Chapter 3
Working Memory

Working memory is central to all learning. This is embodied in the first principle of the ULM: Learning is a product of working memory allocation. As we sketched out in our discussion of the underlying neurobiology of learning, working memory allocation involves attention and capacity limitations. In this chapter, we elaborate how these operate.

Working Memory Capacity

Interest in working memory can be traced to George A. Miller, a psychologist whose distinguished career was recognized by the awarding of the National Medal of Science in 1991. In 1956, Miller published one of the most famous and widely-cited papers of all time: "The magical number seven, plus or minus two: Some limits on our capacity for processing information." In this paper, Miller summarized many studies of sensation and memory and concluded that people seem to have a limited capacity for short-term memory of sensory input, a capacity of about 7 ± 2 things.[1] As the study of memory and cognition began to flourish in the 1970s, numerous scientists started examining Miller's limit. Alan Baddeley and his colleagues were among the most prominent of these researchers. Baddeley and Hitch coined the term *working memory* for this limited short-term capacity.[2]

Current models of working memory generally agree that working memory has two main components:

- A working memory storage area for temporarily and briefly holding elements of sensory input and/or knowledge retrieved from long-term memory.
- A processing system encompassing attention and other cognitive actions that operate on (i.e., change) the content of the temporarily-stored elements.

The working memory storage area corresponds most closely to Miller's original memory capacity. Further study of this capacity has reduced Miller's original 7 ± 2 down to approximately 4.[3] Working memory storage capacity seems to be a function of span and possibly speed:

D.F. Shell et al., *The Unified Learning Model*, DOI 10.1007/978-90-481-3215-7_3,

- span, the absolute number of individual elements (things like sensory input or retrieved knowledge) a person can retain at one time, and
- speed, how fast a person can do some type of cognitive action or processing on the elements being temporarily retained before they decay and are replaced with new elements.

Working memory storage can be limited by not having any span left because all available holding places (often called slots) are occupied or by not being able to process everything that is in span before it is erased. Just think about the last time you sat in a professional development session, and the speaker rattled off a series of effective ways to teach students how to comprehend what they read. Unfortunately, she did this without including the slide with those recommendations listed in her *PowerPoint* presentation. You wanted to remember each of them, but there were six intriguing suggestions in her list – an overload for your working memory span. You try to write down what you do remember, but find that you only partially recall the last one – your retrieval for all the words you want to write in your notes is not fast enough to hold them in working memory. You resort to glancing at your neighbor's notes to try to refresh your memory about what you wanted to write.

Studies of working memory processing are recent. As a result, today more is known about how the storage component functions than how the processing component functions. The primary component of working memory processing is *attention* (sometimes called *controlled attention*). Attention generally refers to how many of the elements in working memory storage can be focused on at any time despite distractions and interference. Think of this as reflecting how well you can maintain concentration. Processing largely involves combining temporarily stored elements. Learning is about connections; processing capacity determines how many simultaneous connections can be made between temporarily stored elements. These connections transform or change the original elements into something new. The four elements limit appears to be the capacity for processing or combining in attention or, the same as the number of storage elements.[4]

How Working Memory Functions

At the neural level, working memory is receiving a continuous stream of inputs from the senses. Since working memory can hold only about four elements in its temporary storage, all of the incoming sensory input can't be saved. There are pre-working memory selection mechanisms in the sensory processing areas that influence what does or does not get into the available four slots in working memory. The neurobiology and cognitive operation of these are beyond our scope here. Suffice it to say that they tend to work based on novelty (i.e., patterns of sensation that are new) and salience (i.e., how strong or large is the sensation-like a loud noise). Once something is in working memory's temporary storage, however, the processing component of working memory determines what happens to it.

Think about something as simple and common as being awake in the world. Sensory sensations are continuously coming at you. As soon as one sensory input is put into temporary storage, another different input is waiting to be put there. To accommodate the continuous nature of the real world, working memory only temporarily holds information for a very brief period of time. After this time period, sometimes called a cycle, the temporary contents are "erased" and new input comes in. Without something intervening, inputs would flow continuously through working memory as they were happening. To differentiate or focus on some piece of this input, something in working memory has to stop the continuous flow. This something is *attention*.[5]

When we *attend* to something in temporary storage, the attended element is not erased; it is held in storage beyond the normal temporary memory cycle. New input is blocked from replacing it in temporary storage. If one or two elements are receiving attention, there still is reduced room for new input. If attention were focused on the entirety of temporary storage, however, all input would be blocked. Blocking all new input often proves dangerous; a tree might pick that very moment you are attending to the temporarily stored elements to fall on you. That's why driving a car and speaking on a cell phone is dangerous. Most driving situations require minimal resource allocation. If the cell phone conversation requires many resources, however, those needed for driving may become unavailable leading to an accident. Attention can be redirected from current temporary contents to new sensory input. On the other hand, most of us have had experiences of reading a "page turner," a book we just can't seem to put down, and discover that we have read way past our normal bed times – something for which our bodies pay the price of being very tired the next day.

Recent brain research has identified a buffer area that is a part of working memory that allows the current temporary memory contents to be held while new input enters temporary memory for immediate attention. Working memory can "task switch" between temporary memory and the temporary memory buffer.[6] Think back to when you were reading a page turner – and were interrupted by a spouse or child or roommate. A momentary interruption, perhaps where you exchange a brief greeting, might not disturb you. Responding to a question, however, would most likely cause you to "lose your place" in the reading.

Attention does not just pick from random sensory inputs; it directs sensory input. When sensory information is attended, working memory can signal the senses to focus on the area where that attended sensation came from. If something "catches your eye," working memory will direct your eyes to focus on that and collect more input. Attention to something in temporary storage prioritizes any related sensory information. We experience this focused chaining of sensory input, attention, redirection of the sense, new sensory input, continued attention, new redirection of the sense, and so on, as *concentration*. As this concentration is going on, the blocking of other sensory inputs can be quite profound. Think about reading the page turner. One of the authors can remember being so absorbed and focused on reading a book, that his grandmother kept trying to call him to dinner with increasing volumes of shouting until finally a very loud scream broke his concentration and caused him to be in trouble because he didn't come when called.

Working memory does not deal with just sensory input. Working memory interacts with long-term memory. A key aspect of working memory is that it activates or retrieves knowledge from long-term memory. While taking in and attending to sensory input is a critical function of working memory, activation of long-term memory knowledge is even more important. Our ability to utilize our experience, or even more basically to make sense of incoming sensory input, is dependent on long-term memory activation. If this were not so, then each input would be treated as something new and unfamiliar, and we would never accomplish anything.

Pattern matching is the basic mechanism of working memory and long-term memory interaction. When a sensory input in temporary memory is the same as something in long-term memory, the long-term memory is retrieved. Not only is the specifically matched long-term memory retrieved, but anything connected to it also is retrieved. In this way, working memory connects the outside world to our internal store of knowledge. Sensory input triggers retrieval of long-term memory knowledge, which can then be attended to and processed on by the processing components of working memory. This is how we can see $7 + 9 =$ ___ and retrieve the knowledge from long-term memory that this is a mathematics equation and the answer is 16.

Pattern matching can evoke complex patterns. For example, when a teacher sees a student choosing a book, the student activates one set of knowledge, and the book activates a different set. The teacher is then likely to pattern match the book and the student, asking herself the question, "Is this book appropriate for this student?"

Learning Principle 1: Working Memory Allocation

The ULM holds that learning is a product of working memory allocation. In the ULM, we combine the temporary storage and processing components of working memory into the overarching framework of allocation. For working memory to be allocated to a task, two criteria must be met. Slots must be available for sensory input or retrieved memory. Then, attention or processing has to be directed toward the slotted element. We are using the term allocation in the everyday (rather than strictly scientific) notion of attention as expressed by William James back in 1890:

> "Every one knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalization, concentration of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others, and is a condition which has a real opposite in the confused, dazed, scatterbrained state which in French is called *distraction*, and *Zerstreutheit* in German."[7]

James' description embodies both aspects of working memory capacity, namely selecting elements that are temporarily stored and directing attention and processing to the selected elements.

In the school classroom or other educational setting, it is impossible to clearly separate the temporary storage and processing components of working memory. When we tell a student to "pay attention," we want them to both take the instructional information into temporary storage and attend to it or process it in ways that get the processed information stored in long-term memory. When we say in the ULM that the key to learning is working memory allocation, we are expressing the need for *both* storage and processing of that material in working memory. The way working memory allocation produces learning is embodied in three of the five rules of learning set forth in Chapter 2.

Rule 1: New Learning Requires Attention

The first way working memory allocation produces learning is through attention. It appears that when working memory processing attends to something it has temporarily stored, it is more likely to be permanently stored. That is, it is placed into long-term potentiation and then perhaps into long-term memory. Table 3.1 comes from think-aloud protocols of individuals reading. In this study, the participants were asked to recall information from an article approximately 15–20 min after the reading had been completed. All are verbatim.

In a think-aloud, the research participant is asked to verbalize anything that comes to mind. Think-aloud researchers have argued that think-aloud verbalizations reflect what is being attended to in the current contents of temporary working memory. What is notable in these short segments is how close the recalled answers were to what was verbalized in the think-aloud during the actual reading. This seems to indicate that attention, by itself, is sufficient for later recall. Very recent research has shown that neurons activated during learning are reactivated during recall, strengthening the view that what was stored by attention is what is retrieved.[8] We have no

Table 3.1 Think-aloud and subsequent recall

Think aloud statement	Recall
The father seems to ask more for someone to do the task and the mother seems to want . . . she'll just do it herself	The mothers were more apt to doing(sic) the tasks themselves and the father(sic) were more willing to ask the children.
Mothers take on more housework than fathers.	Mothers do a lot of the household tasks.
Hum, what kind of perceptions do kids have of household jobs? How come just 3, 6, and 9?	This article deals with children's perceptions of household tasks during grades 3, 6, and 9.
So regular jobs, sometimes jobs, and never jobs.	3 categories: tasks they often did, tasks they sometimes did, and tasks they never did.

way of knowing how long this memory was retained. The 15–20 min interval was within the time frame of long-term potentiation, so it is possible that no long-term memory was created.

Rule 2: Learning Requires Repetition

Working memory allocation can also increase learning by repetition. In the preceding think-aloud example, attention was focused on some information once. What if attention were focused more than once? Attention keeps a temporary memory element from being erased. A single act of attention, however, can only hold an element for a few temporary memory cycles. What if we kept repeating our attention focus? This would keep putting the element back into temporary storage over many more cycles. The term for this in the learning and study strategies literature is *rehearsal*. In a think-aloud, we would detect this as someone repeating something to themselves over and over. We don't quite know exactly how rehearsal works at the neural level. Is it just time in temporary storage that matters, is it repetition in temporary storage that matters, or is it actually retrieval and restorage in long-term potentiation that matters? Whatever the details of the mechanism, we know that rehearsal creates permanent long-term memories. This is the foundation of *rote memorization*. Information that is attended to repeatedly is stored in long-term memory. The problem with rote memorization as a learning strategy is that it usually short changes the learner. Those additional connections likely to facilitate retrieval in similar contexts are not made. Transfer to related or novel contexts at a later time is much less likely.

Repetition does not have to be continuous. Although we think of rehearsal as repeating things over and over continuously, the rehearsal effect appears to operate for the duration of long-term potentiation. Nuthall and Alton-Lee used an extensive array of observational and tape-recorded tracking measures to follow children during school lessons, including out-of-school times.[9] They then traced back end-of-the year final exam answers to the lessons where they were being taught. They found that for most information to be answered correctly in the final exam, it had to appear a minimum of four times in verbalizations or other activity that indicated the information was being attended to. They further found that information needed to reoccur at least once within a day to be retained. In the language of the ULM, the information had to be brought into working memory multiple times within contiguous days to be learned. These repetitions likely involve retrieval or reactivation of the long-term potentiation areas, with the multiple repetitions sufficient to transfer the long-term potentiation to long-term memory.

The final way repetition works is over an extended time period. When working memory processing attends to some sensory input and activates/retrieves knowledge from long-term memory through pattern matching, the long-term memory knowledge that is retrieved is strengthened. (A neuron's firing potential is increased every time it is activated). Extended repetition leads to faster and more consistent retrieval of the information. This is common practice; think of learning the multiplication tables, learning lines in a play, or memorizing a chemistry or physics formula. While at some level, these are "rote memorizations," they may be highly meaningful. Extended repetition makes them more accurately recalled and more usable.

Extended repetition is critical for retrieval. Knowledge is retrieved based on pattern matches. To be usable or to transfer to different settings outside the classroom, even rote knowledge, like a math formula or economics fact, must be connected to a variety of retrieval cues. An example of this comes from elaborated repetition based on work done in primary grade classrooms, where word learning is crucial in laying the groundwork (or neural connections) for later complex knowledge development. Beck and McKeown advise using an instructional progression from their *Text Talk* project that begins with contextualizing a word by talking about its use in the story ("In the story you will hear about how the farmer trudged home after a long day of work.[10] That means that he walked heavily, like he was really tired.") Then, the teacher explains the meaning of the word. ("When you trudge, you walk like your legs are tired from working and they feel heavy.") Next, the children repeat the word, articulating it clearly to form a clear mental representation (Say trudge with me: trudge.") Subsequently, to think about transfer, the word is used in contexts that are different from the book ("You may trudge back to your tent, if you have been out hiking all day.") ("You might trudge if you walked through a path with a lot of thick, heavy mud that stuck to your boots.") Teachers would then push up the level of students' thinking, by having them make a few evaluations using the word ("Would you trudge to the kitchen, if you just finished taking a nap and were full of energy? Why or why not?") The students would then offer examples of their own ("I trudged home after I . . .). Finally, the word's mental representation would be further supported by asking a question that incorporates its meaning. ("What word means to walk heavily, as if you were exhausted?") Within this instructional format, students hear and say the word repeatedly in ways that strengthen their long-term memory knowledge of the word and increase the number of visual, auditory, and contextual retrieval cues for pattern matching.

Rule 3: Learning Is About Connections

Working memory doesn't just focus attention; it also processes information. When processing occurs, the result is likely to be stored in long-term memory. Craik and Lockhart were the first to note what they called "levels of processing."[11] Similar concepts emerged in the literature with labels such as deep processing, transfer appropriate processing, encoding specificity, and deep versus surface learning strategies. All of these frameworks were based on a common property of working memory: information in working memory that is changed or altered is better remembered. Contrast this with the repetition effect. In repetition, the processing attends to something that is in temporary memory and stores a copy of it. The temporary memory element is not changed in any way from its original state. When working memory processes temporarily-stored information, however, the original temporary memory element is changed from its original state into something different. Think about the difference between trying to learn something verbatim versus trying to remember the basic idea or gist of it. How often are students told to remember the idea by "putting it into your own words?" Often when students have memorized knowledge with few connections, replacing some words with synonyms operationalizes "in your own words." Any time working memory manipulates temporarily held contents, the result of that manipulation appears to be stored, at least into long-term potentiation. That is, even if it is not permanently stored, it is retrievable for some time (possibly hours) after the manipulation takes place. In the research and practice of study strategies, we see the levels-of-processing concept as strategies directed at paraphrasing and summarizing information that is to be learned. Most recently, in the cognitive load literature, this act of processing has been termed *germane load*. Germane cognitive load is related to how information is presented in instruction. If the information to be learned is presented in a way that promotes appropriate processing of the information, then it is considered to be part of the germane cognitive load for the learner.[12]

Connections are at the heart of Pavio's well-known *dual coding theory*.[13] While auditory and visual information come in through separate sensory systems and are stored separately, subsequent activation of either one leads to activation of the other. This is the rationale supporting some teaching approaches that are used when working with students with specific language disabilities. Students are asked to say the word to be spelled, say each letter name as they write the word, and pronounce the word again as they look at it. The students are getting both visual and auditory input as they learn the word to help facilitate later retrieval when they see it in print or need to write it.[14]

The processing effect ultimately is about connections between things. Information in the sensory input that is coming into temporary storage is connected in a certain way. Working memory processing can break down existing connections as well as create new connections. A paraphrase or summary is a different way of connecting the current information in working memory. Nuthall and Alton-Lee found that remembrance of information was enhanced by it being connected to other information.[15] Most study and note-taking systems, from creating matrices to drawing concept maps, are based on facilitating connections between the information that is being learned.

The capability of working memory processing to create connections also allows working memory allocation to connect new sensory information to existing knowledge. When pattern matching retrieves knowledge from long-term memory, anything that is currently in temporary memory with that retrieved knowledge can be connected to it and stored with it. This ability to connect pieces of knowledge together underlies how working memory allocation can create the integrated knowledge structures talked about in the literature as concepts, propositional networks, schema, production systems, or neural nets. We will have more to say about the nature of these integrated knowledge structures in Chapter 4.

Expanding Working Memory Capacity

We have talked about the temporary storage capacity as being about four elements. We have noted that those elements can be sensory inputs or retrieved long-term memory knowledge. But, we haven't really talked about the exact nature of an element. As a working memory capacity test, try the following:

Read each row. After the row is finished, look away for 5 s. Then, without looking back, recite the row. Check your accuracy.

x g c w
m q p t x r
z p w x m v b t
m t p j w s d l q z

As the number of letters increased, you probably noticed yourself having more difficulty recalling the letters. If you could recall the last row or even the last two rows accurately, consider yourself unusual. Now try this test, doing the same as before. Read the row, look away for 5 s, and then recite the row.

dog farm rocket
onion frame car rodeo

You probably didn't have much trouble remembering the first line and most likely didn't have much trouble with the second line either. But count the number of letters. The first line of dog, farm, rocket has 13 letters. The second line of onion, frame, car, rodeo has 18 letters. In the first test, the maximum number of letters in any line was 10 and you were probably beginning to have trouble with the third line of 8 letters.

From this example, it seems fairly clear that an "element" that is filling a slot in temporary storage is a variable thing. Temporary memory can hold four or a few more letters, but it can also hold four or a few more words, even if these words add up to far more than four letters.

The generic name in the scientific literature for these variable elements is a chunk. A chunk is a connected grouping of knowledge. Accordingly, we can say that working memory has four slots, and that each slot can accommodate one chunk. We will discuss chunks in more detail in the next chapter on knowledge. Suffice it to say for now, a chunk is associated with meaning. Chunks are individual entities (like specific sounds or visual input) that have been connected together into a single meaningful entity, such as letters combining to form a word. The meaningful nature of a chunk can be seen in the following.

Like the previous exercise with letters, look at the following list of numbers, then look away for 5 s, then try to recite the numbers.

6
0
2
5
7
1
2

Fairly difficult. Now look at the following.

602-5712

This seems easier to remember now. What is the difference here? The list of numbers is the same list of numbers, but the second is arranged in the well-known form of a telephone number. Many telephone numbers are meaningful; think of your home or work phone number. Also, we routinely have to deal with phone numbers so we are well practiced in seeing and using numbers in this form. Essentially, we are used to seeing certain number combinations as a "telephone" chunk. We recognize that the Greek letter π (pi) often represents the chunk 3.141. . .. In language learning, word families or onsets – sounds before the vowel in a word – and rimes – the rest of the word (m-ap, tr-ap, ch-ap, str-ap) are chunking examples that help us recognize words quickly and spell them with less effort once we understand how they work.

Chunks dramatically expand working memory capacity. We really don't know the limits of how big a chunk can be. We also don't fully know whether they are retrieved into temporary memory as a single group or as serially connected or chained spreading activations or some combination of these. Chunks do dramatically increase the amount of knowledge that working memory has available in temporary memory for processing. As we will discuss in the knowledge chapter, chunks underlie most development of skill and expertise.

Chunks reflect the two-way interaction between working memory and long-term memory. It isn't just that working memory retrieves knowledge from long-term memory. The knowledge that is retrieved actually affects the span and efficiency of working memory processing.

Working memory appears to be a biological entity, something that has a physical realization in the brain. Although the basic capacity of working memory is likely a function of genetics and basic brain architecture, long-term knowledge chunks can expand it. Working memory capacity is not fixed. While we each have about four slots, the capacities of these slots grow as a result of chunking. Dehn has addressed many of the issues connected with measuring working memory capacity.[16]

Working Memory as Consciousness

When we go back to William James' quote (p. 22), he singles out consciousness as a property of attention.[17] It is tempting to think of working memory as the seat of our consciousness, our awareness of ourselves, our thinking, and our behavior. Most likely, this notion is not correct. While we might be able to make a case that anything we are conscious of is in working memory, we certainly are not conscious of everything that happens in working memory. Operation of the attention and processing components of working memory can occur without our self-awareness. Similarly, elements can be moved in and out of temporary memory without our awareness. In a sense, to be conscious of the contents of short-term memory or working memory processing, we have to direct working memory's attention on itself.

Similarly, working memory is not necessarily voluntary. As with consciousness, we can exert some deliberate control over what is being input into temporary memory, where attention is directed, and how we are processing what is in temporary memory. But, these working memory operations can operate without our voluntary initiation and sometimes in spite of our intentions. While we might want to pay attention to our teacher in class, our attention may go back to the scene earlier in the day when our dog was hit by a car or to the funny skit that opened *Saturday Night Live*. Sensory input mechanisms are providing continuous feeds and pattern matching in working memory that are operating continuously to retrieve long-term memory knowledge. These things happen whether or not we are trying to control them.

It is important that voluntary control on working memory allocation is possible, however, because that is what allows education to be possible. Because a student can control working memory allocation, we can set up teaching and learning conditions that help students direct their working memory allocation to specific learning materials. We can, in fact, conceptualize teaching and instruction as the management of voluntary working memory allocation.

Basic Rules of Working Memory

We can summarize this chapter on working memory into the following set of rules.

Storage Rules

1. If something in working memory is attended to, store it in long-term memory (the attention effect).
2. If something is in working memory for multiple cycles, store it in long-term memory (the repetition/rehearsal effect).
3. If something in working memory is processed, store it in long-term memory (the levels of processing effect).
4. If things are in working memory together, store them together in long-term memory (the connection or association effect)

Retrieval Rule

1. If something in working memory is the same as something in long-term memory, retrieve the long-term memory contents (the pattern matching effect).

Notes

1. The beginning of formal descriptions of the amount of long-term memory humans could access at one time is attributed to Miller and the number of items was, at that time, thought to be seven. See Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63*, 81–97.
2. The original formal use of the term working memory began with Baddeley and Hitch. (Baddeley, A. D., & Hitch, G. J. (1974). Working memory. In G. Bower (Ed.), The psychology of learning and motivation. (Vol. VIII, pp. 47–90). New York: Academic Press.) Until recently some researchers sought to distinguish this term from another that had been in prior use – short-term memory. Based upon very recent work, the need for that distinction has been re-evaluated (Unsworth, N., & Engle, R. W. (2007). On the division of short-term and working memory: An examination of simple and complex span and their relation to higher order abilities. *Psychological Bulletin*, *133*(6), 1038–1063.)
3. Saults, J. S., & Cowan, N. (2007). A central capacity limit to the simultaneous storage of visual and auditory arrays in working memory. *Journal of Experimental Psychology. General*, *136*(4), 663–684.
4. Halford, G. S., Cowan, N., & Andrews, G. (2007). Separating cognitive capacity from knowledge: A new hypothesis. *Trends in Cognitive Sci*ence, *11*(6), 236–242.
5. For a recent review and discussion see: Knudsen, E. I. (2007). Fundamental components of attention. *Annual Review of Neuroscience, 30*, 57–78.
6. Koechlin, E., & Hyafil, A. (2007). Anterior prefrontal function and the limits of human decision-making. *Science, 318*, 594–598.
7. James, W. (1890). The principles of psychology. The quote cited here is found as part of James' book which is reproduced as part of Classics in the history of psychology. http://psychclassics.yorku.ca /James/Principles/prin11.htm. (Accessed October 11, 2008).
8. Gelbard-Sagiv, H., Mukamel, R., Harel, M., Malach, R., & Fried, I. (2008). Internally generated reactivation of single neurons in human hippocampus during free recall. *Science, 322*(5898), 96–101.
9. Nuthall, G., & Alton-Lee, A. (1995). Assessing classroom learning: How students use their knowledge and experience to answer classroom achievement test questions in science and social studies. *American Educational Research Journal, 32*(1), 185.
10. Beck, I., & McKeown, M. (2006). Different ways for different goals, but keep your eye on the higher verbal goals. In R. K. Wagner, A. E. Muse & K. R. Tannenbaum (Eds.), *Vocabulary acquisition: Implications for reading comprehension* (pp. 182–204). New York: Guilford Press.
11. Craik, F. I. M., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior, 11,* 671–684.
12. Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational Psychologist, 38*(1), 1–4.
13. Pavio, A. (1990). *Mental representations: A dual coding approach*. Oxford: Oxford University Press.
14. Slingerland, B. H. (1985). *Basics in scope and sequence of a multi-sensory approach to language arts for specific language disability children: A guide for primary teachers.* Cambridge, MA: Educators Publishing Service.

15. Nuthall, G., & Alton-Lee, A. (1995). Assessing classroom learning: How students use their knowledge and experience to answer classroom achievement test questions in science and social studies. *American Educational Research Journal, 32*(1), 185.
16. Dehn, M. J. (2008). *Working memory and academic learning: Assessment and intervention*. New York: J. Wiley & Sons. The issues regarding measurement are potentially economically significant. Changes in standard tests coupled with definitions of learning disability have resulted in important changes in special education funding eligibility.
17. Although obviously a very important phenomenon, consciousness is not well understood. We might ask the question, What is different between being conscious or not conscious, as when sleeping? Francis Crick described approaches to consciousness in his book. Crick, F. (1995). *The astonishing hypothesis: The scientific search for the soul (*paper*)*. New York: Scribner. A recent review of studies of persons under anesthesia suggests that consciousness may involve an integration of information, one that is lost during sleep or while under anesthesia. See: Alkire, M. T., Hudetz, A. G., & Tononi, G. (2008). Consciousness and anesthesia. *Science, 322*(5903), 876–880.