade. Interestingly, some measures that had high correlations to the MCA-III did not yield very accurate identification of students as Proficient. For example, in our correlational analyses we found that the Number Sequence and Decomposing tasks were some of the most significantly correlated measures with the MCA-III. However, classification accuracy analyses suggested that these measures independently were only able to correctly classify 69% and 65% of students into proficiency groupings; typically the standard for accuracy of identification is 85%. The Numeral Identification showed the highest classification accuracy at only 74% accuracy. While overall accuracy was modest, the measures using the 40th percentile as a cut-point did all show high positive predictive values indicating that they are strong in identifying students at-risk. In contrast, the early math measures in the present study may under identify students at risk; there was a high proportion of students above the 40th percentile in first grade that later performed in the Below Proficient range on the state-test. Future research may consider alternate ways to determine cut-points in order to find the best indication of later risk. Future research may also examine different composites or groups of measures that may better predict, when considered in combination, later mathematics proficiency on state tests. This may also inform the identification of learning disabilities such that multiple sources of data may yield most accurate identification efforts. VanDerHeyden et al. (2017) provide one example of how the prediction of elementary mathematics performance may be expanded upon and improved by using iterative or gated screening procedures. This research may be helpful in determining the ideal screening measures to use to predict long term performance.

Different Early Mathematics Skills are Important for Different Mathematics Domains

As noted in previous reviews and meta-analyses of mathematics performance, few studies have examined the patterns across different domains of mathematics (Nelson & Powell, 2017). This is concerning given that recent standards and best practices (e.g., NCTM, 2006; NGA & CCSSO, 2010) suggest that skills such as Number and Operations, Algebra, Data Analysis and Probability, and Geometry and Measurement are all necessary for later success in mathematics. Thus, it was important for us to further examine which first-grade early mathematics skills may serve as the strongest predictors of different strands on a state test.

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To answer our third research question, when we explored only early numeracy and computation skills, we found that the Number Sequence task – which measured students' counting ability and understanding of the mental number line – explained significant variation in MCA-III scores across three of four strands. However, when we added in the variables of Reading and FRL, Number Sequence was no longer a significant predictor. It is possible that since the Number Sequence task involved listening comprehension and responding orally to verbal questions that it overlapped with some of the variance explained by the Reading MCA-III scores. We also found that when we considered Reading, it explained significant variation across all four strands. This expands on the recent literature that explores the relation of reading and mathematics skills as our study looks as specific mathematics strands on a state test, while others tend to focus on broad mathematics achievement.

Numbers and Operations. The Numbers and Operations strand was best explained by the early skills of composing and decomposing numerals and sets (Decomposing), understanding of the mental number line (Number Sequence) and verbal responses of subtraction facts (Verbal Subtraction). Decomposing is the foundation to later operational and computational skills. We were surprised that the Verbal Addition and Computation measures did not explain significant variation above and beyond the other skills considering most skills in the early numeracy Operations domain focus on understanding whole number operations and are prerequisite skills for later mathematics skills.

Algebra. In regards to the Algebra strand, it seemed logical that Number Sequence and Computation skills explained a large portion of the variation in scores as those skills are widely used in Algebra standards. We were surprised that the Story Problems measure did not add additional explained variation in both analyses (i.e., with and without reading) as that measure explicitly asked students to select appropriate equations and solve word problems which are both fundamental skills related to Algebra. Perhaps at this age level, it seems that the ability to count and understand the mental number line and solve computation skills are more important before students can apply those skills to solving algebraic problems.

Data Analysis. Our findings in regards to the Data Analysis strand were interesting, as none of the predictors remained consistent when comparing the model with and without the Reading and FRL variables. When Reading and FRL were considered, the Data Analysis strand was the only strand such that socio economic status was a significant predictor ($p < .05$). Previous research indicates that students from low socio economic status backgrounds exhibit significantly lower levels of mathematical understanding compared to peers from higher socio economic status backgrounds as early as preschool (Starkey, Klein, & Wakeley, 2004); it is plausible that students with more rich mathematics experiences in the home tend to gain better knowledge of data analysis because that is a domain that may not be as natural in every day life. We found it unexpected that FRL did not significantly predict the Algebra or Geometry strands and it only significantly predicted the Number and Operations Strand at the .10 level. Perhaps Number and Operations, and Data Analysis question rely more on the specific interpretation of numbers; while the Geometry and Algebra strands rely more on real world application and word problems. These inferences are suspect at this time and this is an area of mathematics development that may warrant additional exploration. Given that socioeconomic status is not something that can be intervened on in the educational environment, perhaps educators should tend more time and emphasis on these skills at earlier grades to provide more equitable exposure to these skills. Providing students with exposure to order and graphing may be one potential strategy. Adults may often ask students to count or identify shapes in their every day life, but it may be less natural or intuitive to ask questions about comparing numbers in a statistical way.

Geometry and Measurement. Lastly, the results from the Geometry and Measurement strand found that when examining mathematics skills only, Number Sequence, Decomposing, Verbal Subtraction and Place Value were the significant predictors that explained most of the variation in scores. When Reading and FRL were added, Number Sequence and Verbal Subtraction no longer added significant explained variance and instead Reading also was a strong predictor of Geometry and Measurement related skills. This was the only strand that the Place Value task explained significant variance above and beyond the other scores, especially as Place Value is taught as a precursor to Operations skills. The Place Value measure assessed students' understanding of base-ten concepts using pictures of base-ten blocks. This was the only measure that included geometric images. This was a timed measure such that students who were able to more quickly distinguish the number of base-ten blocks were perhaps able to answer more questions accurately with fluency. It seems plausible that students' conceptual understanding of base-ten blocks is influenced by their ability to distinguish shapes and use concrete and representational strategies. More research may be warranted in this area.

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Across all 10 of the predictor measures, Numeral Identification and Verbal Addition were not significant predictors for any of the mathematics strands. This was surprising as these are skills that are both often emphasized in early instruction and also used as academic skills screeners. It is possible that in the spring of first grade these skills were mastered for many students; however, when examining the descriptive statistics variability does not seem to be a concern. If these skills are not significant predictors of later mathematics performance, perhaps educators may use measures that emphasize more relational math skills. Specifically, Decomposing and Number Sequence may be preferable measures at this stage of mathematics development because they both were significant predictors of two or more later mathematics strands or domains. The Decomposing and Number Sequence measures in this study are distinct from other curriculum based measures used in research and it is warranted to examine these and the extent to which they may be stronger than other available measures. Further research is warranted to investigate if these measures also aid in the identification of learning disabilities.

Limitations and Future Research

There are a few limitations to this study that should be considered when interpreting the results. First, due to the sample size we dichotomously grouped students on the MCA-III outcome as Below Proficient and Proficient. Results of previous research indicate that students who are collectively identified as having MD may, in fact, represent different groups of students with varying degrees of mathematics deficits (Nelson & Powell, 2017). Future research may benefit from studies with larger sample sizes that would allow for a greater number of groups that may represent difficulty with mathematics. A larger sample size would also benefit future research as the results may lend better to generalizing across more settings and diverse students. Second, this study represents a sample of students from suburban areas in one state in the Midwest. The results of this study may not generalize to students in urban or rural settings in the same state, or even students from similar geographical and socio economic status backgrounds from different states. Future research may consider similar studies of the relation between early mathematics skills and performance on state tests across different states. Third, the results represented a longitudinal study through third grade. Other reviews have pointed to the need for more longitudinal research beyond elementary school (Nelson & Powell, 2017) as the bulk of longitudinal research in mathematics ceases in late elementary. Little is known about how early numeracy skills relate data analysis, geometry, and measurement as measured in middle school, for example. Future research may consider continuing longitudinal studies into later grades to determine the importance of early mathematics skills for later achievement beyond broad mathematics. More research related to the influence of reading achievement on mathematics performance across grade levels is also warranted. Longitudinal studies of mathematics performance that only consider mathematics without controlling for reading achievement may provide skewed results of significant predictors of mathematics achievement; results that do not consider the relation between reading and mathematics achievement over time may lead to incorrect instruction and intervention decisions by practitioners.

Conclusion

Many students in the United States experience difficulties with mathematics that tend to persist throughout adulthood. It is important to examine the strongest predictors of these difficulties at an early age in hopes of being able provide intervention services so that students can better develop the fundamental skills of mathematics and avoid later difficulties. This is particularly important for students who may have learning disabilities. Our findings suggest that those students with difficulties in early numeracy skills also tend to struggle with broader mathematical concepts later on. Thus, results from this study add to the current evidence of the importance of early identification of difficulties and disabilities. Findings from this study suggest that the best predictors of later mathematics achievement vary depending on the domain of mathematics and the student's level of proficiency. Thus, educators would likely benefit from using more comprehensive measures of early mathematics to better understand student mathematics development to ensure that students do not have gaps in their knowledge that may prevent them from becoming successful learners of mathematics.

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Table 1

Means and Standard Deviations of MCA-III Performance

MCA-III Subtest	*N*	*M*	*SD*	Min	Max
MCA-III	175	358.60	13.12	326	389
Below Proficient	43	341.12	7.39	326	349
Proficient	132	364.30	9.06	350	389
Number and Operations	175	5.13	1.73	1	9
Algebra	175	5.10	1.69	1	9
Data Analysis and Probability	175	5.27	1.82	1	9
Geometry and Measurement	175	5.09	1.69	1	9

Note. MCA-III = Minnesota Comprehensive Assessment. Below Proficient = Received a score of does not meet or partially meets standards on the MCA-III; Proficient = Received a score of meets or exceeds standards on the MCA.

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Table 2

Means and Standard Deviations by MCA-III Performance Groups and Group Comparison

	Below Proficient			Proficient			Group Comparison*	
earlyMath Subtest	*N*	*M*	*SD*	*N*	*M*	*SD*	Hedges' *g*	CI (95%)
Numeral ID	43	41.28	7.12	131	46.60	7.62	.71	.41 – 1.82
Decomposing	42	6.76	3.37	132	10.38	3.70	1.00	.46 – 1.53
Number Sequence	43	9.14	3.17	129	11.74	2.34	1.00	.62 – 1.40
Verbal Addition	43	4.81	1.48	131	6.24	1.50	.95	.73 – 1.17
Verbal Subtraction	43	4.07	1.79	131	5.58	1.69	.88	.62 – 1.13
Story Problems	43	3.77	1.66	129	4.53	1.23	.56	.36 – .76
Place Value	33	6.21	1.85	121	7.98	2.59	.72	.33 – 1.11
Computation	34	17.53	7.18	121	23.83	5.65	1.04	.48 – 1.41

**Note*. All *t*-tests were significant at the p <.01 level; Below Proficient = Received a score of does not meet or partially meets standards on the MCA-III; Proficient = Received a score of meets or exceeds standards on the MCA-III.

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Table 3

Correlations of Early Mathematics Measures by MCA-III Performance Groups

earlyMath Subtest	MCA-III	NO	A	DA	GM
Total Sample (*N*=175)					
Numeral Identification	.39**	.40**	.30**	.21**	.36**
Decomposing	.55**	.50**	.45**	.35**	.54**
Number Sequence	.56**	.52**	.45**	.40**	.50**
Verbal Addition	.42**	.39**	.37**	.25**	.43**
Verbal Subtraction	.48**	.44**	.35**	.33**	.48**
Story Problems	.42**	.36**	.34**	.35**	.41**
Place Value	.36**	.34**	.23**	.26**	.39**
Computation	.45**	.41**	.40**	.30**	.43**
Below Proficient (*N*=43)					
Numeral Identification	.42**	.32*	.31*	-.09	.47**
Decomposing	.43*	.25’	.24	-.07	.62**
Number Sequence	.55**	.39**	.39**	.13	.60**
Verbal Addition	.25	.20	.26’	-.22	.22
Verbal Subtraction	.44**	.40**	.12	-.05	.47**
Story Problems	.50**	.26’	.44**	.31*	.50**
Place Value	.24	.14	.29’	.04	.31’
Computation	.33’	.28	.38*	-.00	.16
Proficient (*N*=132)					
Numeral Identification	.23**	.28**	.12	.05	.18*
Decomposing	.41**	.35**	.31**	.19*	.36**
Number Sequence	.39**	.35**	.26**	.22*	.27**
Verbal Addition	.21*	.16’	.18*	.06	.27**
Verbal Subtraction	.31**	.25**	.22*	.19*	.32**
Story Problems	.34**	.29**	.19*	.25**	.30**

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Place Value	.23**	.20*	.05	.12	.29**
Computation	.24**	.16’	.19*	.09	.29**

Note. MCA-III = Minnesota Comprehensive Exam, NO = Number and Operations strand, A = Algebra strand, DA = Data Analysis and Probability strand, GM = Geometry and Measurement strand.
** = <.01; *<.05; ‘<.10

Table 4

Prediction of Proficiency Status on the Third-Grade MCA-III

earlyMath Subtest	Accuracy	Sensitivity	Specificity	PPV	NPV
Numeral Identification	74%	0.83	0.44	0.82	0.46
Decomposing	65%	0.67	0.56	0.82	0.36
Number Sequence	69%	0.68	0.70	0.87	0.42
Verbal Addition	63%	0.55	0.91	0.95	0.39
Verbal Subtraction	63%	0.56	0.86	0.93	0.39
Story Problems	58%	0.57	0.60	0.82	0.31
Place Value	63%	0.70	0.42	0.79	0.31
Computation	69%	0.75	0.51	0.83	0.40

Note. PPV = Positive predictive value; NPV = negative predictive value

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Table 5

Summary of Linear Regressions across Strands of the MCA-III

	Numbers/Operations		**Algebra**		**Data Analysis**		**Geometry/Measurement**	
Predictors	Math Only	With Controls	Math Only	With Controls	Math Only	With Controls	Math Only	With Controls
Intercept	-2.73 (.43)*	-11.77 (1.02)*	-2.55 (.44)*	-9.19 (1.25)*	-1.68 (.48)*	-9.82 (1.25)*	.40 (.72)	-12.43 (1.89)*
Numeral ID	.01 (.01)	.01 (.01)	.01 (.01)	.01 (.01)	-.01 (.01)	-.01 (.01)	.01 (.02)	.01 (.02)
Decomposing	.06 (.02)*	.04 (.02)*	.04 (.02)	.03 (.02)	.04 (.03)	.01 (.02)	.10 (.04)*	.08 (.03)*
Number Sequence	.10 (.03)*	.03 (.03)	.10 (.03)*	.06 (.03)’	.08 (.04)*	.02 (.03)	.10 (.05)’	.02 (.05)
Verbal Addition	-.07 (.06)	-.05 (.05)	-.01 (.07)	-.01 (.06)	-.10 (.07)	-.07 (.06)	-.00 (.11)	.01 (.09)
Verbal Subtraction	.11 (.05)*	.05 (.04)	.03 (.06)	-.02 (.05)	.10 (.06)’	.04 (.05)	.11 (.09)	.03 (.78)
Story Problems	.01 (.06)	-.05 (.05)	.03 (.06)	.00 (.06)	.11 (.07)’	.06 (.06)	.18 (.10)’	.11 (.09)
Place Value	.03 (.03)	.02 (.02)	-.02 (.03)	-.03 (.03)	.02 (.04)	.01 (.03)	.09 (.05)’	.08 (.05)’
Computation	.01 (.01)	.02 (.01)	.03 (.01)*	.04 (.01)*	.01 (.02)	.02 (.01)	.01 (.02)	.02 (02)
Reading MCA-III		.03 (.00)*		.02 (.01)*		.03 (.00)*		.04 (.01)*
FRL Status		-.23 (.12)’		.03 (.15)		-.34 (.15)*		-.06 (.22)
R^2	.41	.66	.33	.46	.25	.49	.43	.60

Note. Math Only refers to analysis including only math related measures, With Controls refers to analysis with math measures and control variables (i.e., Reading MCA-III and FRL Status).
** = <.01; *<.05; ‘<.10