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An analysis of the mathematics vocabulary knowledge of third- and fifth-grade students: Connections to general vocabulary and mathematics computation☆

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ABSTRACT

To read mathematics textbooks, answer questions on mathematics assessments, and understand educator and student communication, students must develop an understanding of the academic language of mathematics. A primary aspect of academic language is vocabulary. In this study, we focused on the mathematics-vocabulary performance of students in 3rd and 5th grade. We designed and implemented a measure of key mathematics vocabulary in the late elementary grades, and we compared performance on this measure to scores from general vocabulary and mathematics computation measures. Student performance at both grades was variable, with a 62-point range at 3rd grade and a 95-point range at 5th grade. General vocabulary and mathematics computation were significant predictors of mathematics vocabulary, but the influence of these predictors differed by mathematics-vocabulary performance levels.

1. Introduction

On mathematics assessments, students are regularly prompted to read words and sentences to solve mathematics problems. In order to provide appropriate mathematics instruction to all students, it may be necessary to consider the reading and language demands in mathematics, above and beyond mathematical concepts and procedures. In this study, we administered an assessment of mathematics vocabulary, along with assessments of general vocabulary and mathematics computation. We explored how students in the late elementary grades respond to mathematics-vocabulary items and aimed to understand the connections, if any, among general vocabulary, mathematics computation, and mathematics vocabulary.

In this introduction, we describe the language and reading demands on mathematics assessments. Then, we discuss the construct of academic language as it relates to mathematics, and describe why mathematics vocabulary is a component of academic language. Finally, we describe the purpose and research questions of this study.

1.1. Language and reading demands on mathematics assessments

All school-age students take mathematics assessments designed to measure mathematics competency. Results from such assessments have assisted educators in deciding promotion from one grade level to the next (Maggio & Sayler, 2013) and whether students were prepared to enroll in upper-level mathematics coursework in high school (Spielhagen, 2006). Performance on mathematics assessments has also been related to the number of college acceptances for a student (Lee, 2012) and whether a student would graduate from college (You & Nguyen, 2012). Importantly, data from a longitudinal survey showed that scores from a set of mathematics assessments (i.e., arithmetic reasoning and mathematics knowledge) given in high school were stronger predictors of adulthood outcomes than scores from a set of reading assessments (i.e., word knowledge and paragraph comprehension; Dougherty, 2003). In a comprehensive study, Ritchie and Bates (2013) learned that both mathematics and reading assessments at age 7 predicted higher economic outcomes at age 42, with mathematics scores having a slightly stronger influence. This collection of research demonstrates how performance on mathematics assessments is important for success during school and beyond.

The difficulty with using a mathematics assessment as a determinant for mathematics competence is that mathematics assessments rarely assess the single construct of mathematics. For example, the National Assessment of Educational Progress (NAEP; U. S. Department

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of Education, 2013) is administered to students across the United States every two years. In the most recent iteration of the NAEP with released items (i.e., 2013), fourth-grade students answered 46 mathematics questions. These questions represented the areas of numbers and operations; geometry; measurement; data analysis and statistics; and algebra. Of these 46 items, all but two used words within the item prompt. The median number of words in a single prompt was 28, whereas the median number of numbers or symbols for interpretation was 5. The total number of words in a prompt ranged from 0 to 76. In fact, two questions had 76 written words in the item prompt. Even if we consider the median number of words (i.e., 28), a typical student has to read 28 words and interpret the meaning of those words before attempting to do the mathematics. Similarly but on the international stage, the Trends in International Mathematics and Science Study (TIMSS) 2011 fourth-grade release questions ($n = 65$) featured a median of 23 words per prompt (range = 0 to 152), whereas the median of numbers and symbols was 5.

NAEP data from 2015 presented a disappointing picture of mathematics performance in the United States (U. S. Department of Education, 2015). Only 40% of fourth-grade students performed at or above proficient levels. This result indicated that the majority of fourth graders did not meet minimum proficient standards related to mathematics competency. Scores in eighth grade and 12th grade did not show improvement. In fact, only 33% of eighth-grade students and 25% of 12th-grade students met proficient levels. These low performance levels signify that students in the United States have difficulty with mathematics. It is likely that many students have weak mathematics skill, but it is also possible that the heavy reading requirement involved in mathematics assessment items may cause additional difficulty for many students (Carter & Dean, 2006).

We are not aware of an investigation of NAEP data as it relates to reading within mathematics, but several studies have demonstrated how performance on mathematics assessments may be influenced by reading and vocabulary demands. For example, Pierce and Fontaine (2009) analyzed third-grade standardized mathematics test items. Over 40 separate mathematics-vocabulary terms used within assessment questions had a specific mathematics definition or a meaning in both mathematics and general English. The authors concluded that educators must provide explicit instruction on mathematics vocabulary in order for students to perform well on mathematics assessments. At the high school level, Wieher (2010) explained that many students have difficulty with mathematics questions on college entrance exams because of a limited knowledge of the mathematics-vocabulary terms presented within the questions.

1.2. Academic language and mathematics vocabulary

Cummins (2000) described academic language as the vocabulary, grammar, and language that students use in school. Nagy and Townsend (2012) explained that academic language includes written and oral forms used in academic settings that facilitate communication and thought within an academic discipline. Academic language is difficult for many students because it differs from social language (i.e., language used in the home and community; Fang, Schleppegrell, & Cox, 2006), and it may involve interpretation of non-spoken academic language (e.g., gestures, images; Simpson & Cole, 2015). Academic language is a significant predictor of academic achievement (Townsend, Filippini, Collins, & Biancarosa, 2012); therefore, educators must focus on academic language from the time that students begin formal schooling (Morin & Franks, 2010; Schleppegrell, 2012).

Mathematics may be thought of as a universal language because of the numbers and symbols used to perform calculations, but Cavanagh (2005) explained that mathematics is not a universal language due to the reading and language required to understand mathematics. In fact, the academic language of mathematics should have the same instructional focus as academic language in other content areas (Schleppegrell, 2010). Proficiency with academic language in a content area (e.g., mathematics) requires oral exposure, written exposure, oral production, and written production within the content area (Ernst-Slavit & Mason, 2011; Moschkovich, 2015; Yore, Pimm, & Tuan, 2007). As Schleppegrell (2012) noted, many educators are not aware of the academic language level of individual students and how students use language in academic situations. Riccomini, Smith, Hughes, and Fries (2015) explained that many educators ignore the language of mathematics when teaching mathematics. Because the language of mathematics introduces new terms but also repurposes many terms to have a mathematical meaning (Bay-Williams & Livers, 2009; Schleppegrell, 2007), it is not surprising that many students have difficulty with the academic language of mathematics (Powell & Nelson, 2017; Rubenstein & Thompson, 2002).

In this manuscript, we focus on mathematics vocabulary, which is a component of academic language but not the only component (Morgan, 1996; Moschkovich, 2015; Simpson & Cole, 2015). Mathematics vocabulary is necessary for understanding mathematics and communicating about mathematics (Adams, 2003). Monroe and Panchyshyn (1995) described mathematics vocabulary as belonging to one of four categories: technical, subtechnical, general, or symbolic. Technical terms have one meaning and this meaning is specific to mathematics (e.g., *reciprocal*, *numerator*). Subtechnical terms have more than one meaning, and one of these meanings is specific to mathematics (e.g., *round*, *regroup*). General terms are those from everyday language that students encounter in mathematics (e.g., *more*, *longest*). Symbolic vocabulary terms explain numerals and symbols (e.g., *zero*, *equal*). Researchers have used this four-category framework to describe performance differences related to mathematics vocabulary (e.g., Harmon, Hedrick, & Wood, 2005; Pierce & Fontaine, 2009; Powell & Driver, 2015).

There are many opportunities for confusion of mathematics language (Rubenstein & Thompson, 2002); therefore, all students are language learners in mathematics (Barrow, 2014), and this is evident in mathematics standards. For example, the *Curriculum Focal Points* of National Council of Teachers of Mathematics (NCTM, 2006) mentioned mathematics vocabulary as an important component of mathematics competence. That is, students are expected to “develop vocabulary to describe” various attributes of shapes (p. 31) or use “language” to compare quantities (p. 11). The communication process standard of the NCTM (2000) standards stated that students should be able to “use the language of mathematics to express mathematical ideas” (p. 63). Similarly, the standards of the Common Core State Standards (CCSS; National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010) outlined that students should use “language to describe” (p. 42) or “describe their physical world using…vocabulary” (p. 9). The standards for mathematical practice of the CCSS suggested students be able to construct viable arguments; critique the math reasoning of others; explain how to solve problems; use clear definitions and vocabulary; and communicate precisely to others. All of these practice standards require an understanding and use of mathematics vocabulary.

1.3. Purpose, research questions, and hypotheses of the present study

In this study, our primary purpose was to investigate the mathematics-vocabulary knowledge of students in the late elementary grades, when the administration of high-stakes mathematics assessments typically begins in the United States. To conduct this investigation, we created an assessment of mathematics vocabulary. Then, we explored how general vocabulary knowledge and mathematics computation (i.e., a proxy for procedural mathematics knowledge) related to mathematics-vocabulary performance, especially for students with varying levels of mathematics-vocabulary knowledge. Based on theoretical accounts of mathematical problem solving, as well as empirical studies conducted with younger students, our hypotheses were directional, with general vocabulary and mathematics computation predicting mathematics vocabulary.

Our first research question was: To what extent do general vocabulary and mathematics computation explain the variance in mathematics