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The role of language in fraction performance: A synthesis of literature

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A B S T R A C T

The purpose of this review was to examine the role of oral language in fraction outcomes for school-age students. A comprehensive literature search yielded three studies conducted in the United States for synthesis from which conclusions were drawn. The studies included elementary students in first through fifth grade. Overall, findings suggest that oral language plays a meaningful role in fraction performance. However, heterogeneity across included studies and measurement concerns limit comparisons and conclusions. Differences in measures and other potential confounding variables are discussed. Future research is needed to determine the causal role of language in fraction performance and the extent to which subconstructs of language impact student learning, and the cognitive load of instructional language warrants consideration.

1. Introduction

A fundamental knowledge of fractions is an important for overall proficiency in mathematics, which is predictive of achievement in more advanced mathematical concepts and subsequent employment in the United States (Murnane, Willett & Levy, 1995; National Mathematics Advisory Panel [NMAP], 2008). However, fractions remain a particular weakness for many students when compared to whole numbers (Hecht & Vagi, 2010; NMAP, 2008; Vukovic et al., 2014). This is not surprising, as many properties of whole numbers are not true for fractions (Siegler & Pyke, 2013), and even though fractions are integral in the conceptualization of rational numbers, instruction often treats these topics as unrelated (Schmidt, Wang, & McKnight, 2005).

This disconnect, coupled with a stable national deficit in fraction competence (NMAP, 2008), merits a continued emphasis on the developmental precursors that lead to the identification, treatment, and prevention of fraction difficulties. As researchers identify specific areas of mathematics that are uniquely predictive of later achievement, society can emphasize instruction in those target areas (Siegler et al., 2012). Currently, the emphasis on the importance of fractions in American schools is evident in the curriculum changes within the Common Core State Standards and funding allocation by the Institute of Education Sciences of the U.S. Department of Education. An important next step is a theory-based focus on aptitudes that may be uniquely predictive of fraction performance.

1.1. Language and mathematical development

Oral language forms a foundation for academic achievement throughout early childhood and adolescence. The relation between oral language and reading has been well documented (e.g., Dickinson, Golinkoff, & Hirsh-Pasek, 2010; Roth, Speece, & Cooper, 2002). While the contribution of oral language in predicting mathematics achievement has been investigated (e.g., Duncan et al., 2007; Fuchs et al., 2005), the nature of this contribution is less well understood. In terms of numeral cognition, research has suggested that language may be crucial in the representation of quantities larger than 3 or 5 (Spaepen, Coppola, Spelke, Carey, & Goldin-Meadow, 2011). Theoretically speaking, outside the realm of educational mathematics, human beings may not need to describe discrete quantities such as "14," "21," or, "36;" rather, general quantitative concepts such as *more* or *less* suffice to represent numerical quantities (Carey, 2004; Landerl, Fussenegger, Moll, & Willburger, 2009; Spaepen et al., 2011). Research has indicated that brain regions associated with word processing are recruited during exact arithmetic tasks, whereas regions associated with language-independent visuospatial processing are activated during general magnitude tasks (Dehaene, Spelke, Pinel, Stanescu, & Tsivkin, 1999), supporting the argument that language may play a distinct role in the representation of quantities.

In education, general language ability has been found to predict mathematical outcomes in students who speak English as a first language, in addition to those who speak English as a second language, suggesting that oral language in general, rather than language competency in a given language, plays a unique role in mathematical competency (Lager, 2006; Vukovic & Lesaux, 2013). One area of mathematics performance that is linked with and confounded by language is word-problem solving. Jordan, Levine, and Huttenlocher (1995) found that children

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with language impairment performed significantly lower than typically developing peers on arithmetic word problems. Further, research has shown that school-age word problems are the best predictor of subsequent employment and salary (Murnane, Willett, Braatz, & Duhaldeborde, 2001; Parsons & Bynner, 1997; Rivera-Batiz, 1992). Because word problems require students to decode a written narrative, construct a problem model, and identify missing information, the importance of language comprehension is intuitive. Other research has indicated that language may be linked to *specific* realms of mathematics. For example, Vukovic and Lesaux (2013) found that first grade oral language predicted fourth grade geometry and probability skills, but not arithmetic and algebraic skills. The complexity of the relation between language and other cognitive abilities in the development of mathematical competency has led some scholars to propose *multiple pathways* to mathematical competency, with numerical cognition, visuospatial acuity, and oral language potentially each uniquely contributing to mathematical development (Lefevre et al., 2010; Vukovic & Lesaux, 2013; Vukovic et al., 2014).

Thus, various aspects of linguistic competence may facilitate comprehension of mathematics concepts, as well as their ability to manipulate information within problems. For fractions, language may play a crucial role in concept development and subsequent performance.

1.2. Fraction knowledge and understanding

Difficulties with fractions have been linked to general mathematical skill, but also to other cognitive abilities, such as attention and nonverbal reasoning, as well as possible cognitive biases. For example, students may initially encounter difficulties with fractions due to whole-number bias, where students may incorrectly over-generalize whole-number concepts and procedures (Ni & Zhou, 2005). As fraction knowledge develops, two types of conceptual understanding are considered most relevant in learning fractions: *part-whole* and *measurement* understanding (Hecht, 1998). Part-whole understanding focuses on the concept where a fraction is understand as part of a whole object or group, and has been evident as early as preschool (Mix, Levine, & Huttenlocher, 1999). Measurement understanding targets the concept that fractions are numbers that reflect cardinal size (Hecht & Vagi, 2010) and can be ordered from lowest to highest values. This ordinality is not common in part-whole-focused curricula, which is the primary focus in American schools (Charalambous & Pitta-Pantazi, 2007).

Forms of fraction knowledge and the distinction between part-whole and measurement understanding are important in an instructional context because of the differential load on comprehension. Instruction on part-whole concepts may be less cognitively demanding than measurement concepts because part-whole concepts are more intuitive and require less explicit teaching (Fuchs et al., 2014). Conversely, measurement understanding is thought to be much less intuitive, and concept acquisition relies on formal instruction, and requires the detailed explanation of the symbolic notation, inversion property (e.g., holding the numerator constant, fractions decrease as the denominator increases), and the infinite density of fractions on any given section of the number line (Fuchs et al., 2013, 2014). Further, the procedures involved in measurement understanding problems often require mastery of these properties.

Proficiency in fractions has been proposed to involve (1) children's conceptual understanding of the nature of fractions relative to whole numbers and (2) children's ability to manipulate this information in making fractions judgments or computations. Rittle-Johnson, Siegler, and Alibali (2001) describe these two factors as *conceptual knowledge* and *procedural knowledge*." According to Rittle-Johnson, Siegler, and Alibali (2001), *conceptual knowledge* refers to "implicit or explicit understanding of the principles that govern a domain and of the interrelations between units of knowledge in a domain," whereas *procedural knowledge* encompasses "the ability to execute action sequences to solve problems" (p. 346). Within this rubric, part-whole and measurement understanding would both fall under the umbrella of *conceptual knowledge*, as each require children to comprehend the relations between quantities (Hecht & Vagi, 2010). Conversely, computation-based tasks that require sequential manipulations of quantities, such as adding or multiplying fractions, would be described as *procedural knowledge.*

Research has indicated that conceptual knowledge may precede procedural knowledge in both proportional reasoning (Dixon & Moore, 1996) and fraction addition (Byrnes & Wasik, 1991). However, other work suggests that prior conceptual *and* procedural knowledge both predict gains in the other domain and should thus be considered in terms of bidirectional causality (Rittle-Johnson et al., 2001). For the purpose of the current review, it is important to consider how conceptual and procedural knowledge may be differentially related to subconstructs of linguistic competency, such as vocabulary knowledge or sentence comprehension.

1.3. The importance of language in fraction performance

Thus, we must consider the variety of factors that influence fraction outcomes, from (a) the specific level of how the comprehension and manipulation of fractions fundamentally differ from whole numbers, to (b) the more global level of how fraction-based instruction is verbally scaffolded. Language may facilitate proficiency in fractions on both of these levels. Further, it may be important to consider whether different subcomponents of linguistic proficiency (e.g., vocabulary, syntax, comprehension) differentially relate to different aspects of fraction competency.

The purpose of this paper is to synthesize the available literature that examines the developmental role of language on fraction outcomes of school-age students, and discuss the findings and implications of the review relative to language, outcomes, and other relevant considerations.

2. Method

The studies selected for this review met four criteria. First, included studies examined fraction outcomes for school-age students. Second, study procedures included least one measure of language in the analysis. Third, designs were longitudinal in nature. That is, all studies examined participant change over time (i.e., development). Fourth, studies needed to be published in English-language peer-reviewed journals.

We conducted a search of the literature via electronic databases including ERIC, Google Scholar, ProQuest, and PubMed using combinations of the following search terms: *fraction**, *rational number**, *mathematic**, *language*, *language ability*, *oral language*, *develop**, *predict**, and *education*. Our initial search strategy yielded 7,387 published papers through January 1, 2015. Then, we read titles and abstracts to identify potential studies that met inclusion criteria. This resulted in full-text examinations of 91 studies, of which only five met all four of the present review's inclusion criteria. Two intervention studies met initial search criteria, but were excluded because of the developmental nature of this review (we discuss the intervention studies in section 3.2). Thus, we examine and synthesize three longitudinal studies that considered the unique impact of student oral language proficiency on fraction outcomes.

3. Review of included studies

The purpose of this review was to examine the developmental role of oral language in studies with fraction outcome measures. All studies that predicted that language influences fraction outcomes yielded significant relations, suggesting that language meaningfully contributes to fraction performance. The three included studies all examined the fraction outcomes for samples of students over time. Jordan et al. (2013) used one language measure, Vukovic et al. (2014) used two measures to create a latent composite score, and Seethaler, Fuchs, Star,