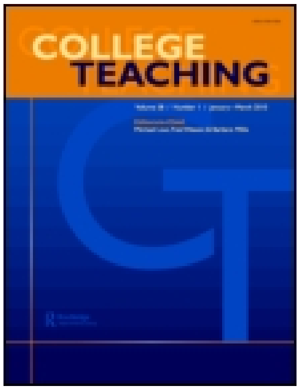

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What College Teachers Should Know About Memory: A Perspective From Cognitive Psychology

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Cognitive psychology has much to contribute to our understanding of the best ways to promote learning and memory in the college classroom. However, cognitive theory has evolved considerably in recent decades, and it is important for instructors to have an up-to-date understanding of these theories, particularly those—such as memory theories—that bear directly on how students absorb new information. This article offers a non-technical overview of major theoretical ideas on memory, geared to instructors who want to optimize their teaching to take advantage of the way human memory works. Relevant theories of short-term and working memory are reviewed, with particular attention to how these have been refined and changed in recent years. Long-term memory is also discussed, with emphasis on the concept that human memory is an adaptation shaped by natural selection, an idea that instructors can use to create more memorable learning experiences. Lastly, the article presents a set of predictions regarding future trends in teaching-related cognitive theory; these include an increasing emphasis on the role of attention in memory, new understanding of the limitations of working memory, de-emphasis on perceptual learning styles and increased emphasis on frequent testing.

Keywords: cognition, current developments, educational theory, memory, theory

Cognitive psychologists have mixed feelings about the use of memory research to inform pedagogical practice. On the one hand, a working understanding of memory processes is clearly useful for instructors, who work very hard to promote long-term retention of course material, and fortunately, there is no shortage of theoretical research detailing the inner workings of memory. On the other hand, when this theoretical research is translated into specific suggestions for pedagogical practice, it is too often misinterpreted, oversimplified, or substantially out of date. Further complicating this translation from theory to practice, technical terms like "short-term memory" are likely to be used very differently by educated non-experts than by cognitive psychologists (Glick & Budson 2005). Faced with poorly "translated" information on current cognitive theories, the non-expert will come away with either no useful ideas, or worse, incorrect ideas about how to promote student learning.

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The field of memory theory is currently so complex that it is essentially impossible to summarize, even for experts (Roediger 2008). This complexity may contribute to the preponderance of inaccurate and outdated information in the educational literature. With this in mind, I will focus selectively on the memory concepts most germane to college teaching, contrasting now-outdated ideas with their newer counterparts, and discussing how those concepts translate into teaching practice.

In the Beginning, There Were Three Boxes: The Modal Model of Human Memory

Arguably the first well-elaborated, empirically supported theory of human memory, the "modal model" was developed in the late 1960s by the researchers Atkinson and Shiffrin (1968). Based on how people remember lists of unrelated words, Atkinson and Shiffrin theorized that memory consisted of three distinct components, each with a separate function. These three components worked in concert to perform information processing—i.e., turning sensory experience into a "code" that can be stored and retrieved when needed. These components included the following:

1. Sensory memory. This component holds visual and auditory information for approximately 1–5 seconds prior to any kind of interpretation or analysis.
2. Short-term memory. This component holds any information currently being used to accomplish a task, plus any information deemed important enough to be passed along from sensory memory. It is also brief in nature; typically, information stays only a few seconds before it is displaced by new, incoming material and is consequently lost forever. The exception to this immediate-displacement principle occurs when an individual engages in *rehearsal*—that is, saying something over and over (silently or out loud). One frequently used example of rehearsal is repeating a phone number over and over until it has been successfully dialed.
3. Long-term memory. As the name implies, this component retains information for long periods, even permanently. However, information in long-term memory cannot be directly used to perform a task but must first be retrieved and "reloaded" into short-term memory.

These three components—sensory memory, short-term memory, and long-term memory—work together much like an assembly line, with information making stops at each "station" before being passed along. Of course, not every bit of information makes it all the way into long-term memory. On the point of how we decide what to pass from sensory to short-term memory, Atkinson and Shiffrin are less specific. By contrast, they expound considerably on how information makes it from short-term to long-term memory, reasoning from their data that rehearsal is one critical step that allows material to be transferred from short-term to long-term memory. Among other things, rehearsal explains why people tend to remember the first few items in a list better than the subsequent ones; most people, when rehearsing a list, start over from the beginning each time they add a new item, so that the first items accrue a higher number of rehearsals by the time the memorization period is over.

This model provides an elegant, empirically supported account of human memory. And yet, vanishingly few cognitive researchers—Atkinson and Shiffrin included—now believe the modal model to be the best theory of human memory. While it has been incredibly influential in shaping researchers' evolving understanding of memory, the three-box idea has been left behind by cognitive models. Here are just a few of the many critiques and questions raised over the years:

What is sensory memory for?

In a brilliant series of studies predating Atkinson and Shiffrin's work, the cognitive scientist George Sperling demonstrated that we do retain visual information briefly, in "unanalyzed" form, although we have little conscious awareness of this memory (Sperling 1960). However, the functional role that this plays in the memory system remains unclear, even today. In other words, we don't know why this store exists or what it helps us do; one researcher (Haber 1983) famously declared that its only apparent purpose is to help us read in a thunderstorm! Others (e.g., Coltheart, 1983) have argued that it buys time for the visual recognition system to identify stimuli in a rapidly shifting scene. Either way, it is better described as a minor component of the perceptual system rather than as a fundamental part of memory.

Short-term memory: One system or many?

As researchers delved into the details of short-term memory, it rapidly became apparent that more was going on in this component than simple maintenance of "chunks" of information. In particular, short-term memory, as measured in studies of list recall, seems especially geared toward maintaining speech sounds. In a groundbreaking series of studies, the researcher Alan Baddeley and his colleagues showed that purely speech-based factors such as word length radically altered the capacity of short-term memory. For example, you can remember only a short list of long words—*refrigerator, elephant, grandmother*—but a longer list of short words—*car, mouse, aunt*—even when factors such as word commonness and the ease of picturing the word are all held constant (Baddeley, Thompson, & Buchanan 1975).

Is rehearsal in short-term memory necessary for transfer to long-term memory?

Repetition and rehearsal do seem to aid recall in many contexts, a fact that is, appropriately enough, repeated time and again in advice to teachers. However, it does not seem to be a necessary step, as vividly demonstrated by studies of people who, due to strokes or other brain injuries, have lost their capacity to hold and rehearse information in short-term memory (Martin & Breedin 1992; Martin 1993). Such individuals show a near-total inability to recall material such as number lists, yet they fail to show even subtle problems with long-term memory.

These and other findings were part of the rise of the framework termed the *working memory model*, spearheaded by Alan Baddeley (see, e.g., Baddeley, 1986, 1998). In short, this model retains the multiple-components idea from the modal model but expands and elaborates on the short-term memory part. The working memory model posits that we have several sub-components of short-term memory, each geared to retaining a certain kind of information. One example is the "phonological loop" component, which functions to retain a limited number of word sounds at a time. These components hold and reshuffle information to accomplish whatever task is at hand, such as understanding a sentence, formulating a spoken reply, manipulating a mental image, or solving a problem. Their efforts are coordinated by a "central executive," which is not so much a memory store as a decision-maker and supervisor.

Like the modal model before it, the original working memory concept has been influential, but it has also triggered debates that should discourage us from taking it as settled psychological fact. One debate in particular echoed the earlier questions about sensory memory. Consider the following: Phonological working memory has been well documented in numerous studies. We do appear to have a component—actually, a dedicated set of brain regions, as documented by brain imaging research (Jonides et al. 1998; Martin, Wu, Freedman, Jackson, & Lesch 2003)—that temporarily holds word sounds. At first, researchers quite logically assumed that such a component must be important for comprehending sentences—e.g., it might hold a backup record that you can consult if a sentence is long or grammatically complicated. However, research with brain-injured individuals failed to find a conclusive link between phonological memory and sentence comprehension. As a consequence, for a while theorists were in the unsettled position of believing in a brain component with no conceivable function other than to help people parrot back random word lists.

Later research, led by Susan Gathercole and others, revealed an unexpected connection: phonological short-term memory is crucial for learning new vocabulary items, both in children and adults (see Baddeley, Gathercole, & Papagno 1998, for a review). Patients with injured phonological components can *understand* speech (Freedman & Martin 2001) but are nearly incapable of learning new terms (e.g., words in a foreign language). In light of these findings, the phonological store seems to function primarily as a way to hold speech sounds long enough to create a memory representation in long-term memory. As for processing information in any more meaningful way, it plays little role. Research suggests that when we understand the words and ideas being conveyed in a sentence, we send those ideas directly to other components of memory (Martin & He 2004) or incorporate them into a lasting representation of the overall sentence structure (Potter & Lombardi 1990) without any need for temporary storage, rehearsal, or the like.

This total reversal of how researchers think about phonological working memory serves as a lesson on the need to consider the *ecological* or evolutionary purpose of memory. In other words, you can't understand how a memory component *works* until you understand what it is *for.* This idea suggests a larger and more profound set of questions about the application of working memory research to situations such as teaching. Much of the theoretical memory research cited in advice to instructors was conducted using a very limited set of experimental paradigms, primarily recall of lists of unrelated words or numbers presented under strictly controlled conditions. This type of paradigm is well suited for exploring the inner workings of the cognitive system but does not necessarily reflect on more realistic learning situations.

Contemporary concepts of working memory cast doubt on the claim that limitations in working memory determine what students can learn. Unless one's teaching style consists of listing unconnected items to be memorized, students will rely on other aspects of memory to encode the information. It is true that the commonly offered advice to structure information meaningfully—in hierarchies, "chunks," "schemas" and the like—will probably promote retention, but for reasons that may be wholly unrelated to working memory capacity. Caution is therefore warranted in reshaping one's pedagogy according to the classical conception of working memory.

By contrast, the "adaptive," or ecological view—in which the focus is on larger issues of how memory evolved to help us survive challenges we would have faced in our long history as hunter-gatherers—offers more productive avenues for classroom application. This view does not supplant or compete with the working memory research discussed above; rather, it is an alternative framework for understanding why we remember and forget the things that we do, with an emphasis on long-term memory rather than short-term or working memory. We will return to the adaptive memory idea shortly, but first, let us consider some crucial characteristics of long-term memory. The long-term memory component has been the focus of less research than the short-term and working memory components. However, a recurring theme in the research to date is the importance of *cues*. In long-term-memory, the limiting factor is not storage capacity, but rather the ability to find what you need when you need it. Long-term memory is rather like having a vast amount of closet space—it is easy to store many items, but it is difficult to retrieve the needed item in a timely fashion.

Cues solve the retrieval quandary by triggering the information needed in a given situation. When we encode information, such as a name, we link it to other information that is present at the time—a face, a person's appearance, where we're standing when we are introduced. Provided with the right set of cues, we can retrieve that person's name. Without those cues, we are at a loss. That's why we all experience the unsettling situation from time to time of vaguely knowing that we know a person, without being able to remember how or why.

Understanding the role and importance of cues enables a richer and more accurate understanding of why people remember—and forget—what they do. It also leads to a number of pedagogical applications. One is the principle that students should study material over short, spaced periods and in a variety of contexts, rather than in concentrated sessions. The idea that cram sessions lead to reduced learning is commonly cited, but the reason why is often inaccurately described. Here is one explanation for why spaced study works: When you take in information, you encode along with it a whole host of other things, such as your surroundings, your mood state, the time of day and so on. These "other things" then become cues to retrieval. If those cues are reinstated—e.g., if you take a test in the same room where you studied—that functions to your advantage. But, if those contextual cues are changed, retrieval may fail. On the other hand, if you connect material to a wider range of contexts, any single cue (surroundings, mood, etc.) is less likely to dominate, and you have a better chance at retrieval. Another practical principle that follows from the theory of cues is the idea that you should practice using study activities that are highly similar to those used during a test—what is technically termed "transfer-appropriate processing." This principle suggests, for example, that having students learn material by writing personal journal entries is less likely to raise multiple-choice exam performance than is a test-like activity such as online practice quizzing. This is not to say that journals are poor learning activities, just that learning they produce will be difficult to measure with assessments that are very dissimilar to journal writing, such as a traditional multiple-choice exam.

Turning back to the "adaptive memory" idea, let's expand on other reasons why people remember some things and forget others. Let us assume that long-term memory capacity is a limited resource. It follows that we should be very selective about what we choose to store, limiting our choices to information that is likely to impact our future survival. Research has indeed supported that survival relevance has a substantial impact on memory (Nairne & Pandeirada 2010; Nairne, Thompson, & Pandeirada 2007), as if we were retaining cognitive vestiges of our hunter-gatherer past (Nairne, Pandeirada, Gregory, & Van Arsdall 2009).

If survival relevance is a guiding principle to memory, we need mechanisms to help us quickly determine what is relevant to survival. Here are what I believe to be the cues that trigger us to "tag" information as being survival-relevant. First, there is the sensory impact, termed *vividness*. Concrete information that comes accompanied by sound, visual qualities, even tactile sensation tends to be more memorable than abstract information. Visual information is particularly salient to human beings, so that anything that can be visualized tends to be particularly memorable.

Emotional impact is another cue that incoming information warrants long-term storage. Consider situations that relate to survival in a "natural" setting—a sudden danger, a new food source, encountering an enemy—and all would come accompanied with an emotional "charge." Relevance to one's own personal history is another indication that information will be useful in the future. Similarly, structure and meaning—the ability to interpret information and put it into context—helps us distinguish useless background clutter from information that we need to keep.

Lastly, there is personal participation, as contrasted with passive exposure. This will come as no surprise to those familiar with the "active learning" trend. If we watch someone else do something, that activity may or may not be relevant to us, and it we will likely opt not to form a detailed memory of it. However, if we ourselves carry out the action, there is a greater likelihood that we will need to learn from and recall that experience later. We may also encode a richer set of cues when we are actively involved, which increases the likelihood of retrieving the information later.

The adaptive view of memory offers many ideas for promoting memory, and also provides an important caution to students and their teachers. Essentially, we are attempting to process and remember 21st-century information using a hunter-gatherer brain, so that what we "think" is important to remember is completely different from what we retain based on primitive mechanisms for determining importance. This is perhaps why we forget information like the model number of our DVD player, intricacies of our health policies, and the latest changes to journal citation style, while remembering in perfect detail movie plots, lurid news items, and gossip. The former are important in an abstract, long-range way but the latter are vivid, emotionally arousing and meaningful—and these qualities win out most of the time.

Recent Findings, Theories, and Trends to Watch

Memory research will only continue to grow over the course of an instructor's career, and few will be able to keep up with the exploding complexity of what these research projects uncover. With that in mind, I present a selection of a few key trends that will be directly relevant to college instruction.

Increased emphasis on the connection between memory and attention

The discovery in the late 1990s of the *change blindness* effect in visual perception (O'Regan, Rensink, & Clark 1999; Rensink, O'Regan, & Clark, 2000; Simons & Levin, 1997) provided a stark and surprising example of how little information is encoded in the absence of focused attention. The effect is elicited by showing alternating pictures in which some major element (e.g., a mountain peak or traffic markings) is changed across alternations, and the viewer is asked to identify the change. If attention is briefly disrupted between alternations, viewers are slow or even completely unsuccessful at detecting the change. Elements that attract focused attention—so-called "central interest" elements—are less subject to change blindness, suggesting that attentional limitations underlie the failure to encode and recall all of the elements of the picture across alternations.

Other developments from within the memory theory literature suggest further powerful linkages between attention and memory. Some theorists believe that what we have traditionally termed "short-term memory" is in fact attentional focus—i.e., that maintaining something in short-term memory is essentially the same as bringing that item into attentional focus (see Jonides et al. 2008, for a review and discussion).

New understanding of limitations on WM capacity

Tightly linked to the attentional focus theory is a major shift toward viewing working memory/short-term memory capacity as being far more limited than traditional theories suggested. Extensive studies by Nelson Cowan and colleagues (see Cowan 2010 for a review) have demonstrated that when strategy use is limited, individuals can typically retain at most four items. Even more provocatively, others have suggested that perhaps only one item can truly be the focus of attention at a time, and thus, that capacity is only one item (Jonides et al 2008). Further research will elucidate how capacity should be defined and what capacity limits typically are, but clearly the downward revision constitutes a major shift in thinking about memory.

New refinements in how we apply theoretical ideas of capacity limitations

Given that working memory capacity works very differently from once thought, it makes sense to update how we apply the idea of capacity limitation in the classroom. Simply presenting fewer than five "chunks" of information at a time is not enough to promote better learning and memory; instead, instructors should focus their efforts on gaining and maintaining students' attention, as well as on how they structure material being presented. There may be a certain amount of "wiggle room" in capacity depending on the precise qualities of the information being processed, such as how much and what kind of interaction it demands from the learner and how much the learner already knows about the material (see, e.g., Sweller, van Merrienboer, and Paas, 1998 for discussion of cognitive load and instructional design). Even so, the general trend has been toward looking at cognitive capacity less as a fixed number of items and more as the process of allocating highly limited processing resources across different demands.

Widespread acceptance of and increased interest in applying the testing effect

The *testing effect* is an effect whereby the mere act of taking a test on to-be-remembered material produces a powerful positive effect on memory for that material. Studies have established that this effect produces substantial gains and extends beyond the laboratory to realistic, complex academic material (see, e.g., Karpicke & Blunt 2011; Karpicke & Roediger, 2008; McDaniel, Roediger, & McDermott 2007). As research has settled earlier questions about whether the testing effect was limited in scope or produced only superficial, temporary gains in learning, more instructors will likely take advantage of this effect using techniques such as frequent, low-stakes online quizzing.

Decreased emphasis on individual learning styles, particularly perceptual learning styles

The concept of learning styles has pervaded the field of education and even popular culture. Under one version of the learning styles idea—the so-called *perceptual learning styles* theory—people vary according to whether they best absorb information that is presented visually, auditorily, or kinesthetically (i.e., physical manipulation or movement). It follows from this idea that learners will do better in learning environments that match their styles and worse in environments that mismatch their styles. Recent research has cast serious doubt on this central prediction of the perceptual learning styles theory. Pashler, McDaniels, Rohrer, and Bjork (2008) review a series of studies that fail to support and in some cases actively contradict the "meshing hypothesis"—i.e., the idea that modality of presentation interacts with individual learning style to produce better performance when style matches modality. Other researchers echo this concern, further pointing out that individuals' intuitions about their perceptual learning styles are inaccurate (Krätzig & Arbuthnott 2006). Other researchers, notably Robert Sternberg and colleagues, continue to explore and refine the learning styles idea with more emphasis on styles as a matter of personality, cognitive strengths, and general approach to processing information, as opposed to sensory modalities, but in general, the trend in cognitive research is away from an emphasis on matching learning styles to learning environments.

Conclusions: The Essential Take-Home Messages For College Teachers

Any truly evidence-based approach to college teaching must take into consideration what cognitive research tells us about human memory and related processes. That said, the intricacies of memory theory make it surprisingly difficult for anyone, particularly non-experts, to generate concrete applications based on this research. College teachers can confidently take home the following principles for practice based on what has been discussed here:

1. Short-term memory in the traditional sense—i.e., the part of the mind that allows you to rehearse something like a phone number—plays a limited role in most real-world memory tasks and should therefore not be a major concern when designing materials. The human mind has a remarkable capacity to take in information when that information is well structured, personally relevant, and rich in emotional and sensory qualities.
2. "Working memory" is more relevant to realistic learning and memory situations, not in a literal sense of being able to hold five to nine pieces of information at a time, but in the looser sense that there are limitations on how much we can pay attention to at one time. Even asking students to juggle two things simultaneously may be pushing the limits of cognitive capacity.
3. Obtaining and holding student attention is critical, as is students' willingness and ability to focus on the material at hand. Without attention, there is no memory. Varying the type and sensory modality of learning activities may be helpful, not as a way of "matching"

student-learning styles but rather as a way of promoting attention and engagement across learners in general.

4. Frequent testing is not an interruption to the learning process; rather, it is central to it. For reasons that have now been thoroughly explored from both theoretical and practical perspectives, students should engage with material frequently and in ways that require them to retrieve material from memory. The precise format and presentation of these testing opportunities is relatively unimportant; the important thing is that they are time well spent.

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