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General and math-specific predictors of sixth-graders' knowledge of fractions☆

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ABSTRACT

The present study examined predictors of student's knowledge of fraction concepts and procedures in sixth grade ($N = 334$). Predictors included both math-specific and more general competencies, which were assessed in fifth grade. Multiple regression analyses showed that whole number line estimation, non-symbolic proportional reasoning, long division, working memory, and attentive behavior contributed uniquely to a general measure of students' fraction concepts; on a measure of fraction procedures, whole number line estimation, multiplication fact fluency, division, and attention made unique contributions. The combined predictability of the measures was lower for fraction procedures than for fraction concepts. Although the unique predictors and the amount of explained variance differed according to the fraction outcome, the ability to locate whole numbers on the number line was a major contributor to prediction in each model. Non-symbolic proportional reasoning was particularly predictive of children's conceptual understanding of fractions.

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Facility with fractions supports student learning of advanced mathematics, such as algebra and geometry (National Mathematics Advisory Panel [NMAP], 2008). Fraction knowledge in middle school accounts for much of the gains students make in mathematics achievement more generally (Bailey, Hoard, Nugent, & Geary, 2012). Additionally, fraction knowledge at ten years of age predicts algebra knowledge in high school, after controlling for family education, income, IQ, and knowledge of whole number arithmetic (Siegler et al., 2012). Proficiency in algebra and advanced mathematics, in turn, prepares students for success in higher education as well as for careers involving science, technology, engineering, and mathematics (NMAP, 2008; Sadler & Tai, 2007). There are many potential sources of students' difficulties with fractions. For example, some students may attend separately to the numerator or the denominator, rather than considering the magnitude that the fraction represents (Meert, Grégoire, & Noël, 2008). Moreover, the "rules" students learn in early elementary school for whole numbers do not always apply to fractions (Ni & Zhou, 2005). Multiple fractions can refer to the same magnitude (4/8 and 6/12). Fractions can be represented in various ways, even though they have one and only one precise mathematical definition. They can be understood as a part of a whole, a division problem, a ratio, an operator, or a measure on a number line (Behr & Post, 1992). Many students have trouble developing core fraction concepts for these reasons. Around the same time students are learning fraction concepts, they must also engage in arithmetic computations with fractions, which are different from computation with whole numbers (e.g., multiplication of fractions leads to a smaller number). Skill development in fraction concepts and fraction procedures is intertwined, with an increase in one type of knowledge leading to an increase in knowledge of the other (Hecht, Close, & Santisi, 2003; Hecht & Vagi, 2010, 2012; Rittle-Johnson & Siegler, 1998; Siegler et al., 2012). Thus, development of both fraction concepts and procedures are important areas of concern.

Fractions are complex, and not surprisingly, individual differences in a range of number-related and more general processes affect learning of fraction concepts and procedures (Hecht & Vagi, 2012; Hecht, Vagi, & Torgesen, 2007; Jordan et al., 2013). In the present study, we investigated the degree to which a theoretically motivated group of number-related competencies (e.g., whole number line estimation, non-symbolic proportional reasoning, multiplication fluency, and division), as well as more general competencies in working memory, attentive behavior, and reading fluency predict fractions outcomes at the end of sixth grade. Sixth grade is a key benchmark period for examining competence with fractions, as students typically have had roughly three years of formal instruction on the topic; this instructional trajectory is reflected in the Common Core State Standards in Mathematics (Council of Chief State School Officers and National Governors Association Center for Best Practices (2010). Moreover, sixth grade often is the last year students receive instruction with an intensive focus on fractions, and the gap between students with low fractions achievement and students with high fraction achievement in sixth grade widens by eighth grade (Siegler & Pyke, 2013).

1. Number-related predictors of fraction knowledge

1.1. Numerical magnitude representations

Accurate representations of magnitudes on a mental number line are important for the early acquisition of fraction skills and knowledge, just as they are for whole number skill acquisition (Siegler, Thompson, & Schneider, 2011). Jordan et al. (2013) found that students' ability to estimate whole number locations on a 0–1000 number line in third grade uniquely predicted their performance on fraction outcomes in fourth grade, over and above other number-related and domain-general skills. Similarly, Vukovic et al. (2014) report that number line estimation in second grade predicts fraction concepts in fourth grade.

One explanation for this finding is that students who have a strong grasp of whole number magnitudes can more easily make the connection that fractions, too, have magnitudes and can be absolute measures of quantity (e.g., 1/2 min is the same as 30 s). An alternate explanation is that estimating numbers on a number line may involve proportional reasoning. Thinking about a number line in terms of its constituent parts enhances children's accuracy on estimation tasks (Barth & Paladino, 2011). For example, 1000 can be divided in half or into quarters to estimate locations on the line (e.g., 245 would be close to the quarter reference of 250).

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