Working Memory in the Classroom and Beyond
by Grace C. Ashton, Ph.D.

Reprinted with permission from PA & Delaware Branch of IDA

The role of working memory in attention and learning continues to gain more interest from psychologists, speech-language pathologists, occupational therapists, educators, and parents.

What is Working Memory?

Working memory is a critical cognitive function necessary for a wide-range of tasks in our daily lives. Working memory is the ability to keep information in mind for a few seconds, manipulate it, and use the information in thinking. Working Memory can be thought of as a mental workspace that enables one to mentally manage multiple task demands simultaneously. Remembering plans or instructions, performing mental arithmetic, following directions, comprehending long sentences, holding conversations, and remembering a telephone number, involve working memory. There is a very strong relationship between attention and working memory. Researchers have argued that working memory is the control process that allows the mind to focus, direct mental efforts, accomplish tasks, and ignore distractions, as well as allowing the mind to inhibit impulses, purposefully shift attention, and direct conscious effort without losing relevant information (Baddeley, 2006; Swanson & Saez, 2003).

Model of Working Memory

In 1974 Baddeley and Hitch proposed a multi-component model of working memory that has gained a great deal of empirical support and has since been updated (Baddeley, 2006). The original model comprised three aspects of working memory: a phonological loop, a visuospatial sketchpad, and a central executive that controlled and regulated the two subsystems.

- The phonological loop is responsible for storage of verbal information. Baddeley divides the phonological loop into two subcomponents: a temporary, passive phonological input store and a sub vocal, articulatory rehearsal process. The phonological loop is like a tape recorder of a limited length, and plays a critical role in language processing, literacy, and learning. The phonological loop transforms verbal perceptual stimuli into phonological codes that include acoustic, temporal, and sequential properties of the stimulus. These phonological codes are then paired with existing codes such as phonemes and words stored in long-term memory, and also linked with memory representations.

- The visuo spatial sketchpad carries out the short-term storage of visual and spatial information, such as memory for objects and their locations, and also plays an important role in the generation and manipulation of mental images. The visuospatial sketchpad is also made up of a passive temporary store and an active rehearsal process. The visuospatial sketchpad is thought to serve an important function during reading, as it visually encodes text based letters and words, while allowing the reader to backtrack and keep his or her place on the page.

- The central executive is responsible for controlling the other three subsystems and regulating and coordinating all of the cognitive processes involved in working memory performance. The central executive allocates finite attention resources and controls the flow of information through working memory. The central executive, according to Baddeley, is a supervisory attentional system responsible for the control, regulation, and monitoring of many cognitive processes related to working memory. For example, the central executive is involved with the effortful activation, retrieval, and manipulation of long-term memory representations. The central executive allows for attention shifting in working memory, inhibiting irrelevant information, and sustained attention. The central executive also conducts the higher level processing of the verbal information such as putting words together to form an idea.

In 2000, Baddeley added a third subcomponent to the model, the episodic buffer. The episodic buffer helps explain the influence of long-term memory on the contents of working memory. The episodic buffer is a consciously accessible subcomponent that interfaces with long-term episodic and semantic memory to build integrated representations based on new information from the phonological and visuospatial storage systems. Pickering and Gathercole (2004) report that the episodic buffer provides direct encoding into long-term episodic memory. Large amounts of information, such as connected speech, exceed the capacities of the phonological loop and visualspatial sketchpad, but may be processed and stored in the episodic buffer.

The amount of information a person can hold in mind, process and manipulate at any given time is his/her working memory capacity. Working memory capacity develops in childhood, reaches adult capacity around age 14 or 15, and begins to decrease around middle age. This capacity is limited and varies greatly between individuals of the same age. Research has shown that the growth lines for individuals with weak working memory capacities in childhood do not catch up with those of their peers as they age (Gathercole & Alloway, 2008). Their working memory skills do improve, but not at the same rate as those with stronger working memory capacity, and so the discrepancy between those individuals with weak and strong working memory widens as they age.

Working Memory in the Classroom

Learning is obviously dependent on working memory. To learn, students must receive, store, retain, and retrieve information when needed, processing functions which pass through working memory. A finite pool of mental resources is used both to store information and to carry out processing activities (e.g., reading and counting). This is why working memory activities that involve difficult processing demands leave fewer mental resources to support long-term memory storage. As processing demands increase, working memory storage availability decreases. Fortunately, as children age, most become more efficient at carrying out mental processes, freeing up more cognitive reserve to meet the working memory demands of progressively more challenging academic tasks.

Working memory allows individuals to process what they see and hear efficiently so that they can react appropriately; weak working memory may negatively impact students' social interactions, as well as interactions in games and sports. In a conversation, a person must keep track of who said what to whom and who asked what, while thinking about what he/she wants to say and waiting to speak instead of interrupting. In a game, the child must keep track of whose tum in next, what cards have already been played or what stage the game is in. Difficulties with these social tasks are often seen in children characterized as having problems with attention and impulsivity.

Working memory is considered by some to be a "pure" measure of a child's learning potential because it is independent of prior experience and socio-economic factors. Drs. Gathercole and Alloway, leading experts in working memory and the consequences of poor working memory on learning and behavior, have found that the majority of children and adolescents with weak working memory struggle in the academic areas of reading, math, and science (2008). They have concluded that the learning activities of many classrooms place a considerable burden on working memory, a burden beyond the capacity of many students. For a student with poor working memory, capacity is taxed by an activity such as writing down a sentence the teacher has just dictated while simultaneously struggling to spell some of the words and remembering how far he/she has progressed in the sentence. Once working memory is overloaded, the student may forget the sentence he/she was writing, skip, or repeat words. When working memory is overloaded, crucial information necessary to guide the ongoing activity is lost. Information is also lost from working memory through distraction and the student cannot continue with the activity unless he/she is provided with the information that is needed, typically through teacher support. Without this support, the student is left to guess or often quit the task before its completion. Therefore, these children may not get the learning benefit of completing an activity successfully, which impedes their rates of learning.

Gathercole and colleagues have found that teachers rarely identify students with weak working memory as having a memory problem. Instead, these students are characterized as having attentional problems. The student may be described as not paying attention to directions, when in fact he/she may have simply forgotten what to do. Children with poor working memory are more likely to engage in "day-dreaming" or "mind-wandering" when performing cognitively demanding tasks that overload their working memory capacity. When a student's working memory is overloaded, he/she shifts attention to something else, further increasing the struggle to keep pace with ongoing classroom activities. Students with working memory impairments may present in the classroom with low abilities in reading and math (Gathercole & Alloway, 2008). They frequently lose their place in complicated tasks, have incomplete recall of information, have difficulty remembering instructions, and abandon difficult tasks before completion. These students often have normal social interactions with peers yet are reserved in group settings (for example, they may rarely volunteer information in class). Students may raise their hand to answer a question but may have forgotten what they were going to say when the teacher calls on them.

Working Memory and Learning Problems

Deficits in working memory are associated with a wide range of neurodevelopmental and genetic disorders of learning. Children with learning problems in reading and math typically have very weak working memory capacities, and assessments of memory completed early in their school careers are robust predictors of their learning problems and future academic performance. (Gathercole & Alloway, 2008).

Reading:

Berninger and Wolf (2009) write that "dyslexia is both a language disorder and working memory disorder (p.134)." The impaired word-level reading and spelling skills in dyslexia are associated with impaired phonological and orthographic processes in working memory. Berninger (2008) defines and differentiates dyslexia, dysgraphia, and language learning disability within a working memory model. Berninger's research indicates that dyslexia "is characterized within a working memory architecture that includes three main components: (1) word storage in phonological, orthographic, and morphological code format; (2) a time-sensitive phonological loop for integrating verbal and visual codes in oral or written word learning; and (3) an executive system that inhibits irrelevant codes and regulated switching between orthographic and phonological codes. The widely supported phonological core deficit in dyslexia is attributable to deficits in the phonological processes of each of these working memory components, and the frequently observed fluency problems are attributable to inefficiencies in the temporal coordination of the components of working memory (p. 104)." Berninger's research has shown that fluency is impaired because the orchestration of all of the components of working memory is impaired if one or more of the components of working memory is impaired.

Reading comprehension includes skills and abilities that involve working memory such as: decoding words and accessing their meanings; assembling word meanings into larger meaning units; building representations of sentences; linking information across sentences; noticing inconsistencies within the text; focusing attention on ideas; creating visual images; forming novel knowledge representations; drawing inferences based on prior knowledge; monitoring understanding as more text is read; integrating information across paragraphs; and integrating information from what was read with information from long-term memory. These components of reading comprehension place heavy storage and processing demands on working memory. Other cognitive and memory processes that support reading comprehension include fluid reasoning, executive processes, processing speed, verbal abilities, vocabulary knowledge, prior knowledge, and decoding skills.

Written Expression: Writing is essential to success in school and working memory is essential for the functioning of the cognitive processes involved in writing. Skilled writers have automatized the basic skills (e.g., handwriting or typing, spelling, capitalization and punctuation) for transcribing words into text, which frees up working memory resources for higher level processing. Swanson and Berninger (1995) found that working memory capacity predicts written composition ability. Part of the reason that working memory is taxed during the writing process is because much of the writing process cannot be automatized. "Much of a skilled writer's time is spent planning, revising, monitoring, evaluating, and regulating the writing process" (Graham, MacArthur & Fitzgerald, 2007, p.4). Young writers often have to or choose to devote large amounts of working memory to lower-level skills such as handwriting or keyboarding and have reduced working memory capacity left for higher-level processes such as planning. "The effective writer must negotiate the rules and mechanics of writing while maintaining a focus on factors such as organization, form and features, purposes and goals, audience needs and perspectives, and evaluation of the communication between author and reader" (Harris, Graham, Mason & Friedlander, 2008). Students with weak working memory capacity often struggle with many of the basic writing processes, which further challenges their ability to remember their ideas as they transform their ideas into words and connected text.

Mathematics: Many studies have also documented the strong relationship between working memory skill and performance in math. Both basic calculation and math problem solving involve short-term and working memory components to varying degrees (Dehn, 2008). Mathematical fluency requires the ability to formulate an efficient plan of action whose accuracy is dependent upon adequate working memory skills and sufficient cognitive flexibility to double-check the plausibility of a given result (Feifer & De Fina, 2005). Processing speed is another important cognitive process involved in mathematics activities. It is difficult to separate processing speed from working memory because processing speed involves encoding, retrieval, and other working memory functions.

Attention Deficit Hyperactivity Disorder: Deficits in working memory capacity are seen in some types of Attention Deficit Hyperactivity Disorder (ADHD). Children with both ADHD and a reading disability may have more severe deficits in executive working memory (Martinussen & Tannock, 2006). Children with ADHD alone often have relatively intact verbal short-term memory with deficits seen in visuospatial short-term memory and both components of working memory. Children with combined type ADHD have particular deficits in visuospatial working memory capacity.

Oral language development and comprehension: Many children with specific language impairment (normal age-range nonverbal intelligence and marked expressive and/or receptive language difficulties) have significant deficits in working memory (Alloway & Archibald, 2008; Montgomery, Magimairaj, & Finney, 2010). Working memory is very important in oral language development and comprehension because in order to understand the meaning of a sentence, a person must be able to remember the previous words in order to relate them to later occurring words. Although much of spoken language processing occurs immediately, when the syntactic structure or meaning of a sentence is confusing, verbal working memory processing will result. Vocabulary learning has been directly linked with phonological short-term memory capacity (Gathercole & Baddeley, 1990). Verbal working memory links the correct pronunciation of a new word with a semantic representation.

To continue this article and read the sections, “Recommendations for the Classroom” and “Beyond the Classroom: Promising Research on Improving Working Memory” – please go to our website

---

Recommendations for the classroom

Excellent classroom recommendations to support students with weak working memory may be found in Gathercole and Alloway's 2008 book Working Memory and Learning: A Practical Guide for Teachers. These authors recommend that first; teachers must recognize working memory deficits in their students in order to carefully monitor the student's performance in class. Monitoring includes looking for warning signs of working memory overload, asking the student to describe what he/she is doing and is planning to do next, and repeating information when needed. The authors also recommend that learning activities be modified, breaking down tasks and instructions into smaller steps. Lengthy verbal instructions should be broken down, kept short, and delivered in context with demonstration and visual support whenever possible. These instructions should be repeated often. Many students with learning disabilities and weak working memory learn and remember best through direct experiences (what they have seen and done for themselves) rather than through indirect experiences. Students should be encouraged to ask for information to be repeated and to learn to be self-observant about their own performance. Student should also be explicitly taught and encouraged to use a variety of methods to support their working memory and learning. Accommodations such as providing notes for the student, recording lessons or information to be listened to later, using a calculator for math, reading along with recorded books, and various assistive technology resources can help support the academic processes vulnerable to working memory deficits.

Other excellent suggestions for classroom interventions may be found in Lynn Meltzer's new book: Promoting Executive Function in the Classroom (2010). Dr. Meltzer suggests that teachers sequence instruction in memory strategies as follows: (1) ensure student's understanding of each strategy, why it aids memory, and when they can apply it; (2) explicitly teach students how to use each strategy through direct instruction and teacher modeling of strategy use; and (3) ask students to use a specific strategy for a task and require them to reflect on how well it worked for them. The strategies described in Meltzer's book are based on four basic approaches: (1) attending to details, (2) repetition, rehearsal, and review, (3) attaching meaning, and (4) chunking information. Lyn Meltzer recommends many of the same general accommodations for students with weak working memory in the classroom as those suggested by Drs. Gathercole and Alloway.

Beyond the classroom: promising research on improving working memory

Scientists now recognize that the brain remains surprisingly plastic throughout life. Through the use of increasingly sophisticated technologies such as functional magnetic resonance imaging (fMRI), we are gaining a better understanding of the functional neuroanatomy involved in both reading and working memory. For example, Shaywtiz and colleagues reported that evidence-based reading intervention in children ages 6 to 9 led to increased activation in key brain areas for reading as well as significant gains in reading accuracy. A year afterwards, follow-up brain imaging showed that these improvements persisted. Meyler and colleagues found that immediately after 100 hours of intensive instruction, poor readers made substantial gains in reading ability and demonstrated significant increases in activation in key brain regions (2008). The study reported that the brain region activation increases were still seen one year after the intensive intervention.

For many years working memory capacity was thought to be fixed and interventions focused on accommodating weak working memory by means of changing the classroom, home, and work environment. Dr. Klingberg and colleagues at the Karolinska Institute in Stockholm, began to research the potential for change in working memory through computerized training, training which eventually was developed into Cogmed Working Memory Training. Their 2005 randomized, double-blind, placebo-controlled study of computerized working memory training in children ages 7-12 with ADHD caught the attention of many researchers and practitioners. The study showed a significant treatment effect both post-intervention and at follow-up. Significant effects for secondary outcome tasks including verbal working memory, response inhibition, and complex reasoning were also seen. Parent ratings showed significant reduction in symptoms of inattention and hyperactivity/ impulsivity, both post-intervention and at follow-up. The authors concluded that working memory can be improved by training in children with ADHD. Numerous studies using Cogmed have subsequently been conducted by researchers associated with the Karolinska institute and by independent researchers. Studies have been published in peer reviewed journals including Journal of the American Academy of Child and Adolescent Psychiatry, Science, Developmental Science, Journal of Clinical and Experimental Neuropsychology, Nature Neuroscience, Journal of Experimental Psychology, and Child Neuropsychology. For complete references and abstracts of these research studies, please refer to www.cogmed.com.

As described above, Susan Gathercole's research has focused on the various aspects of working memory and the impact on academic success. She has also conducted research on finding ways to reduce working memory demands in the classroom to support the academic success of students with weak working memory capacity. Recently, Gathercole and colleagues have conducted studies using Cogmed Working Memory Training. One study compared the impact of stimulant medication treatment versus Cogmed Working Memory Training on the working memory performance and IQ of children with ADHD (Holmes, Gathercole, et. aI, 2009). Working memory was assessed using the Automated Working Memory Assessment (AWMA), which provides multiple measures of both verbal and visuo-spatial storage, and verbal and visuo-spatial working memory. The participants also completed the Wechsler Abbreviated Scales of Intelligence (WASI). Results indicated that medication treatment improved performance on visuospatial working memory, but not on verbal short-term memory, visuospatial short-term memory, or verbal working memory. Cogmed Working Memory Training led to significant gains on all four memory tasks and improved children's performance into the average range on these tasks from the below-average range. Six month follow-up data indicate that the working memory training gains had persisted. IQ scores were neither affected by the Cogmed training intervention nor the stimulant medication intervention.

Holmes, Gathercole and Dunning (2009) investigated the impact on working memory of a training program (Cogmed) designed to boost working memory. Children with low working memory skills were assessed on measures of working memory using the A WMA, IQ using the W ASI, and academic attainment, using the l Wechsler Objective Reading Dimensions and Wechsler Objective Number Dimensions before and after training on either adaptive or non-adaptive versions of the program. Adaptive training that taxed working memory to its limits was associated with substantial and sustained gains in working memory, with age-appropriate levels achieved by the majority of children. Mathematical ability also improved significantly 6 months following adaptive training. These findings suggest that common impairments in working memory and associated learning difficulties may be overcome with this behavioral treatment.

Growing excitement about the intervention possibilities for children and adults with limited working memory capacity is now seen across scientific and academic disciplines, as well as in the mainstream. These research trends are sure to continue in the next decade and translate into more effective interventions for a broader range of individuals.