Available online at www.sciencedirect.com
ScienceDirect
Educational Research Review 1 (2006) 83–98
Educational Research Review
www.elsevier.com/locate/EDUREV

Working memory, fluid intelligence, and science learning

Kun Yuan *, Jeffrey Steedle, Richard Shavelson, Alicia Alonzo [1], Marily Oppezzo

School of Education, Stanford University, 485 Lasuen Mall, Stanford, CA 94305, USA

Received 16 January 2006; received in revised form 24 August 2006; accepted 28 August 2006

Abstract

A review of the history of working memory (WM) studies finds that the concept of WM evolved from short-term memory to a multi-component system. Comparison between contemporary WM models reveals: (1) consensus that the content of WM includes not only task-relevant information, but also task-irrelevant information; (2) consensus that WM consists of phonological and visuospatial components; (3) consensus that short-term memory storage is a function of WM; (4) disagreement as to whether an independent executive control is a necessary WM component; and (5) disagreement as to whether the control function is active or passive. Methods for measuring WM differed across studies with a preponderance of various dual-tasks; little psychometric work has been done on these measures. Correlational studies supported a close relationship between WM and measures of fluid intelligence and science achievement, but we found no experimental studies on the impact of WM training on science achievement. Finally we suggest how WM research findings may be applied to improve fluid intelligence and science achievement.

Keywords: Working memory; Fluid intelligence; Science learning

Working memory (WM) is responsible for temporarily maintaining and manipulating information during cognitive activity (Baddeley, 2002). It has been found to be closely related to a wide range of high-level cognitive abilities such as reasoning, problem-solving, and learning (Kyllonen & Christal, 1990). In addition, WM is related to academic achievement in the domain of reading (Daneman & Tardif, 1987), writing (Abu-Rabia, 2003), mathematics, and science (De Smedt, Ghesquiere, & Verschaffel, 2004; Gathercole, Pickering, Knight, & Stegmann, 2004). As WM plays an important role in cognitive activity, researchers are exploring ways of applying WM research to improve abilities such as fluid intelligence – the ability to understand complex relationships and solve new problems (Martinez, 2000) – and science achievement. This paper tracks the history of WM studies, synthesizes the definition of WM, contrasts measures of WM, summarizes the relationship between WM and fluid intelligence and science achievement, and discusses how to apply findings from WM research to improve fluid intelligence and facilitate science learning.

1. History of WM studies

Studies of WM date back to the 1880s when Ebbinghaus (1885) pioneered the use of nonsense syllables to study learning and forgetting in controlled experiments. Through his research, Ebbinghaus found that he could correctly recall

* Corresponding author. Tel.: +1 650 387 3088; fax: +1 650 725 7412.
E-mail address: katyuan@stanford.edu (K. Yuan).
[1] Present address: Department of Teaching and Learning, College of Education, The University of Iowa, USA.

1747-938X/$ – see front matter
doi:10.1016/j.edurev.2006.08.005

seven syllables after just one reading. James (1890) introduced the term "primary memory" to represent the cognitive construct responsible for temporary maintenance of information. He explained that images in primary memory are lost forever unless they are consciously sustained in the mind for a sufficient period of time. More than half a century later, Miller (1956) proposed the term "immediate memory" and described its capacity as 7 ± 2 units or "chunks" of information, which is consistent with Ebbinghaus' finding on temporary memory capacity.

As cognitive psychology developed, research provided more detailed understandings of memory. Atkinson and Shriffrin (1968) proposed a memory model which included a sensory store, short-term memory (STM), and long-term memory (LTM). According to their model, incoming information was first registered in the sensory store. A limited amount of this information was attended to and passed onto STM; information not attended to was lost. STM was viewed as a capacity-limited, unitary memory store which temporarily kept information for further processing. Information in STM decayed after two seconds if not rehearsed (Miyake & Shah, 1999). Rehearsed information was encoded and saved in LTM, an unlimited store that retained information for long periods. Information relevant to a cognitive task could be retrieved from LTM at a later time.

Memory researchers recognized that theories of STM could not adequately describe the kind of temporary memory that complex cognitive tasks require (Shah & Miyake, 1999). Eventually, memory research gave rise to theories in which STM was seen as one component of a larger system known as WM. Researchers proposed different theories to demystify WM, including models focusing on the structure and function of WM (Baddeley & Hitch, 1974; Cowan, 1999; Engle, Kane, & Tuholski, 1999; Oberauer, Süß, Wilhelm, & Wittmann, 2003), models emphasizing WM processes (Kieras, Meyer, Mueller, & Seymour, 1999; Lovett, Reder, & Lebiere, 1999; Young & Lewis, 1999), and a model stressing the source of content in WM (i.e., the connection between WM and LTM) (Ericsson & Delaney, 1999). These models provided different but complimentary views of WM and contributed to a comprehensive understanding of WM.

2. Definitions of working memory

Although studies of WM have a long history, researchers have not reached unanimous agreement as to what WM is (Kyllonen, 2002). Differences in WM models commonly reflect different ideas about the complexity of WM. According to Miyake and Shah (1999), WM models have evolved from a single unitary memory store to a system containing multiple cognitive subsystems responsible for different storage and executive control functions. For example, Miller's (1956) finding that immediate memory stored only 7 ± 2 "chunks" of information represented the early understanding of WM as a single information store. Baddeley and Hitch's (1974) model of WM as a multiple-component system consisting of a phonological loop, a visuospatial sketch pad, and a central executive started the age of decomposing WM into different components. The same idea is reflected in other WM models that followed. Although researchers differ in their specifications of WM subsystems, most agree that WM includes multiple subsystems working together to activate task-related information, maintain activation, and manipulate information during the performance of cognitive tasks (Miyake & Shah, 1999). The evolution of WM models shows that ideas about WM have shifted towards a more dynamic and systematic view.

In addition to their different ideas about the complexity of WM, researchers also took different perspectives when they defined WM. Contemporary models define WM from different angles such as content, structure, function, or a combination of these dimensions (Miyake & Shah, 1999). In order to develop a comprehensive understanding of WM, we will compare different perspectives on WM that reflect the aforementioned dimensions.

2.1. Content

Most researchers agree that WM stores task-relevant information (Baddeley & Hitch, 1974; Engle, Kane, et al., 1999; Ericsson & Delaney, 1999; Oberauer, Süß, Schulze, Wilhelm, & Wittmann, 2000). Some researchers argue that certain task-irrelevant information is also stored in WM. For example, Lovett et al. (1999) defined the content of WM as a group of activated declarative knowledge nodes, which included both task-relevant and task-irrelevant information. They asserted that some task-irrelevant knowledge nodes were also included in WM because they were highly activated. The inclusion of task-irrelevant information in WM might contradict prior understanding of WM. However, as discussed later, the control function of WM is partially exhibited in inhibiting the influence of task-irrelevant information. Therefore, the inclusion of task-irrelevant information is reasonable and helpful for an accurate understanding of the information content of WM.