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REVIEW ARTICLE

Cognitive Load Theory: A Broader View on the Role of Memory in Learning and Education

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Abstract According to cognitive load theory (CLT), the limitations of working memory (WM) in the learning of new tasks together with its ability to cooperate with an unlimited long-term memory (LTM) for familiar tasks enable human beings to deal effectively with complex problems and acquire highly complex knowledge and skills. With regard to WM, CLT has focused to a large extent on learning task characteristics, and to a lesser extent on learner characteristics to manage WM load and optimize learning through instructional design. With regard to LTM, explanations of human learning and cognition have mainly focused on domain-general skills, instead of domain-specific knowledge held in LTM. The contributions to this special issue provide a broader cognitive load view on the role of memory in learning and education by presenting the historical roots and conceptual development of the concept of WM, as well as the theoretical and practical implications of current debates about WM mechanisms (Cowan 2014), by presenting an updated model of cognitive load in which the physical learning environment is considered a distinct causal factor for WM load (Choi et al. 2014), by an experimental demonstration of the effects of persistent pain on the available WM resources for learning (Smith and Ayres 2014), and by using aspects of evolutionary educational psychology to argue for the primacy of domain-specific knowledge in human cognition (Tricot and Sweller 2014).

Keywords Cognitive load theory · Working memory · Learning · Education · Instructional design

The importance of the role that working memory (WM) and long-term memory (LTM) play in human learning is undisputed. Cognitive load theory (Paas et al. 2003; Sweller et al. 1998, 2011) uses a cognitive architecture consisting of a WM that is limited in capacity to 4±1 elements of information (Cowan 2001; Baddeley 1986; Miller 1956) and duration to about 30 s (Cowan 1988; Peterson and Peterson 1959) when dealing with novel information. The capacity and duration limits of WM are eliminated when it deals with familiar information that

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is stored in LTM in cognitive schemas. Cognitive schemas (see Bartlett 1932) are used to store and organize knowledge by incorporating or chunking multiple elements of information into a single element with a specific function. Skilled performance develops through the construction of increasing numbers of ever more complex schemas by combining elements consisting of lower level schemas into higher level schemas (see Chi et al. 1982). If the learning process has occurred over a long period of time (see Ericsson and Charness 1994; Simon and Gilmartin 1973), a schema may incorporate a huge amount of information and become automated (Kotovsky et al. 1985; Schneider and Shiffrin 1977). Both schema construction and automation processes reduce the load on WM. Because a schema can be treated by working memory as a single element or used unconsciously after automation, the limitations of working memory disappear for more knowledgeable learners when dealing with previously learned information stored in long-term memory (Sweller et al. 2011). As a result of the relation between WM and LTM, once information is stored in the long-term memory, the working memory can handle a complex material that exceeds its capacity prior to the information being stored.

The main goal of cognitive load theory (CLT) is to optimize learning of complex tasks by efficiently using the relation between the limited WM and unlimited LTM. To achieve this goal, cognitive load researchers attempt to engineer the instructional control of cognitive load by designing methods that substitute productive for unproductive working memory load. This approach has been very successful, as CLT theory over three decades has identified a number of learning environments that are problematical and provided strategies to make them more effective. However, as research in the field of instructional design has expanded, through for example the use of new technologies (e.g., mobile learning environments; Liu et al. 2014), and the development of neuroscience (e.g., electroencephalography; Antonenko et al. 2010) and evolutionary educational psychology (e.g., identification of primary and secondary biological skills; Geary 2008; Sweller 2008), it has become apparent that cognitive load theory, research, and practice may profit from a broader view on the role of memory in learning and education. The four articles in this special issue provide a starting platform for this expansion by focusing on different ways that the view on memory in cognitive load theory can be broadened.

The first article by Cowan (2014) provides researchers with an in-depth review of the historical roots and conceptual development of the concept of working memory and the theoretical and practical implications of current debates about WM mechanisms. Cowan examines the early history of research into WM and the human memory system, noting the pioneer work of Miller (1956) on the capacity of WM and the contributions made by Baddeley and Hitch (1974) in identifying different sub-components of WM. Comparisons are also made with alternative WM models, as well as noting many unanswered questions and controversies surrounding WM that impact on our understanding of cognitive development, learning, and education.

The second article by Choi et al. (2014) will make researchers aware of the effects that aspects of the physical learning environment can have on WM load and learning. Arguably, CLT-based instructional methods have focused to a large extent on manipulating aspects of the learning task, such as goal specificity (e.g., Ayres 1993; Paas et al. 2001; Sweller 1988), redundancy (e.g., Sweller and Chandler 1991; Kalyuga et al. 1999; Liu et al. 2011) and split attention (e.g., Ayres and Sweller 2005, in press; Chandler and Sweller 1992; Kalyuga et al. 1999), and to a lesser extent, on manipulating combinations of aspects of the learning task and learner characteristics, such as prior knowledge (the expertise-reversal effect; e.g., Kalyuga 2007; Kalyuga et al. 2003, 2012) and age (Paas et al. 2001; Van Gerven et al. 2002; 2004). However, research in fields that are not directly related to learning and education suggests that the working memory capacity that is available for learning is not only determined by task and learner characteristics but may also depend on aspects of the physical environment and affective factors. Hence, a much greater potential for exploring learning interactions occur by combining the learning environment with learner characteristics and instructional strategies.

An example of the role that the physical environment can play is provided by a research in the field of forensic psychology, which shows that while working on a task, working memory resources are consumed by unintentional monitoring of the environment. The research of Vredeveldt et al. (2011) has shown that eye closure reduces working memory load and improves performance on eyewitness memory tasks by freeing working memory resources that would otherwise have been involved in monitoring the environment.

The third article by Smith and Ayres (2014) broadens the research into CLT and individual differences and CLT be examining the impact of persistent pain on learning. With the exception of aging research (see Paas et al. 2001), CLT has rarely investigated individual differences unless related to variations in prior knowledge. It is well known that as the mind ages, memory, including WM, declines (see Baddeley 1986). Smith and Ayres review the literature on how pain impacts negatively on working memory. For example, it has also been shown that pain may interfere with the brain's ability to keep information in mind while working on other tasks that require attention (e.g., Dick and Rashiq 2007). Processes that contribute positively to both pain and executive working memory performance share capacity-limited resources. Smith and Ayres also experimentally demonstrated how learning could be affected by persistent pain in a multimedia environment.

Other examples of how cognitive load can be influenced by individual differences, and not just the physical environment or expertise, include emotions (see Fraser et al. 2012) and anxiety (see Eysenck 1985). In stressful situations, such as high-stakes exams, working memory resources are consumed by intrusive worries about failure, especially in high-anxious students. A study conducted by Ramirez and Beilock (2011) showed that a brief expressive writing assignment that occurred immediately before taking a test improved test performance by freeing working memory resources associated with worries about failure.

The fourth article by Tricot and Sweller (2014) presents historical and empirical evidence to argue against the prevailing idea that skill acquisition can be explained by the acquisition of domain-general knowledge and in favor of domain-specific knowledge as a primary factor in skill acquisition Whereas research seems to clearly indicate that the only factor that alters as expertise develops in fields, such as chess and medicine, is the accumulation of domain-specific knowledge held in LTM (e.g., Ericsson and Charness 1994), explanations of human learning and cognition have been focusing more on domain-general skills than on domain-specific knowledge. In the final contribution to this special issue, Tricot and Sweller (2014) show that there is every reason to suppose that the same cognitive aspects apply to all educationally relevant curriculum areas and use aspects of evolutionary educational psychology (see Geary 2012; Paas and Sweller 2012) to argue for the primacy of domain-specific knowledge in human cognition.

In summary, Cowan's (2014) discussion of contemporary models of WM, as well as an historical account, can potentially expand the theoretical base of CLT. Choi et al. (2014) examine the influence of the environment and how it impacts on WM, opening up more interactions with strategies and affective factors that need to be considered when designing learning environments. Smith and Ayres (2014) widen the research base on CLT and individual differences by considering learners who live with persistent pain. Tricot and Sweller (2014) provide a compelling argument based on evolutionary educational psychology as to why domain-specific knowledge needs to be the focus of research into learning and teaching.

The first three articles discuss ways to broaden the view on memory in cognitive load theory, research, and practice and are focused on WM, whereas the fourth article is related to LTM. We hope that the contributions to this special issue will provide the reader with knowledge and ideas, potentially leading to a new research on how cognitive load theory can be enhanced by considering a wider perspective of human memory.

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