Chapter VI
Nous:
Cognitive Models of Working Memory

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ABSTRACT

The path to the study of cognition has to take into account working memory, as it is a key process of thinking operations in the human cognitive system. Naturally, this also holds for cognitive operations in the Web. The chapter introduces readers to current trends regarding models of working memory. The major models proposed in the literature are discussed here: Baddeley and Hitch’s multi-component model, Daneman and Carpenter’s account, Cowan’s embedded-process model, Kane and Engle’s executive attention model and long-term working memory model by Ericsson and Kintsch. The chapter focuses on the Baddeley and Hitch model, and the author argues that this specific model offers a more theoretically sound account of working memory operations. Unresolved issues and inefficiencies are also discussed and research directions are proposed.

INTRODUCTION

In order to explain how learning occurs, we have to thoroughly investigate phenomena like memory, language and thinking. Learning and memory provide the theoretical substratum for the study of education. Therefore, research in cognition, from perception to memory and from problem solving to higher-order interactions, is of great importance. That evidently applies to learning in the Web because, as Wolfe (2001) stresses, the web is basically based on cognitive technology. Recent advances in the psychology of learning point towards four dimensions of importance in web learning: a) individual differences that are provided for in a web environment, b) learning as a social process, c) the learning context, which web learners seem to be very sensitive to, and d) fundamental cognitive processes, such as perception, memory and metacognition.

In order to introduce memory structures and operations, we should at this point refer to the
most basic distinction proposed in the literature, the distinction between short-term memory (STM) and long-term memory (LTM) (see Atkinson & Shiffrin, 1968). Short-term memory is the part of memory that deals with our “psychological present”; it receives and retains stimuli for very short periods of time. It is a fragile system of very limited capacity (typically 7 ± 2 items of information at any given time) and duration (information is retained there for approximately 20 seconds). When short-term memory capacity becomes overloaded, information is very susceptible to loss, because it either decays or is replaced by new items. Loss of information also occurs when stimuli remain in the system longer than approximately 20 seconds. After 20 seconds elapse, items must either be transferred to a permanent memory system, long-term memory, or they are cleared from short-term memory. Long-term memory deals with our “psychological past”. It is viewed as a huge store of practically unlimited capacity and duration. Information from short-term memory is transferred there and can remain for long periods up to a lifetime. Everything we know about ourselves and the world is stored in this system.

In the past 30 years, the concept of working memory has appeared to challenge the traditional view of short-term memory. Working memory is, no doubt, one of the “hottest” and most exciting areas in cognitive psychology and cognitive neuroscience. It also is one of the most researched areas, as it serves as a backbone to cognitive processes. Various working memory models have been developed, quite diverse in their scope and emphasis. As Miyake and Shah (1999, p. xiii) rightly point, existing models account for certain aspects of processes and functions in a sophisticated manner, nevertheless they tend to omit specifying in detail some other aspects.

This chapter is concerned with the ways working memory plays a major role in information processing. The objective set is to present the main theoretical frames of working memory and to describe its structure and organization. The chapter also aims at demonstrating how the system is intertwined to learning and academic performance. It introduces working memory accounts by Daneman and Carpenter (1980), Cowan (1995; 2005), Kane and Engle (2000), Ericsson and Kintsch (1995) and focuses on the multi-component model by Baddeley and Hitch (1974; Baddeley, 2000). I will argue that the Baddeley and Hitch model is better equipped to offer a theoretical explanation of how working memory operates and how it is connected to higher-order cognitive functions.

**BACKGROUND**

The working memory (WM) framework was proposed to replace the traditional STM concept. Since the new framework was introduced, about 30 years ago, research has exploded. However, the bridging has not been achieved to a significant extent. Although the concept of WM has invaded cognition research, in everyday life much uncertainty is related to its nature and functions. Among this voluminous research, the chapter will inevitably present selective work in the area, based on the author’s theoretical views. However, an effort has been made to include the main approaches to the WM concept.

Elaborating on the distinction mentioned in the Introduction, between STM and LTM, let us point that memory was initially conceptualized as a tri-partite structure (see Figure 1). This structure comprises a sensory register (receiving and identifying all environmental stimuli), a limited capacity short-term store (holding information temporarily and at the same time processing that information for the needs of the task to be executed) and an essentially unlimited capacity long-term store, which is fed by the elements that remained long enough in the short-term store (Atkinson & Shiffrin, 1968). Keeping memory traces active in STM (mainly by using rehearsal) was considered to achieve transfer to LTM and,
thus, to secure learning. The main coding mode is sensory in the sensory register (i.e., an auditory stimulus is registered on the basis of its sound properties, a color as a color, a smell by registering the smell properties, and so on), verbal in the STM store (e.g. a color arriving in the system becomes encoded on the basis of its name) and semantic in the LTM store (i.e., the meaning of information is stored in LTM, even if the material is a movie par example).

Although this tri-partite model of memory explains well a wide range of, verbal in particular, data and argues clearly for the separation between STM and LTM systems, the shortcomings of this account gave rise to different explanations. As Craik and Lockhart (1972) have shown in their approach, various levels of information processing lead to different types of learning. The emphasis is shifted, from memory stores to coding strategies. Mere retention of information in STM does not guarantee transfer to LTM (Bjork & Whitten, 1974). More elaborate ways of coding (e.g. semantic) result in more durable learning, whereas more superficial coding (e.g. rehearsal) results in less sustained learning. This concept of processing “depth” proved to be a valuable idea for the explanation of learning mechanisms and has also been extremely useful in terms of educational applications. In other words, deeper, meaningful understanding of verbal material leads to better memory than rehearsal or memorization based on the physical features of the same material.

The modal concept of memory has another serious shortcoming, and it lies with neuropsychological evidence. If STM is the necessary path, which information must pass through in order to end in LTM, then a STM deficit should result in a deficit in LTM as well. Clearly, this is not the case (Shallice & Warrington, 1970). Besides, if STM served as a general WM, as Atkinson and Shiffrin (1968) assume,STM patients should exhibit handicaps in many different cognitive areas. Again, this is not the case. Such patients’ problems appear to be of a limited extent.

**BADDELEY AND HITCH’S MULTICOMPONENT MODEL**

The working memory concept was developed on the basis of the inefficiencies of the modal model. One popular account of WM is that of a memory system, which is involved in the temporary retention and in the concurrent processing of incoming information, until the task or the tasks at hand are completed (Baddeley & Hitch, 1974; Baddeley, 2000). The model formulates a separate-resources WM hypothesis and assumes four components: (a) a core system, which is the central executive, and three temporary storage systems, (b) the phonological loop, (c) the visuo-spatial sketchpad and, (d) the episodic buffer. The central executive was initially conceived as a limited resources pool of general processing capacity that controls attention.

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*Figure 1. The multi-modal model by Atkinson & Shiffrin (1968)*

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and is involved in temporary storage as well as in higher-order mental processes (Baddeley, 1996). The “heart” of WM, it is implicated in all mental activities that call for coordination between storage and deliberate information processing (e.g., mental arithmetic, text comprehension, driving a car while listening to the radio). Very recently, Baddeley (2007, p. 139) attributed three attentional features to the central executive: the capacity to focus, to divide and to shift attention. As Baddeley admits, the concept of a general resource processor was not effective in the frame that it is unable to shed light into the specific processes implicated in executive control. Thus, he currently visualizes the executive as an attentional control system, probably bearing specific subcomponents. As it will be further explained below, a forth characteristic is that the central executive is considered to operate as an interface between WM and LTM.

The phonological loop is specialized in temporary storage and manipulation of oral language material, like words, sentences or numbers. The main mechanism via which the loop operates is articulatory rehearsal; that is, subvocal articulation of incoming material and formation of a phonological code to be retained. The loop can also function as a distinct offline system that stores and manipulates language-based input (Vallar & Papagno, 2002). The visuo-spatial sketchpad handles images, information involving space movement and direction, as well as pictures. When given instructions at the super-market reception as to how we can find pet food three aisles to the left, it is the sketchpad’s job to draw a sketch of the directions. Finally, the episodic buffer was proposed by Baddeley in 2000. It is the fourth component and is visualized as an interface between the other three components and LTM. The buffer binds the information coming from the loop, the sketchpad, the executive, perception and LTM into coherent episodes, albeit limited in their number. It functions as a workspace and is supposed to be accessible via conscious awareness. Following this introductory presentation, let us give a more detailed account of each of the modal model components.

**Phonological Loop**

The phonological loop (PL) is assumed to be speech-based. It is of limited capacity, as all four WM components are. Information remains there temporarily, based on its duration length rather than on time elapsed. While STM store in the modal model by Atkinson and Shiffrin (1968) is assumed to retain information for about 20 seconds, the loop resembles an audio tape, with duration of approximately 2 seconds: the longer the time it takes for the loop to articulate the stimuli, the fewer the words it can maintain. It consists of at least two elements: a passive phonological input store and an active, subvocal articulatory rehearsal process. Auditory information gains direct access to the loop, with no need for prior phonological coding (Hitch, 1990). On the contrary, visual language must be converted to a phonological code in order to gain access (Bablekou, 1989). In one of our experiments, we presented children 5-12 years of age with the very same stimuli (pseudowords) in both modalities, visual and aural. More items were recalled in the aural than in the visual mode, as if children had different spans for the same material presented.
in the two modalities. We interpreted this strange at first look finding in terms of diverse coding prerequisites set at input. Visual stimuli do not gain access to the loop unless converted to and retained briefly in an appropriate phonological code. Auditory stimuli, on the other hand, gain automatic access to the loop and are readily retained briefly, in the same form they entered the system. This hypothesis explains children’s capability of recalling more spoken stimuli, which did not need any rehearsal, than visual stimuli, which needed conversion into a speech-based code. The storage-rehearsal distinction above is also supported by neuropsychological evidence (Vallar & Papagno, 2002).

A point of interest is whether the PL of WM is a language system, having evolved from speech perception and speech production systems. Evidence so far shows that the loop can function as an offline component for the storage and manipulation of verbal material (see Chryschoou & Bablekou, submitted), going beyond the fundamentals of speech perception and production (Vallar & Papagno, 2002). It is responsible for transforming perceptual stimuli into phonological codes that retain the acoustic, temporal and sequential properties of the material (Gilliam & van Kleeck, 1996). The codes are then compared against pre-existing ones in LTM and also against meaning representations, and the right match is selected. However, higher level comprehesion is not executed by the loop, as it demands the involvement of the central executive.

Visuo-Spatial Sketchpad

The visuo-spatial component (VSSP) of WM has been almost totally neglected for many years. Although it embarks from the privileged, rich field of vision research, limited data have been gathered so far. Lately, this pattern seems to be changing. It has been proposed that no more than one and the same system handles both kinds of data, visual and verbal (Farrand & Jones, 1996). However, data reveal the existence of two separate systems, one holding visual objects and a second one responsible for spatial location (Klauer & Zhao, 2004). In a similar line, neuropsychological evidence has pointed to the direction of separate visual and verbal systems (DeRenzi & Nichelli, 1975; Hanley, Young, & Pearson, 1991). The VSSP is thought to operate as an interface between vision, attention and action. The idea brought forward is that of a storage system having the capacity to integrate visual and spatial information, arriving from vision, touch, language or LTM, into a single representation (Baddeley, 2007).

It seems that we are able to maintain up to four items in visual memory, each of them perhaps consisting of multiple features (Irwin & Andrews, 1996). There appears to be no typical short-term forgetting in visual search tasks (Vogel, Woodman, & Luck, 2001), whereas the opposite is the case for spatial STM. Both visual and spatial STM appear to hold serial order with simple tasks. Some initial evidence suggests the existence of a third subsystem that can store actions. The tasks testing the above hypotheses call for simply holding and recalling small amounts of information. However, the WM concept entails some type of manipulation and processing of the items to be remembered. In this frame, more complex tasks are to be involved. The mechanisms underlying visuo-spatial rehearsal are far from evident and it is difficult to untangle the visual and the spatial part experimentally. On the other hand, Garden, Cornoldi and Logie (2002) have shown that sketchpad use is not mandatory. They asked their participants to learn a route through the streets of an unfamiliar city under two conditions: a spatial tapping task on a hidden keyboard or suppressed articulation. Subjects who had the habit of using a mental map deteriorated when using the visuo-spatial task, whereas subjects who reported using landmarks deteriorated when given the articulatory suppression task.

The theoretical implications of the data gathered in this area, could be shaped in two different
forms: is VSSP a kind of “attentionally enhanced perception” or a “post-LTM workspace”? These two hypotheses are not necessarily competitive. They rather investigate the field from different angles. Visual attention researchers place emphasis on attentional and encoding processes (see Woodman, Vogel, & Luck, 2001), whereas WM researchers stress manipulation and executive control (see Della Salla & Logie, 2002). The two traditions seem to be able to merge data in the future and interact on the road to the formation of a unitary theoretical frame, drawing from neuroimaging and animal research (Goldman-Rakic, 1996). In conclusion, current approaches to VSSP see it as a workspace that unifies information deriving from various sources: tactile, visual, kinaesthetic, LTM. Along these lines emerges the similarity to the episodic buffer. Baddeley (2007) suggests that VSSP can be accessed from both perception and LTM and assumes a bridge between VSSP and episodic buffer.

**Central Executive**

The central executive (CE) is the most significant and the least investigated WM component. Two core specifications are its limited capacity and attentional features. Researchers like Baddeley place a strong emphasis on capacity, whereas others, like Cowan (2005), stress attentional and developmental aspects. Baddeley’s work in the area, epitomized recently (2007), concerns four main executive processes; focus, division and switching of attention, as well as interfacing WM and LTM. Evidence shows that localization of the CE lies in the frontal lobes of the brain (Kane & Engle, 2002). Case studies of patients suffering from a bilateral frontal lobe damage serve as the strongest supporters of the frontal lobe hypothesis (see Baddeley & Wilson, 1988).

- **Focus of attention.** Overwhelming evidence exists in favor of system limited capacity, in directing and focusing attention. In fact, this attribute probably is the most crucial feature of WM. Still, when absolutely needed, two demanding tasks can be carried out concurrently (Allport, Antonis, & Reynolds, 1972). Practice and automaticity play a major role. Tasks that were executed with a detrimental effect of one onto the other were conducted with no effect after practice (Teasdale, Dritschel, Taylor, Proctor, Lloyd, Nimmo-Smith, & Baddeley, 1995).

- **Attention switch.** Influential research has brought forward the question whether task switching is based on attentionally demanding processes and implicates a limited capacity executive system or not (Allport, Styles, & Hsieh, 1994; Rodgers & Monsell, 1995). The data seem to point to the conclusion that, at least under certain circumstances, switching may be attentionally demanding. Very active experimentation efforts have proved fruitful, leading to the suggestion that task executive switching does not seem to be dependent on some unitary executive function (see Monsell, 2005). Nevertheless, no solid evidence exists for a subcomponent of the CE devoted to this operation. It appears that attention switching is not a general function. Rather, pros and cons of switching between tasks seem to vary depending on the specific circumstances (Rubenstein, Meyer, & Evans, 2001). Again, task switching proves to be much easier when direct cues are given (Baddeley, Chincotta, & Adlam, 2001).

- **Attention division.** Many times people have to divide attention between tasks. Writing a report and also listening to music is an example, as is cooking, watching a favorite TV program and keeping an eye on the little one playing on the floor at the same time. Divided attention implies certain limited capacity to be allocated in tasks. However, this is not a one-and-only interpretation. Performance decrement could, for instance, be attributed to varying degrees of difficulty
between the tasks or variations in processing speed (see Baddeley, 2007). Unlike task switching, divided attention seems to be directed by a specific CE subcomponent (Baddeley, Bressi, Della Sala, Logie, & Spinler, 1991).

Summing up, the CE is considered to be an attentionally limited control system. The CE notion was primarily based on neuropsychological evidence, from patients with frontal lobe damage in particular. Three executive component processes have been proposed: the capacity to focus system resources, the capacity to switch attention and the capacity to divide attention.

Episodic Buffer

The fourth feature attributed to the CE is different and refers to connecting WM with LTM. The original model by Baddeley and Hitch fell short of accounting for certain important issues. One of them was short-term storage of information that could not readily be explained by the PL or the VSSP, the second one referred to the ways the visuo-spatial and the phonological systems interact and, last and most important, how WM and LTM interact and communicate. Thus, the question to be answered was how WM systems can act as a workspace, as manipulators and information processors and as a connection with LTM. For instance, where are phonological and semantic codes stored, if the CE has no storage capacity? How are they combined?

In order to account for these problems, Baddeley (2000) proposed a new component, named the episodic buffer (EB). The component integrates information into coherent episodes and this information may be arriving from the loop, the sketchpad, LTM, or even perception. Its connection to episodic and also semantic memory is obvious. It is of limited storage capacity. Capacity in the buffer is defined in terms of chunks of items and its main responsibility is to bind information from various sources into chunks. Contrary to retrieval from LTM, the buffering process may be demanding in terms of attention. There appear to be two types of binding: a rather passive one, like automatically applying the “same color” principle to organize parts of an object into the same chunk; and an active one, attentionally demanding, like unifying fragments of a picture into a chunk. Based on its binding capacity, Baddeley considers the EB to form the foundations of conscious awareness.

ALTERNATIVE MODELS OF WORKING MEMORY

The Baddeley and Hitch proposal is not the only WM model. Some popular alternative accounts view WM as a general resource, limited capacity system, operating as a kind of mental workspace in which material can be processed and maintained at the same time (e.g., Daneman & Carpenter, 1980). To this hypothesis, other researchers add that WM is either the activated part of LTM and not a functionally distinct system, or a system very closely connected to LTM (e.g., Engle, Cantor, & Carullo, 1992; Ericsson & Kintsch, 1995; Cowan, 2005).

Daneman and Carpenter’s Account

Daneman and Carpenter’s work (1980) has expanded the WM construct with reference to language processing. On the basis of their data, the two researchers have developed a complex WM measure that has become a reliable and very popular tool among other researchers in the area. They argued that simple spans, like digit spans, are not able to pinpoint complex operations as reading comprehension is. Daneman and Carpenter devised a complex measure, called reading span, demanding simultaneous processing and storage operations. This new measure obtained high correlations with complex cognitive performance, like
Nous reading comprehension. Daneman and Carpenter stress the processing aspect of WM and they argue in favor of a “trade-off” between processing and storage. They point that what seems to be limited storage capacity may in fact be the outcome of inefficient processing mechanisms, thus reducing resources available for information maintenance. Activities that tax too much either processing or storage functions will probably overload the system and result in task failure. The more efficient the processing, the more capacity is available for temporary storage.

In essence, this is a processing efficiency hypothesis; processing efficiency and not storage capacity is the factor differentiating WM performance (Daneman & Tardiff, 1987). This is the domain people vary. Individual differences in performance are due to more or less efficient manipulation between processing and storage operations. According to this approach, WM essentially corresponds to the CE of the Baddeley and Hitch Model. However, this is an argument challenged by data showing that an important determinant of WM complex span performance is storage capacity (Bayliss, Jarrold, Gunn, & Baddeley, 2003). Nevertheless, it should be stressed that reading span predicts cognitive operations much more efficiently than measures of simple word span or episodic LTM.

Cowan’s Embedded-Process Model

Nelson Cowan, a leading figure in memory research, has expanded the WM construct significantly. His work has connected WM to LTM and has modified our view of WM capacity. His embedded-process model (1995, 1999, 2005) uses focus of attention, activation levels and expertise as key concepts. He views memory as a single memory storage system that functions depending on various activation levels. Since the single memory storage system is LTM, Cowan in essence embeds WM within LTM. He acknowledges the need for the two different constructs, however he posits that long-term retrieval precedes short-term processing. In this frame, long-term structures enhance WM performance. Working memory refers to information held in LTM and activated above a certain threshold level.

One main distinction in the model is between the activated part of LTM and the focus of attention. The model can be conceived in terms of three concentric circles, the smallest one being embedded in the second, and the two of them being embedded in the outer circle. The outer circle contains a vast pool of long-term memories in an inactive state, which are available for activation and retrieval. The middle circle consists of LTM items, recently activated through automatic or conscious effort. Finally, the inner circle contains only a few items that are highly activated and are found in the focus of attention every single time. Items in the middle, activated circle move in and out of the inner, focus-of-attention circle, depending on the cognitive task to be executed. Thus, activation spreads automatically among related information and, on reaching a critical threshold level, enters the inner circle, which is the easy accessibility circle. Thus, the focus-of-attention pool is embedded within the activated memory pool.

The focus-of-attention concept replaces the CE and the separate storage subsystems in the Baddeley model. The focus-of-attention idea restricts WM retention and processing, but not storage capacity. Storage in the focus-of-attention pool is limited to 3-5 items or units of information. On the other hand, the activated items pool can hold a much larger number of items. This rationale explains the ability we have to handle much more information than is accounted for by experimental measures of WM. Information processing demands constant shift of attention to necessary items only. Relevant findings support Cowan’s hypothesis. McElree (1998) has shown that items expected to be in the focus of attention are retrieved more quickly than recently activated ones that are no longer within the focus. Besides,
activated items being outside the focus of attention need more time to be accessed (Verhaeaghen, Cerella, & Basak, 2004).

According to Cowan (2005), WM interacts with LTM by forming new episodic links between items activated in LTM and items being processed on the spot. A high activation level refers to current WM elements, the focus of attention, whereas a moderate activation level refers to information that has been in the focus very recently, being connected with the current WM elements but no longer belonging there. Because of this moderate activation, contents are readily available upon WM request. When they are called into WM, they form new episodes for long-term storage. In this frame, Cowan’s formulation of new episodes in LTM is consistent with Baddeley’s (2000) EB operations.

Cowan also presents strong evidence in favor of 4 items defining WM capacity (2001). He posits that the limit of 4 is universal, across modalities and irrespective of expertise. The differentiating factor is the size of the chunks people form, not their number. In his view, 4 is the limit found in people under normal circumstances in which processing is automatic. If rehearsal or another memory strategy is used, capacity can be extended to 6 or 7 items. Although Cowan offers strong evidence in support of his view, recent studies indicate that the focus of attention capacity may actually be just one chunk (Oberauer, 2002; Verhaeaghen et al, 2004).

Kane and Engle’s Executive Attention Model

In these researchers’ view, WM is an executive attention system, distinct from STM. The main function of WM does not have to do with short-term capacity, but with attention control. Attention control is related to the maintenance of information in an active and easily accessible state. Kane and Engle state that executive (or controlled) attention is “an executive control capability; that is, an ability to effectively maintain stimulus, goal, or context information in an active, easily accessible state in the face of interference, to effectively inhibit goal-irrelevant stimuli or responses or both” (Kane, Bleckley, Conway, & Engle, 2001). Controlled attention focuses on targeted information while inhibiting irrelevant stimuli. Thus, WM capacity depends on the effectiveness of attention: on the extent to which executive attention is directed to relevant information. It does not depend on short-term storage or interval lengths between stimuli.

Kane and colleagues (2001) base their proposal on observations, according to which high span individuals are also better in controlling attention and resisting interference. By focusing on selected material and by paying attention to it, they are able to process more information. Thus, WM efficiency does not have to do with capacity. It has to do with the ability to block distracting stimuli and remain focused on processing the relevant ones (Hester & Garavan, 2005).

Kane and Engle (2000) also stress WM involvement in retrieving and maintaining information from LTM. Individuals achieve that by attaching appropriate cues to stimuli in the beginning of the retrieval phase. Besides, cues are used to bring back stimuli just lost from STM due to various distractions. Their research shows that low WM capacity individuals are less capable of selecting the right retrieval cues for effective LTM search. This results in too many irrelevant items interfering with the desired ones and retrieval failure occurs. Thus, WM differences are not just related to attention control, but also to the ability to block irrelevant items and employ appropriate cues to retrieve relevant information from LTM (Unsworth & Engle, 2007). In the 2007 paper, it is proposed that WM consists of activated memory units, some of which are at a high activation level and correspond, so to speak, to STM storage while some other units are at a lower activation level and remain in a larger pool for longer times. Focus of attention allows for
maintenance of a few representations for ongoing processing, and this is a notion consistent with Cowan’s model above.

Kane and Engle (2000) study the relationship between WM and cognition, too. They believe that controlled attention is the factor uniting all higher-level processes and functions. In this respect, executive attention binds WM to fluid intelligence (Engle, 2002). The reader may detect that the present and Baddeley’s model share certain views. Baddeley (2007) also stresses the importance of attentional and executive processes in the CE. They divert in terms of WM capacity. Baddeley places emphasis on PL span. Kane and Engle do not consider this parameter to be of great significance, for they attribute span differences to more or less efficient inhibition of distracting stimuli. Miyake and Friedman (2008) hold a different view in relation to this issue. They demonstrate that complex WM span tasks, demanding both processing and storage operations are good predictors of general intelligence, a finding well established in the literature. The complex span tasks they used were a reading span, an operation span (equation verification plus digit span) and a rotation span task (mental rotation plus orientation).

In conclusion, the model views WM as a domain-general controlled attention system, which maintains activation of relevant information in LTM and retrieves desired stimuli. Individual differences are attributed to the degree of efficiency of inhibiting undesired items and retrieving desired ones. Thus, inhibitory control and concurrent selection of appropriate stimuli are features of primary significance and capacity is closely related to them.

**Long-Term Working Memory**

Long-term and WM are so interconnected that certain researchers advocate a long-term working memory (LT-WM) (Ericsson & Kintsch, 1995). In this frame, LTM and WM are not distinct. Rather than arguing in support of a separate WM system, LTM advocates argue in favor of the currently activated part of LTM which functions as a WM. This is to say, it processes input and encodes new information into LTM. Such a notion alters our perspective on storage capacity. Instead of examining how many items or chunks can be maintained in short-term storage, capacity is now defined in terms of number of nodes or representations in a highly active state at any given time (Richardson, 1996a, 1996b). If Cowan’s suggestion regarding a capacity of 4 items is correct, then an individual can manipulate that amount of information concurrently. This assumption means that activated parts of LTM must return to an inactive state fast, thus giving space to new long-term representations to become activated. In this frame, WM span can never be strictly identified. It is also possible that the currently activated material is retrieved from LTM and not WM. One recognizes in this frame of reference the ideas of Anderson (1983), one of the very first to conceive WM as the currently activated LTM knowledge.

According to Ericsson & Kintsch (1995), effective use of LTM information depends on the person’s expertise and the use of memory strategies, both of which enable the person to employ LTM as an extension of WM. Strategies allow the individual to encode incoming stimuli fast into LTM and at the same time to attach retrieval cues to them in STM. The cues activate relevant long-term information during recall, thus giving the impression of an extremely high WM capacity. An example of that is chess masters’ performance, seemingly having tremendous WM capacity. Long-term WM theorists argue that what seems to be WM capacity is in fact LTM storage. Extended WM is based on chunking information and creating associations with familiar schemas already stored in LTM. Encoding in LTM needs to happen rapidly. On the other hand, the schema the new information is associated with must be quickly accessible on demand, via retrieval cues that are well practiced and deliberately attached.
When successful cueing takes place, then LTM retrieval is as fast as STM retrieval. Deliberate retrieval from LTM takes 1-2 seconds on average; however, experts’ LTM retrieval can reduce time to an impressive 400 milliseconds, because STM limitations are bypassed (McNamara & Kintsch, 1996).

Another example of application of the LT-WM hypothesis seems to be text comprehension. Comprehension makes significant, ongoing demands on WM. Besides, it could not be carried out effectively without LTM participation. Text representations are constructed in LTM as the reader proceeds with the text. These representations expand more and more, as new information is arriving and needs to be integrated while it remains continually accessible. In essence, the accessible parts in question constitute an extended WM. As Dehn (2008) points out, Ericsson and Kintsch’s (1995) argument seems to hold well in view of the individuals’ dramatic increase in the ability to comprehend text, while their short-term and WM capacity remain the same. The increase in performance is attributed to the greater skill of encoding information in LTM.

Although comprehension data fit nicely with a LT-WM explanation, some data deriving from experiments in new word and pseudoword learning offer evidence against the LT-WM hypothesis. In a study by Masoura, Gathercole and Bablekou (2004), a group of Greek children 5-7 years were assessed for their nonverbal intelligence, vocabulary knowledge and PL capacity using three different means: digit span, repetition of Greek pseudowords and repetition of English pseudowords. As it can be observed in Table 1, a strong correlation was observed between the measures of phonological memory and the vocabulary test. The correlation remained strong even when non-verbal ability and chronological age were partialled out. These results allow for the following conclusion: since the children in the study did not have any knowledge whatsoever or habituation with English, it seems highly unlikely they were based on a LT-WM system or long-term knowledge in order to repeat the English pseudowords. The pseudowords, being totally new material, were not related to any LTM representations. Thus, their nonword repetition ability was based on the quality of PL entries rather than on long-term knowledge.

In fact, most theorists adopt a separate WM concept (Gobet, 2000). Even if this system is fed by LTM information that becomes activated, it still is considered to be a separate cognitive entity. On the other hand, exceptional WM performance

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<td>.42</td>
<td>-</td>
</tr>
<tr>
<td>6. Chronological age (months)</td>
<td>.15</td>
<td>.26</td>
<td>.32</td>
<td>.34</td>
<td>.26</td>
</tr>
</tbody>
</table>

Numbers in bold indicate a significant difference at the 5% level.

df = 46

Table 1. Correlations among nonword repetition, digit memory, vocabulary, non-verbal intelligence and chronological age
seems to apply only to individuals who have developed specialized memory strategies to achieve it. Besides, their exceptionally broad WM span is limited to their area of expertise, (e.g. chess). Nevertheless, even if WM is different from LTM, their interaction is extremely close. It is probable that incoming stimuli activate relevant LTM representations before being processed in WM (Logie, 1996). This assumption is also shared by Conway and Engle (1994). On the other hand, Baddeley (2007) criticizes LT-WM models on the grounds that they offer no clear explanation of how WM is connected to LTM. Undoubtedly, there is a very close interaction and the evidence shows that WM depends on LTM. That does not equate WM and LTM though. Exploration of LTM operations does not guarantee understanding of WM functions. Similarities between WM and LTM should not be interpreted as identity of the two.

WORKING MEMORY MODELS: HOW DO THEY FARE?

In the above section, I tried to present the distinctive ideas related to the most popular WM accounts found in the literature. In this part, I will attempt to evaluate the models presented so far. Most of the section will refer to the multicomponent model, which holds a prominent position. The model has fared with several advantages and also disadvantages. Let us discuss certain representative issues.

We are all aware of the golden rule of scientific research: between a simple and a complex account, in order to explain a phenomenon equally well, we always opt for the simple account. Researchers can comprehend and apply a simple model. A major advantage of the Baddeley and Hitch WM account lies in its simplicity. This simple model is tested with a very wide range of well designed and elegant experiments. In the case of the CE, simplicity may be a drawback, because it appears that the executive is a very sophisticated system that needs a more complex explanation than the one offered so far. However, as Andrade rightly points out (2001), the introduction of a CE concept to an essentially STM model has been highly successful, for it has enabled research on the relationship between WM and attention using dual-task methodology (i.e. concurrent execution of two competing tasks). In the case of STM operations, on the other hand, it does offer an excellent description of short-term functions.

The breadth of the model is a noteworthy parameter. It provides for the analysis of verbal, auditory, visuo-spatial information, as well as for the temporary storage and concurrent manipulation of material. Such an attribute is valuable when attempting to transfer cognitive processes research to applied settings and real world situations. As its formulations have stayed close to the data, it may not be very exciting theoretically. However, this “boring” feature turns out to be strength, for it has allowed the model to remain in the focus of WM literature for 35 years now. As we have seen, some significant research connects WM to cognitive functions and has managed to show the central place that WM holds in human cognition.

As opposed to the North American notion of WM, the Baddeley and Hitch multi-modal proposal allows for the formulation of specific hypotheses and predictions in relation to how verbal, aural and visuo-spatial material becomes temporarily stored and manipulated. This model exhibits specificity. Adams and Willis (2001) stress that various WM measures are not equally good predictors of language ability. Therefore, a general resource WM model is not of significant help, as compared to a fractionated model that allows specific predictions to be made as to how each part contributes to cognitive functions. As Phillips and Hamilton (2001) point out, the fractionation facilitates research, because we can move from correlational to causality studies, by manipulating experimentally different functions (e.g. verbal rehearsal, visuo-spatial WM) and observing how they affect cognitive performance. Even brain
structures underlying WM operations cannot be pinpointed by a general resource model.

Entering the “shortcomings area”, the strongest shortcoming of the model appears to be the vagueness in the specification of its components, as well as of the interrelationships among them. The CE, in particular, is the system that has received the strongest criticism so far. The years that have elapsed have brought the importance of the CE into light. Nevertheless, what turned out to be the major asset of the multi-component model is also a drawback. The absence of clear formulations regarding the system and how it fares in several fields inevitably led to the phenomenon all unexplained findings, all questions, all problems with various WM approaches to be attributed to the executive. Data show moderate correlations amongst assumed executive functions. Besides, deficits in one function and preservation in another is a sign that CE may not be a unitary entity, but a multiple system (see Andrade, 2001). Although Baddeley’s recent work (2007) advances our knowledge in this area, theoretical fractionation of the CE is still not in sight. The experimental fractionation is therefore impossible, since no theoretical account exists to guide researchers to the type of tasks they should design, in order to tap particular executive functions. The “chaotic” nature of the concept led it to end up being used as “rag-bag” and there appeared the tendency to explain all kinds of cognitive data, which cannot be accounted by the slave-systems, using the CE as a resource tool.

A related point is the observation that the simplicity of a model can reach a critical value, where simplicity can develop into lack of precision. Cognition is too complex a phenomenon, several researchers argue (May, 2001), to be explained by simple accounts of memory. What embarked as a simple and clear-cut WM model may need to include further subcomponents. As discussed, the CE in particular is nowadays an unsatisfactory account of executive functions, especially as long as it remains unspecified. Besides, a point we made above with reference to our own studies (see Masoura, Gathercole, & Bablekou, 2004; Masoura, Gathercole, & Bablekou, 2006), the vast majority of data are correlational and have no capacity to shed further light into the relationship between cognitive performance and WM. Thus, although we theorize about that, we have been unable so far to prove experimentally that WM causes cognitive changes.

Having introduced the causality issue, let us elaborate further. No clear data exists to point to the direction of causality: that is, to indicate if WM affects other cognitive functions or vice versa. However, some evidence is available. Several years ago, we conducted research attempting to address this issue of causality (Bablekou, 1989) in the University of Leeds, U.K. Among other cognitive functions, we investigated WM processes in typical children aged 5-13 and in children with specific language difficulties. In order to explore the direction of causality, we used three groups of participants: an experimental group (children with specific language difficulties), a control group matched for chronological age and a control group matched for language age. It has been stressed that children with specific language difficulties (that is, language difficulties that cannot be attributed to any apparent cognitive, emotional, social, neurological or other dysfunction) may have less exposure to certain cognitive operations connected to language and, thus, the assumed limited exposure could in turn affect memory operations. This rational leads to the suggestion that memory difficulties may derive from language problems, instead of memory difficulties causing language problems. The introduction of a second control group, of younger chronological but of the same language age, could allow us to draw some conclusions in relation to whether it is poor WM that causes poor language (in this case, we would expect children with language difficulties to perform worse than younger children of the same language age) or poor language that results in poor memory (in
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this case we would expect children with language difficulties to perform similarly to or better than younger children of the same language age). Four experiments provided data defending the hypothesis of a specific WM deficit being causally linked to specific language difficulties in children. For the types of stimuli we employed (letters, digits, words, pictures, colors, pseudowords, geometric shapes and abstract shapes), the deficit was pinpointed in the PL component. The comparison of the two experimental groups revealed a very interesting tendency. Overall, the children with language difficulties exhibited similar or worse recall levels to their language age control group. This pattern challenges the view that the memory deficit should be treated as the outcome of limited written language exposure (e.g., Bryant & Bradley, 1995), providing evidence that makes us able to infer (albeit not to prove directly) that it should in fact be memory operations that affected language functions. Even rather typical STM tasks, like the tasks we used involving strings of items, tapped the underlying WM deficit. Similar findings have been provided by other researchers (e.g. Jorm, Share, MacLean, & Matthews, 1984).

It is a hard task to establish the direction of causality experimentally; among other variables, time consuming longitudinal designs covering a very wide age span are needed for that. Methods similar to ours have been used in other studies as well, in an effort to infer the relationship between memory and language functions, Gathercole and Baddeley (1989) used a longitudinal study to examine children's phonological WM and vocabulary acquisition. They demonstrated that WM scores at four years predicted vocabulary knowledge at five years, even when vocabulary knowledge at four had been partialled out. Such data indicate that language development follows WM development. We also explored the relationship between WM and certain language functions in two studies. We already referred to the first one (see Table 1), which investigated contributions of phonological STM to vocabulary acquisition in Greek children aged 6.5 years (Masoura, Gathercole, & Bablekou, 2004). Children were assessed on non-verbal intelligence, vocabulary knowledge and PL capacity, using three different measures (digit span, repetition of Greek nonwords and repetition of English nonwords). A strong link was found between the phonological memory measures and the vocabulary test. Crucially, the link remained strong even when the non-verbal ability and the chronological age factors were partialled out. The findings are in harmony to those reported for the English language (Michas & Henry, 1994; Gathercole, Hitch, Service, & Martin, 1997). The fact that children did not have any contact with English makes the possibility of them being based on LTM knowledge to repeat stimuli highly unlikely. Our assumption is that the task was executed on the basis of phonological WM traces rather than previous language knowledge. Thus, phonological WM capacity, as examined by the nonword repetition test, seemed to contribute to vocabulary acquisition rather than the opposite. Children also exhibited much higher repetition rates for Greek than English nonwords. It seems that repetition in the mother tongue was facilitated by exposure to familiar language speech patterns, but repetition of nonwords in an unfamiliar language could only be based on the phonological memory strength.

We also evaluated how children’s phonological WM and vocabulary knowledge are involved in new-word learning tasks (Masoura, Gathercole, & Bablekou, 2006). Six-year-old Greek children were assessed using measures of phonological WM (Greek nonword repetition, English nonword repetition, digit span), vocabulary knowledge and nonverbal ability. They also participated in a learning simulation task, in which they learned Greek nonwords, which followed the phonotactic rules of Greek language. Learning of the sound structure of nonwords was associated with children’s vocabulary knowledge. Very strong correlations were observed between phonological memory and new nonword learning and weaker between
vocabulary knowledge and nonword learning. When age and nonverbal ability were partialled out, Greek and English nonword repetition remained significantly correlated with vocabulary knowledge. Our findings suggest that learning of new words was supported by phonological WM. Again, we infer that it is WM that has an effect on language functions and not the opposite. However, the possibility of a third factor having an effect on both WM and language cannot be dismissed.

*Working memory as activated long-term memory.* The idea of WM being the currently activated part of LTM has derived from North American researchers in the 1960’s (Melton, 1963) and has been reintroduced recently in different variations (e.g. Cowan, 1995, 2005; Ericsson & Kintsch, 1995; Kane & Engle, 2000; Nairne, 2002). Supporters of a unitary memory system base their argument on demonstrating experimental analogies between the two systems, WM and LTM. Baddeley (2007) notices that the tasks employed involve both WM and LTM operations, thus it is not surprising to observe similarities. On the contrary, a rich volume of WM data derives from treating it as a separate memory system. It seems to involve various subsystems and mechanisms. The point of interest here is how WM and LTM interact. The PL, for instance, makes use of LTM knowledge, when it comes to remembering words, digits, and so forth. In this respect, LTM becomes activated in relation to PL operations. Nevertheless, most cognition involves LTM activation. That does not necessarily mean cognition is the activated part of LTM.

*A general resource versus a separate resource working memory.* Some researchers (Kyllonen & Christal, 1990; Engle, Cantor, & Carullo, 1992) advocate the hypothesis of a memory system that is unitary in architecture. Processing and storage compete for the same pool of resources. Others take the opposite stand (Daneman & Tardiff, 1987; Sha & Miyake, 1999; Baddeley, 2007), proposing a fractionated WM system with domain-specific subsystems specialized in different types of material. Some of the differentiations concern the information code (e.g., phonological, propositional, spatial), the modality via which it is coded (e.g., visual, aural, haptic), the brain parts involved, the processing domain (e.g., oral language, arithmetic, object recognition). The various models focus on different aspects of WM operations and use different methodology, probably resulting in diversions appearing larger than they may in fact be. The general conclusion so far is that there is limited support for the unitary view of WM (Kintsch, Healy, Hegarty, Pennington, & Salthouse, 1999; Baddeley, 2007). However, the number and nature of components postulated should only be established after been tested with different methodologies and clear evidence for system dissociations is observed.

**FUTURE TRENDS**

Where do we go from here? A good way to try and answer this question would be to summarize the consensus points across WM models. First, and very important, is the recognition that all current models do not postulate a structurally distinct system, located in a specific place in the mind or in the brain. Working memory descriptions refer to functional or content dimensions rather than structural ones, namely the “position” of the system, its “place” in the mind. The closest to a structural separation may be the slave systems proposal by Baddeley and Hitch (1974). Similarly, WM seems to be a separate-resource construct and not a general domain one, as was summarizes in the previous section.

The WM system does not serve to strictly memorize things. Instead, it is involved in supporting complex cognition, like language comprehension, problem solving or visuo-spatial thinking. Such a link is valuable, for it constitutes the driving force of WM research. The heart of the system does not of course beat with the recall of strings
of digits or words. Rather, it beats with much more complex cognitive functions. Executive control is an integral part of WM operations. In fact, WM deals with control and regulation of cognitive performance. All current models provide for an executive system within WM, a system that allocates resources to the execution of cognitive tasks and supervises the operations.

The role of LTM is of central importance to WM functions. The core idea is that WM cannot be understood without the contributions from long-term knowledge. This conclusion does not refer to higher order cognitive tasks exclusively; interestingly enough, mundane laboratory tasks, as immediate recall of words is, are affected by LTM. Even models that do not attribute a major role to LTM involvement (e.g., Engle, Kane, & Tuholski, 1999) acknowledge that LTM factors play a role in executing WM tasks.

What is next? Which directions should future WM research follow?

- A main inadequacy is pointed by Miyake and Shah (1999), serving as editors of a very comprehensive book. An unresolved question, still, concerns the basic mechanisms and representations in WM. More investigation is needed as to how exactly encoding, maintenance and retrieval mechanisms function. We also need to know more about the format of information representations in the system. The gap appears to have been created because most work in this area refers to STM tasks. It has not addressed memory processes supporting complex cognitive operations so far. Some steps are being taken by researchers like Engle and collaborators (e.g., Rosen & Engle, 1997) and Ericsson and Kintsch (1995) in the LT-WM framework.

- Obviously, discovery of the precise mechanisms underlying executive control and regulation will remain one of the most challenging WM areas. The clarification of the relationships between the various control processes and of how they are regulated will advance WM theorizing significantly. We think that the same argument holds for the fractionation of the CE in the multicomponent model.

- Although the domain-general versus domain-specific WM system question has been answered to a significant extent, more research would enlighten us as to precisely how domain-specific operations take place, what kind of subsystems are involved and which factors affect domain-specific processing.

- Our knowledge of the biological substratum of WM is still rather limited, although impressive progress has taken place in the past years. Functional neuroimaging studies will offer a powerful tool for mapping WM in the brain and possibly implicating its framework in the mind. We should exercise research cautiously though. No “technical” studies can advance knowledge if they are not supported by a good theory.

- In relation to the multicomponent model, since we believe it proposes the most convincing frame in the literature, more research is due regarding the model subcomponents. The loop has sustained much laboratory work. This has enabled the PL concept to go beyond laboratory, to developmental, educational and neuropsychological applications. However, areas like how exactly serial order is stored and recalled, or how exactly the loop breaks down as length and difficulty of incoming material increase, remain to be investigated. More research is also due in relation to the buffer. Does the EB connect direct to the PL and the VSSP? We have no conclusive evidence yet. Besides, the buffer introduces a separation between the attentional and the storage capacities of the WM model and this is suggested to be a theoretical advancement (Baddeley, 2007). Future research will either prove or disprove
the validity of the separation. In conclusion, the VSSP is currently viewed as a unification workspace; it unifies information from various sources: tactile, visual, kinaesthetic, LTM. It has been suggested that VSSP can be reached from both perception and LTM and is assumed to operate as a bridge between VSSP and the episodic buffer (Baddeley, 2007). This emerges as a theoretical challenge. Data seem to have established the existence of a WM system that integrates visuo-spatial information. It is still unknown whether this system is a subordinate to some other, higher-order system.

The links and relationships between WM and LTM remain unclear, as equally (or even more so) unclear are the relationships between WM, attention and consciousness. How long-term knowledge is differentiated, but still contributes to WM functioning is yet unknown. Current frames that include an explanation (e.g., Cowan’s, Ericsson and Kintsch’s) seem to account experimentally for particular types of information only, under specific conditions, as Ericsson and Kintsch’s account for comprehension par example. On the other hand, although attention has been in the center of certain analyses in the past few years, in fact it has not received so much “attention” from WM models, as Miyake and Shah (1999) rightly point out. It is possible that both attention and consciousness are not unitary constructs and this implicates different properties and operations.

Finally, where exactly do we draw the line between WM and other cognitive systems in explaining cognition? In order to answer this, we have to delineate WM responsibilities and also illustrate its limitations. To achieve such an ambitious goal, we need to demonstrate how WM subcomponents cooperate as a system. We have acquired knowledge regarding single component functions in particular domains, but we have not gained satisfactory insight into subsystems’ cooperation or the various types of codes and representations demanded when complex cognitive processes are executed.

CONCLUSION

When talking about the psychology of the learner, we must consider all fundamental cognitive processes. Cognitive studies are increasingly concerned with how cognition and interaction co-work (Anderson, 2001). Learning, on the other hand, acquires a new dimension in a media environment: based upon the flexibility of navigation, the said environment allows for the learning path each user selects to follow to be individual and ultimately determined by her/ him. Compared to the structured school setting, a media environment can become more “custom-made” according to the user’s personal needs and preferences. In the words of Schroeder and Grabowsky (1995, p. 313, in Riva, 2001), “in a highly learner controlled hypermedia environment, learners navigate through the information creating a personal interpretative representation of that information. Each individual can take a different path encountering different amounts and types of information”.

An impressive volume of research shows that WM is heavily involved in all kinds of cognitive activities: from attention (Cornish, Wilding, & Grant, 2006), mathematics (Bull & Andrews-Espy, 2006), written (Cain, Oakhill, & Bryant, 2004) and oral comprehension (Chrysochoou & Bablekou, submitted) to reasoning (Kyllonen & Christal, 1990), reading (Dufva, Niemi, & Voeten, 2001; Cain, 2006), learning a computer language and playing bridge (Baddeley & Hitch, 2000), to name but a few. On the other hand, poor WM skills can impede learning and academic achievement.

What has been discussed so far in this chapter should enable the reader to conceive the basic
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implications WM functions bear for learning activities and knowledge acquisition. Even the less familiar with memory research could infer certain applications when learning in a web environment. The aim of the present chapter is to introduce readers to WM concept, properties and ways of operating in the frame of cognition. Thus, a discussion of web learning applications is beyond our scope; besides, this is an intact research area. To the best of our knowledge, no studies on precise WM functions in web environments exist yet. Nevertheless, based on the general principles, let us illustrate the link between WM and web learning with an example. Kozma (1991) reviewed the relevant literature on the effect of presentation mode on learning in a media environment. He concluded that simultaneous presentation in more than codes (i.e., visual, aural) results in better recall of material. On the contrary, visual-only or aural-only presentation of information leads to inferior recall levels. Anderson (2001), however, argues that findings are inconclusive, in relation to whether students get benefited from dual coding conditions (Paivio, 1971, 1991) when exposed to a multimedia environment. Certain other research shows that individuals are not influenced in a similar manner by multimodal presentations. Anderson proceeds suggesting that coding and subsequent recall depends on type of material and type of media employed.

In relation to this argument, we think that recall depends mainly on the type of cognitive systems involved in the processing of specific material and on the different processes implicated on every occasion, not simply on material or media types. Let us use the WM paradigm: the way visual information is processed depends on the subsystems involved. If the information is in a verbal code (e.g. a word or a sentence), it is processed by the PL, whereas information containing spatial elements (e.g. a maze route on the computer screen or the solution to a visuo-spatial task) is processed by the VSSP. In this case, tasks can be processed relatively unobstructed. On the other hand, tasks competing for resources within the executive system (as is, for example, concurrent processing of written directions in relation to a screen map and of navigation instructions given over headphones) will be executed less effectively that those competing for different subsystems’ resources. The overall picture is significantly more complicated than learning dependent on dual coding, visual and/or aural.

The present chapter attempted to discuss basic research in working memory, as a backbone to cognition and learning. In this frame, learning environments should be highly adaptive and memory strategies not predetermined, but flexible. A major feature in this complex, higher-order interaction is metamemory, the individual’s ability to evaluate the quality and the processes of his/her memory functions and to plan his/her mental operations accordingly. Metamemory research clearly indicates that high metamemory abilities are closely related to academic performance, in children (Kurtz & Weinert, 1989) as well as in young adults (Everson & Tobias, 1998).

In conclusion, applied research on the effects of working memory functions in web education appears to be a prominent new and exciting area and such research is long due. We have, hopefully, shown that there is no general consensus regarding one theory of WM and many theoretical and experimental issues remain unresolved. Nevertheless, the knowledge provided by cognitive psychologists in the memory field so far offers stable grounds in order to embark on combined studies, exploring WM operations in the web and influences on web learning. Of the prestigious WM proposals outlined in the chapter, we think that the multicomponent model of WM is the most theoretically sound account and will serve as a valuable tool in this direction. In our view, however, selection of one particular model does not exclude all other accounts that can be used in combination and in fruitful interaction.
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**ENDNOTES**
