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# Fluid reasoning predicts future mathematical performance among children and adolescents

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ABSTRACT

The aim of this longitudinal study was to determine whether fluid reasoning (FR) plays a significant role in the acquisition of mathematics skills above and beyond the effects of other cognitive and numerical abilities. Using a longitudinal cohort sequential design, we examined how FR measured at three assessment occasions, spaced approximately 1.5 years apart, predicted math outcomes for a group of 69 participants between ages 6 and 21 years across all three assessment occasions. We used structural equation modeling (SEM) to examine the direct and indirect relations between children's previous cognitive abilities and their future math achievement. A model including age, FR, vocabulary, and spatial skills accounted for 90% of the variance in future math achievement. In this model, FR was the only significant predictor of future math achievement; age, vocabulary, and spatial skills were not significant predictors. Thus, FR was the only predictor of future math achievement across a wide age range that spanned primary school and secondary school. These findings build on Cattell's conceptualization of FR as a scaffold for learning, showing that this domain-general ability supports the acquisition of rudimentary math skills as well as the ability to solve more complex mathematical problems.


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## Introduction

American educators face the tall order of improving outcomes in science, technology, engineering, and mathematics (STEM). To generate solutions to some of the globe's most pressing challenges, educators will need to teach children to become better problem solvers who can apply to their work the information learned in their STEM courses. Courses in mathematics are especially challenging for many students, and these courses have become a gatekeeper to higher education and job opportunities in technological fields (Moses & Cobb, 2001). Because math instruction builds on previously acquired knowledge and skills, it is difficult for children who fall behind early to catch up with their peers. In an effort to improve math and language outcomes across the nation, educators have recently released new national standards for math and language arts education called the Common Core State Standards (National Governors Association and Council of Chief State School Offices, 2014). The new standards lay out progressions of math skill building benchmarks that have opened up discussions about how teachers can provide better support for students in bolstering their math proficiency skills.

Complementary lines of research in psychology and education aim to identify which cognitive precursors lead to proficient acquisition of mathematics skills. A long-term aim of this line of research is to inform educators about the precursors to math development, so that they may create lesson plans that target not only specific math skills but also underlying domain-general cognitive processes. The cognitive abilities required to solve math problems have been difficult to isolate because mathematics is a heterogeneous subject matter (e.g., arithmetic, fractions, geometry, statistics) and problems within the same topic area require several different operations and computations (e.g., adding, subtracting, multiplying, dividing). Nevertheless, researchers have begun to identify common key cognitive functions that are critically important for disparate types of mathematical computations (Bisanz, Sherman, Rasmussen, & Ho, 2005; Desoete & Grégoire, 2007; Krajewski & Schneider, 2009).

Relationships between math and cognitive abilities are often studied within the framework of the Cattell–Horn–Carroll (CHC) theory, arguably the most comprehensive and empirically supported theory of cognitive abilities derived from more than 70 years of psychometric research using factor analytic theory (Keith & Reynolds, 2010). The utility of the theory is in clarifying the relations between cognitive and academic abilities to inform educational and psychological practices. The most recent revision of this model, by Schneider and McGrew (2012), includes 16 broad cognitive abilities, all of which contain more narrow cognitive abilities within them. This model does not include a general intelligence *g* factor; rather, it is based on accumulating evidence that broad and narrow CHC cognitive abilities explain more variance in specific academic abilities than *g* alone and that these specific relationships are more informative to educational practice than general intelligence (e.g., Floyd, McGrew, & Evans, 2008; McGrew, Flanagan, Keith, & Vanderwood, 1997; Vanderwood, McGrew, Flanagan, & Keith, 2002).

In a recent synthesis of studies investigating the concurrent relationships between CHC cognitive abilities and achievement measures (CHC–ACH) by McGrew and Wendling (2010), fluid reasoning (FR) was one of three broad cognitive abilities that was consistently related to mathematical performance in calculation and problem solving at all age ranges throughout development (the other two were verbal comprehension and processing speed). FR was consistently related to future math achievement above and beyond the contribution of general intelligence. FR has been defined by contemporary CHC theory as the ability to flexibly and deliberately solve novel problems without using previous information (Schneider & McGrew, 2012). More specifically, it is the ability to analyze novel problems, identify patterns and relationships that underpin these problems, and apply logic. On FR tests, one or both of the following logic abilities is required: (a) *induction*, the ability to discover an underlying characteristic (e.g., rule, concept, trend) that governs a set of materials, and (b) *general sequential reasoning (deduction)*, the ability to start with stated rules or premises and engage in one or more steps to reach a solution to a novel problem (Schneider & McGrew, 2012). FR tests are commonly administered as part of IQ batteries that are administered to children in schools or in clinical settings. Whereas FR performance is strongly correlated to general intelligence (*g*), as is verbal comprehension, there is unique shared variance among tests of FR that cannot be accounted for by *g* alone (McGrew et al., 1997).