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Mental abilities and school achievement: A test of a mediation hypothesis

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ABSTRACT

This study analyzes the interplay of four cognitive abilities – reasoning, divergent thinking, mental speed, and short-term memory – and their impact on academic achievement in school in a sample of adolescents in grades seven to 10 ($N=1135$). Based on information processing approaches to intelligence, we tested a mediation hypothesis, which states that the complex cognitive abilities of reasoning and divergent thinking mediate the influence of the basic cognitive abilities of mental speed and short-term memory on achievement. We administered a comprehensive test battery and analyzed the data through structural equation modeling while controlling for the cluster structure of the data. Our findings support the notion that mental speed and short-term memory, as ability factors reflecting basic cognitive processes, exert an indirect influence on academic achievement by affecting reasoning and divergent thinking (total indirect effects: $\beta=.22$ and .24, respectively). Short-term memory also directly affects achievement ($\beta=.22$).

Measures of general and specific cognitive abilities have been used successfully to predict students' academic achievement. Strong positive correlations between intelligence and academic performance are a frequently replicated finding in numerous studies and in several meta-analyses. Intelligence has been shown to be one of the best predictors of academic success (Neisser et al., 1996; Ones, Viswesvaran, & Dilchert, 2005). Particularly strong correlations have been identified in analyses combining values from different intelligence scales (e.g., Deary, Strand, Smith, & Fernandes, 2007; Krumm, Ziegler, & Bühner, 2008; Süß, 2001). The nature of the relationship between intelligence and academic achievement, however, is still a matter of debate among educational researchers and in the literature on intelligence. Current models and taxonomies of intelligence describe a large number of different specific cognitive abilities, which – to varying degrees – comprise general intelligence (e.g., Carroll, 1993; McGrew, 2009). These specific cognitive abilities differ, among other things, in the *complexity* of the cognitive processes they require. Fluid reasoning, for instance, requires far more complex cognitive processes than, for example, mental speed. While fluid intelligence often involves diverse mental operations (e.g., classifying, testing hypotheses, or solving problems), mental speed involves the routine, rather automatic performance of relatively easy, over-learned cognitive activities.

The question of how different *specific* intelligence factors relate to academic performance, and, in particular, how they interact in the prediction of performance, still remains largely unanswered (Floyd, 2005; Luo, Thompson, & Detterman, 2003). In this paper, we analyze the interplay between complex and basic cognitive abilities in their impact on academic performance in school.

1. Cognitive abilities and academic achievement

Traditionally, general cognitive ability (g) has been considered to be the best single predictor of academic achievement (e.g., Glutting, Watkins, & Youngstrom, 2003; Jensen, 1998; Rohde & Thompson, 2007). The attempts to identify *specific* intelligence factors that could improve the prediction of

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academic achievement beyond the impact of a *g*-factor typically failed since *g* appeared to account for virtually all sources of predictable variance in academic achievement (Jensen, 1984). Advances in both intelligence models and statistical modeling have created new possibilities for determining the possible explanatory power of specific intelligence factors. Recent publications on this topic stress the important role of more specific cognitive abilities in the prediction of achievement (e.g., Lohman, 2005; Luo, Thompson, & Detterman, 2006; McGrew, 2005; Taub, Floyd, Keith, & McGrew, 2008; Vock & Holling, 2008).

In the following, we discuss the relationship between basic and more complex cognitive processes from a theoretical perspective. We then present empirical findings on their relationships with each other and with academic achievement.

1.1. Theoretical approaches to the relationship between basic and complex cognitive processes

Recent models dealing with the structure of intelligence, such as the Cattell–Horn–Carroll model of intelligence (CHC; Alfonso, Flanagan, & Radwan, 2005; McGrew, 2009) and the Berlin model of intelligence structure (BIS; Jäger, 1984; Jäger et al., 2006; for English descriptions, see Bucik & Neubauer, 1996, or Carroll, 1993) posit a hierarchical structure of intelligence and incorporate complex as well as basic cognitive abilities. These models typically do not specify functional or causal relationships between their components, e.g., by defining some of the operations as the basis for the development or exertion of certain other operations. The BIS model, for instance, describes four cognitive operations, two of which might in fact be classified as reflecting rather elementary, basic processes (namely, the operations of mental speed and short-term memory) and two reflecting higher-order, more complex cognitive processes (i.e., the operations of reasoning and divergent thinking). These differences in complexity are also reflected in the simple vs. complex demands of the tasks used to assess these abilities in tests.

Psychometric mental speed tasks and short-term memory tasks have in common that they require the fairly "automatic" – that is, routine and unconscious – cognitive handling of simple, usually trivial information. Mental speed tasks are easy in the sense that virtually all test-takers would be able to solve them correctly if they had enough time to work on them; it is the tight time limits that make them difficult and that enable the researcher to differentiate among test-takers. Short-term memory tasks only require the storage of information for a short period of time and the mere reproduction or retrieval of that information. Test-takers do not need to use higher-order cognitive processes to solve these kinds of tasks.

Reasoning tasks, however, demand far more complex, multi-step manipulations of given information, and also require the linkage of new information to information stored in long-term memory as well as the storage of intermediary results in working memory (Carpenter, Just, & Shell, 1990; Verguts & de Boeck, 2002). Divergent thinking (also denoted as divergent production or fluency; Carroll, 1993) can generally be described as the ability to generate numerous diverse ideas (Runco, 1991). Divergent thinking tasks require that participants access stored knowledge quickly, make associations, and combine given pieces of information in new and different ways (Batey & Furnham, 2006). Despite the different levels of complexity between processing speed or short-term memory tasks on the one hand and reasoning or divergent thinking tasks on the other, recent models of the structure of intelligence generally place these different aspects of intelligence on the same level within the hierarchy of abilities, based on the results of factor analysis.

Danthiir, Roberts, Schulze, and Wilhelm (2005) distinguish two approaches to analyze the relationship between basic cognitive abilities and more complex cognitive abilities: the *descriptive* approach and the *explanatory* approach. These approaches have emerged from the research on individual differences and have given rise to rather different research traditions, but have only rarely been combined. Researchers using the descriptive approach apply factor-analytic methods to describe the structure of human abilities based on correlations between a range of different cognitive tasks (mostly paper-and-pencil test items), and on this basis, they develop models of the structure of intelligence. In this research approach, basic cognitive abilities like mental speed and short-term memory are considered at the same hierarchical level as other, more complex cognitive abilities.

In the explanatory approach, on the other hand, the focus is on identifying basic cognitive processes that are the source of higher-order cognitive processes and that can help explain the individual differences found in intelligence tests. The typical research methods used here employ a few basic cognitive tasks, often stemming from the experimental paradigm of cognitive psychology, as predictor variables, as well as measures of one or more complex cognitive ability factors as dependent variables (often equated with intelligence). Within this explanatory framework, researchers develop information-processing models of intelligence. In an early information-processing model of intelligence, Campione and Brown (1978) conceived of the speed of information processing as well as memory as basic building blocks of the cognitive system. They described processing speed as a determinant of intelligent behavior, meaning that more intelligent people are faster in processing information. This parallels the modern mental speed theory (e.g., Deary, 2000; Neubauer, 1997), which states that the speed of information processing is important in determining higher mental abilities and that it acts as a limiting factor, meaning that faster processing over the years results in cumulatively higher intelligence and knowledge, whereas slower processing constantly hampers learning and the development of higher-order cognitive abilities (Deary, 1995).

More recently, Woodcock (1998), Dean, Decker, Woodcock, and Schrank (2003) and Mather and Woodcock (2001) proposed a model that combines features of both information processing models and structure of intelligence models (for a critical review, see Floyd, 2005). Woodcock's model describes interactions among cognitive abilities, as specified in the CHC model, that take place during information processing, as well as the different influences facilitating and inhibiting cognitive performance. The model conceives of short-term memory and mental speed as relatively low-level, automatic processes determining cognitive efficiency during information processing. Information that is registered by the senses enters the system and, if attended to, is encoded into immediate awareness, which is represented in the model by the CHC ability short-term memory. Mental speed has the function of a valve, which helps to control the speed of