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

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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...
ability (e.g., Buckingham, 1921, p. 273). Furthermore, theo-
retical 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 crystal-
lized 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
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intelligence, empirical studies do not suggest that all sorts of
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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 Pearberg (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 investigat-
ing 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 responsi-
ble 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 intelli-
gence has been repeatedly investigated and working memory
has been shown as a powerful predictor of fluid intelligence
(Colom, Abad, Quiroga, Shih, & Flores-Mendoza, 2008; Con-
way, Cowan, Bunting, Thirault, & 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 acquisi-
tion 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 perfor-
ance in complex domains usually requires the acquisition
of a great number of schemas, individuals with larger
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