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An account of the relationship between fluid intelligence and complex learning in considering storage capacity and executive attention☆

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ABSTRACT

Although fluid intelligence and complex learning are conceptualized differently and assessed by apparently different measures, both theoretical accounts and empirical evidence suggest a relationship between the two constructs. In this study, major working memory aspects including the storage capacity and executive attention were proposed to account for the relationship between fluid intelligence and complex learning. A sample of 184 participants completed fluid intelligence and complex learning scales, as well as working memory measures that each included two or three treatment levels differing in the demands on capacity or executive control. The differences among the treatment levels provided a favorable precondition for employing fixed-links models to separate the core processes of storage capacity or executive attention from the auxiliary processes. Results indicated that both storage capacity and executive attention contributed significantly to fluid intelligence and complex learning. A further analysis showed that the two working memory aspects, particularly the storage capacity, accounted for most of the shared variance between fluid intelligence and complex learning.

1. Introduction

Fluid intelligence reflects the ability to reason and to solve problems in novel situations where prior experience and acquired knowledge are of no help (Horn & Cattell, 1967) while learning mainly refers to the acquisition of new information permanently or the modification of previously stored knowledge (Sweller, 2005). Fluid intelligence and learning originated from different psychological traditions. Previous research on fluid intelligence and learning so far has been conducted as part of two distinct disciplines of scientific psychology (Cronbach, 1957): the study of intelligence mainly occurred in differential psychology with the purpose of revealing sources of the variation underlying human abilities whereas the study of learning was mainly conducted in experimental psychology aiming at discovering the general laws of behavior without reference to individual variation (Jensen, 1989). In spite of this, available evidence suggests a relationship between fluid intelligence and learning, especially learning in complex situations (e.g., Alexander & Smales, 1997; Williams, Myerson, & Hale, 2008; Williams & Pearlberg, 2006). This study is to explore the nature of the relationship between fluid intelligence and complex learning in considering two major aspects of working memory, i.e., the storage capacity and executive attention, as suspected cognitive source of the relationship.

1.1. The overlap between fluid intelligence and complex learning

Human intelligence and learning are commonly assumed to be related with each other since the early conceptualization of intelligence which seems to be strongly tied to learning

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ability (e.g., Buckingham, 1921, p. 273). Furthermore, theoretical developments in different research traditions have highlighted this relationship. For example, in the framework of individual differences in skill learning, Ackerman (1988, 2007) concluded that human abilities, especially general intelligence, play a substantial part in determining individual differences in task performance at the early stage of learning procedures. There is also the investment theory stating that fluid intelligence is invested in the development of crystallized abilities (Cattell, 1963). A revision of the investment theory even suggests that learning processes may serve as the driving factor in accounting for the role of fluid intelligence in acquiring developed abilities and specific areas of knowledge (Schweizer & Koch, 2002).

Despite those theories associating learning with fluid intelligence, empirical studies do not suggest that all sorts of learning are equally associated with fluid intelligence. It appears that learning is mostly related to fluid intelligence when the learning material is of at least moderate difficulty and complexity (Lohman, 1999). For example, Woodrow (1938, 1946) has reported rather weak or no correlations between performance in a variety of learning tasks and intelligence scores. A general critique of the Woodrow's studies is that the learning tasks he employed were simple and unlikely to be related to complex cognitive abilities (Estes, 1970). Recent research conducted by Williams and Pearlberg (2006) shows that fluid intelligence is more strongly related to the learning rate of complex learning tasks than to that of simple learning tasks (see also Kaufman, DeYoung, Gray, Brown, & Mackintosh, 2009; Tamez, Myerson, & Hale, 2008). Therefore, in investigating individual differences of learning and related abilities, it is necessary to make explicit the type of learning that is under consideration. In this study, we concentrate on complex learning, which involves the acquisition and development of a series of goal-directed strategies and abstract rules (cf. Anderson, Fincham, & Douglass, 1997).

As indicated by previous research, complex learning and fluid intelligence show an established relationship, which indicates an overlap between the two constructs. A question of interest is where the overlap comes from or what the nature of the overlap is. To answer this question, it is of great significance to consider the cognitive sources that are crucial for both fluid intelligence and complex learning. One of the most promising candidates in individual differences research is working memory.

1.2. Working memory and the relationships with fluid intelligence and complex learning

Working memory is a limited-capacity system allowing the simultaneous storage and manipulation of information during completing complex tasks such as reasoning, learning and comprehension (Baddeley, 1986). In an influential model proposed by Baddeley and Hitch (1974), working memory includes two domain-specific storage components responsible for storing verbal and visuospatial information, and a domain-general component, the central executive system that is responsible for the allocation of attentional resources for maintaining or storing information and processing dual tasks.

The relation between working memory and fluid intelligence has been repeatedly investigated and working memory has been shown as a powerful predictor of fluid intelligence (Colom, Abad, Quiroga, Shih, & Flores-Mendoza, 2008; Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Engle, Tuholski, Laughlin, & Conway, 1999; Kane, Hambrick, & Conway, 2005; Kane et al., 2004). In particular, a few of those studies have demonstrated that working memory capacity and fluid intelligence share from around 50% to 70% of their variances (e.g., Kane et al., 2005; Oberauer, Schultze, Wilhelm, & Süß, 2005). Moreover, researchers in this field have already tried to explain why working memory is strongly related to fluid intelligence. Two aspects or specific properties of working memory have been put forth to account for the predictive power of working memory. One group of theories suggests that the capacity to maintain a distinct number of separate representations active for ongoing processing is the genuine contributor to fluid intelligence. A number of studies indicated that this storage capacity of working memory accounts for a unique variance of fluid intelligence independent of other components of working memory (Chuderski, Taraday, Nęcka, & Smoleń, 2012; Colom et al., 2008; Cowan, Fristoe, Elliott, Brunner, & Saults, 2006; Unsworth & Engle, 2007).

A second group of theories suggests that the predictive power of working memory derives from the quality of attention control or executive attention, which is typically involved in monitoring ongoing procedures, the selective activation of relevant representations, and the suppression of irrelevant or distracting ones. This seems in line with Baddeley's (1986) emphasis of the central executive as the primary underlying construct in working memory system. There are also quite a few studies demonstrating that performance in both working memory and fluid intelligence measures depends on the quality of the domain-general control of attention (henceforth called executive attention) (e.g., Engle et al., 1999; Kane, Conway, Hambrick, & Engle, 2007; Kane et al., 2004; Ren, Schweizer, & Xu, 2013; Unsworth & Spillers, 2010).

Theoretical developments on learning and skill acquisition have also emphasized the importance of working memory during complex learning (Anderson et al., 1997; Paas, Van Gog, & Sweller, 2010; Sweller, 1988, 2005; Wittrock, 1992). For instance, in the four-stage model of skill acquisition proposed by Anderson et al. (1997), individuals firstly have to keep specific examples or items in working memory for developing the abstract schema or rules. Secondly, the rules that are derived from those examples should also be maintained in working memory for further using before they are transferred into long-term memory. Another theoretical account that associates working memory with complex learning is the cognitive load theory, which highlights the influence of the limited storage capacity of working memory on learning processes (Sweller, 1988, 2005). Since in complex learning activities learning schemas can be formed only when the amount of information that has to be processed does not exceed the processing capacity of working memory, the capacity of working memory is becoming particularly critical. Moreover, learning performance in complex domains usually requires the acquisition of a great number of schemas, individuals with larger