Learning and Memory Series

amplifire

101 Cognition: 7 triggers for learning

CONTENTS

Correspondence to reality is a phrase that philosophers have long used to describe the goal of humanity's quest for a description of nature. No undertaking yet devised gets closer to reality than the methods of science. Nevertheless, many people don't believe that science can contribute all that much to the important questions of existence. Questions like: What is a conscious human being? How can we be capable of speaking, thinking, loving, hating, and of creating the extraordinary and beautiful works of civilization. How can we then go to war and destroy the same? What is the source of the myriad drives and contradictions that exist in human society and within its building blocks—the individuals that organize it? Science, not philosophy, is now making progress towards answering those kinds of questions.

Before we turn to learning and memory, let's first consider the larger notion of individual self-hood within the realms of psychology and neuroscience. After all, the self is formed through a combination of genetics, experience, and memory. Therefore, a framework on which to hang ideas about the most effective ways to learn is necessary before we can truly understand how learning takes place.

To that end, an idea with an ancient pedigree is returning to center stage and proclaiming a way forward. It is the idea that three components of self form a canvas large enough to paint a complete portrait of any and every individual. While a true likeness of any self will contain millions of daubs of paint and trillions of possible color combinations, we can conceive three areas of canvas that will hold the material—three psychological domains that are capable of making sense of such a grandiose claim. They are cognition, emotion, and motivation. These three pillars of selfhood fully describe who we are psychologically and what we have learned through the patterns of neurons that form the physical circuitry of the brain.

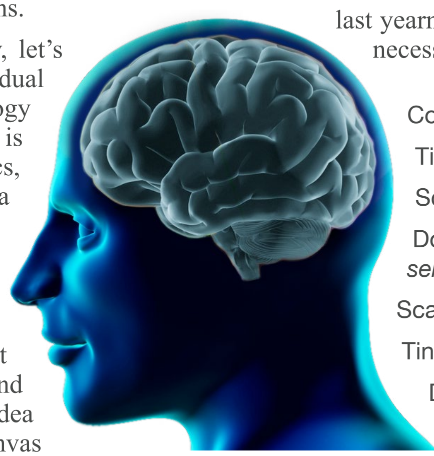
The Tripartite Self

The first conception of a three-part self was crafted long ago. In 380 BCE, Plato (speaking through Socrates) is credited with first thinking up the notion that the complexity of human individuality can be fully described in three domains. In Plato's best known work, *The Republic*, Socrates discusses the nature of the soul as composed of three integrated parts:

> *"The one with which a man reasons we call the rational principle of the soul, the other, with which he loves and hungers and thirsts and feels the fluttering of any other desire, may be termed the irrational or appetitive soul....And what of passion or spirit?... You remember that passion or spirit appeared at first sight to be a kind of desire, but now we should say quite the contrary, for in the conflict of the soul spirit is arrayed on the side of the rational principle."*
> *—Plato, The Republic, Book IV*

In Plato's view, the rational soul uses *thinking (cognition)* to determine the truth of propositions and to make proper decisions that might lead to a fulfilling life. His appetitive soul counterbalances the rationality of thought. It is swayed by *emotion* and feelings that lustfully chase power, sex, and status. Finally, Plato's spirited soul *motivates* people to carry out the will of the rational side. It puts thinking into action.

More than two thousand years later, Frank Baum animated Plato's tripartite soul through his three immortal characters in *The Wizard of Oz*; the Scarecrow, the Tin Woodsman, and the Cowardly Lion. One desires a brain to become a better thinker, imbued with rational thought. One desires a heart so he can feel the emotions that he observes in others. The last yearns for courage— a proxy for the motivation necessary to accomplish great things.



Cowardly Lion: *I'd be brave as a blizzard...*
Tin Woodsman: *I'd be gentle as a lizard...*
Scarecrow: *I'd be clever as a gizzard...*
Dorothy: *If the Wizard is a wizard who will serve.*
Scarecrow: *Then I'm sure to get a brain...*
Tin Woodsman: *A heart...*
Dorothy: *A home...*
Cowardly Lion: *The nerve!*

A modern trilogy

In the 21st century, perhaps no scientist or thinker has done more to extend Plato's tripartite soul into detailed descriptions of brain processes than the neuroscientist, Joseph LeDoux.

> *"The cognitive revolution brought the mind back to psychology, but thinking and related cognitive processes were emphasized (and for the most part still are) at the expense of emotion and motivation. Thinking cannot be fully comprehended if emotions and motivations are ignored."*
> *—Joseph LeDoux, The Synaptic Self*

This is the full three-part package of mental functions that give us our personalities and allows us to change over time through experience and learning. It has been lost to psychology for over 2,000 years. Within each of these three pillars of selfhood, lie triggers that switch on learning and memory formation. In this paper, we'll begin by examining the cognitive function—what many researchers (rightly or wrongly) consider the source of self. With that in hand, we can then take a look at the emotional and motivational components that play an enormous role in our marvelous ability to learn and remember information.

In brief, here's how this modern trilogy can be conceived:

- Cognition (thinking) allows us to focus on information and circumstances so that we can then decide among possible courses of action. Cognition creates and draws upon forms of memory that operate in the present moment and on forms that are stored away in conscious and unconscious brain regions.
- Emotion assigns value to our internal perceptions of external reality and influences our thinking far more than most people realize.
- Motivation concerns how we order the drives, goals, and incentives that propel us to engage in one activity while vigorously avoiding another.

Cognition (thinking)

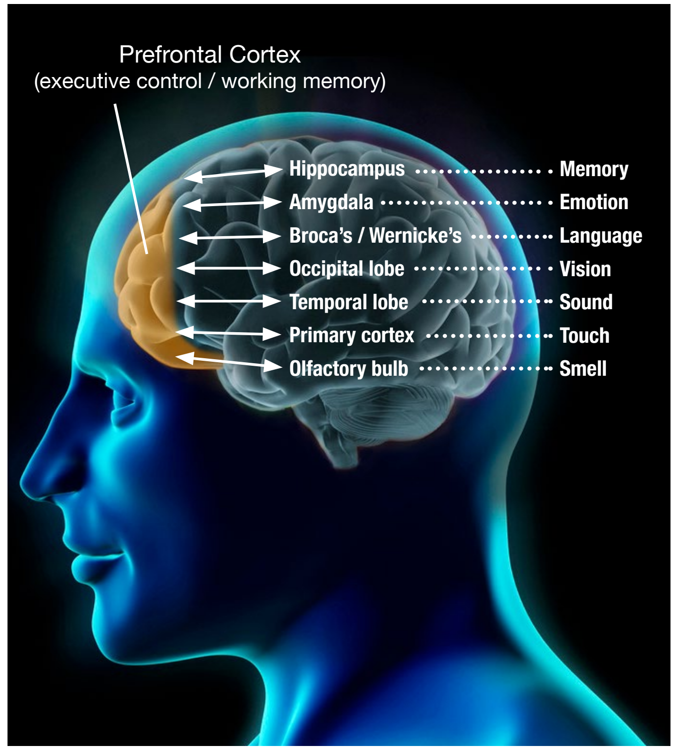
The thinking processes of our mental life take place in a highly distributed manner using multiple circuits, each with a dedicated set of tasks. We'll first discuss the circuits most involved in cognitive processes and the structure of information in the brain. We'll then turn to considering 7 ways that information storage and retrieval can be enhanced—how learning can be improved.

The location of "you"

Our experience of the moment is taking place within the domain of "working memory." Working memory is the brain's extraordinary capacity that let's you keep many aspects of reality in mind as it unfolds in space and time. Human beings can juggle the sensory inputs of sight, sound, smell, and touch while simultaneously integrating this massive stream of incoming information with content retrieved from long-term memory. Working memory gives us the ability to chew gum and walk down the street while listening to the radio, greeting friends by name, and thinking about what to buy for dinner at the store and how to get there. Furthermore, it allows people to hold multiple concepts in mind while learning difficult material, like, say, the storage capabilities of the hippocampus or the geography of Central America.

For decades, it has been known that the frontal lobes are the site of working memory. The two lobes occupy about 1/3 the total volume of the brain. All mammals have frontal lobes, but they mostly use this brain region for motor control. The very front portion of the frontal lobes, aptly called the prefrontal cortex (PFC), is a newly evolved structure that most researchers believe is found only in primates.

Indeed, we are primates and it's now well understood that the PFC is the seat of working memory and other important human capabilities. It is not much of an exaggeration to say that, literally, you are your working memory. It's the source of the moment to moment experience that gives rise to the feeling that you consciously exist in time and space and in relation to other people and objects in your environment.



The Prefrontal Cortex as the ultimate convergence zone

Convergence zone

Neuroscientists consider the prefrontal cortex the region that performs the *binding function*—the vital process that integrates many kinds of information, located in distant parts of the brain, together in one place for consideration. With that "integrated information" the PFC performs decision making, social interaction, voluntary movement, and it resolves conflicts among simultaneous stimuli. As can be seen in the illustration above, it is the PFC that pulls together information streaming in from visual, auditory, and language centers. It then combines that real-time, happening-now kind of experience with long-term memory stored in the hippocampus and with emotion stored in the amygdala and other regions. The coherent firing of its populations of neurons is what gives working memory its abilities to cogitate on many streams of simultaneous information flow. In this way it can gather up facts, places, faces, emotions, and knowledge for integration into current experience. It can then execute motor control (it's sitting right next to motor cortex) so that decisions can be turned into action and speech.

Another superbly interesting aspect of the PFC is that the connections within and between its cortical layers far outnumber its connections with other regions. This massive internal cross-wiring is what allows the PFC to bring in signals from outside and then maintain a level of *neural excitation* within itself. This self-excitation is the space in which we consciously experience the world and where the cognitive component of learning and memory arises.

Executive control

Although the PFC is a convergence zone for all types of information, it also sends instructions back to the regions that inform it. The PFC is like a general receiving information from his commanders in the field. He thinks about their advice and then sends orders back to them for implementation. This flow of information from the PFC to lower regions is called top-down executive control. You can readily experience top-down control yourself through a powerful little experiment called the Stroop task. The task shows words that represent a color. In some cases the word and its color agree. Sometimes, the word and its color conflict. You are asked to name the color of the word. For normal people, when a word and its color conflict, a weirdly disconcerting feeling is produced and it takes longer to correctly arrive at a resolution. Nevertheless, they invariably get it right. Try it.

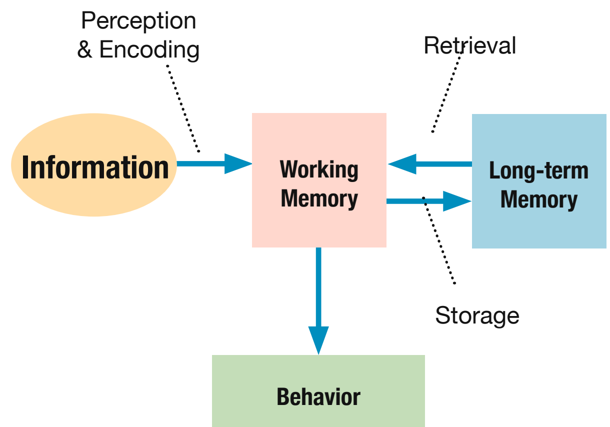
The Stroop Task

So, what's going on here? When you read the word **red** you automatically think of the color red. This is bottom up processing at work and it does not require working memory. It happens naturally and effortlessly based on long-term memory of the word and alignment with its meaning. On the other hand, when you see the word **red**, it takes executive top-down control to override the signals coming up from regions lower down in the sensory hierarchy. You are forced to pay attention and resolve the conflict.

People with damage to their PFC do very poorly on this task. They can't resolve the conflict because they have little ability to control the information flowing up from lower regions. The general can no longer command his soldiers in the field. Without the executive capabilities of the PFC, overriding the natural association between a word and its color is impossible.

Semantic memory

Semantic memory involves facts and ideas about the world. It must first be encoded in working memory before it can be stored in long-term memory. When a learner perceives information, whether it's through a book, a lecture, or a conversation with a friend, the information enters working memory and it associates with information already stored in long-term memory.



Information flow in working memory—perception, storage, retrieval

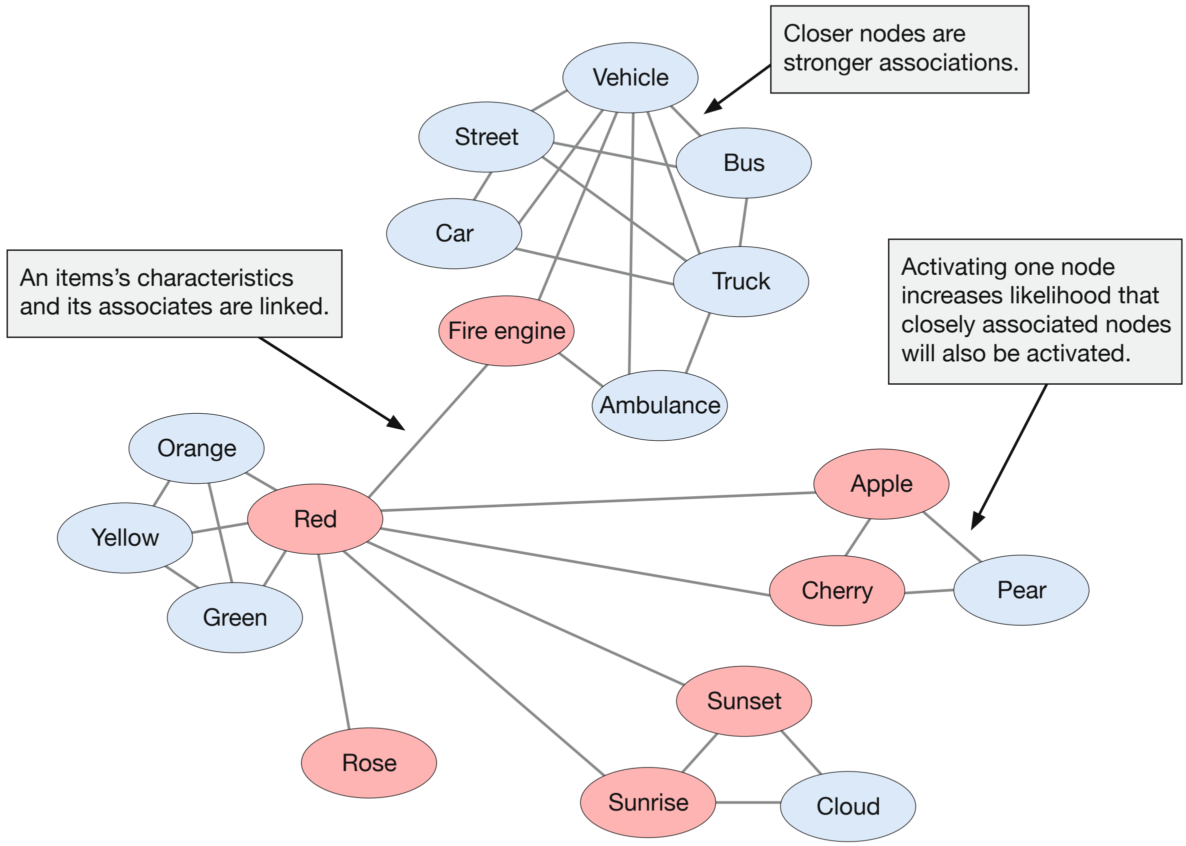
The contents of long-term memory contain units of information at various scales. Some units are low level, containing minimal amounts of meaning—a line, a shape, a color, a word. Other units are grand schemas and structural hierarchies that describe how the world is ordered. This kind of stored information exists as patterns of neural connections that have formed through experience. New learning must be integrated with the pre-existing patterns to form strong memory traces that can be retrieved later in a test, on the job, or in conversation.

The structure of stored information

We can now picture how working memory integrates the information entering the brain in the present moment. And we can understand that it both sends information into long-term memory storage and retrieves information from LTM. But how is that information actually organized? Is there some kind of structure that is optimal for long-term memory?

The network model, as proposed by Loftus et al, shows that information in memory is stored as a network of highly associated units of information called nodes. Each node represents some aspect of a thing or idea. Items in the world have many distinguishing characteristics that identify it as one thing and not another. They have size, color, shape, motion and so on. The hundreds (or thousands) of details about an object are stored as nodes that are brought together in the mind and integrated into the thing itself.

Imagine an object that is hurtling down a highway, with men hanging off the back, and accompanied by a loud siren. It is probably a fire engine. The information about fire engines is perceived, stored, and recalled by the brain as a hierarchy of detailed characteristics. These characteristics are the units of storage—the nodes in the hierarchy. It's a vehicle, its red, it uses a loud siren, its driven by men in heavy jackets. The details of a fire engine are all stored separately but the entire



The semantic hierarchy—nodes of information combine to form memory of an object.

package is an invariant representation of the archetypal fire engine. The illustration above shows a highly simplified model for how the information about a fire engine is stored and associated with other characteristics and similar objects. Each node has meaning and it's the assemblage of associated nodes that results in the meaning of fire engine.

Importantly, the activation of one node of information will also activate other nodes that are closely associated. Those nodes strengthen with activation because neurons that fire together, wire together. In this way, information is cemented into memory with the arrival of associated information. and learning occurs.

Knowledge

This design has critical implications. First, it tells us that knowledge is built upon smaller units of information that are later assembled into larger entities. Abstract mental constructions (schemas) are built over a lifetime. If you understand, say, the theory of evolution, you'll notice that it's constructed from three core ideas (nodes) that are associated in the mind into an elegant explanation for the origin of living forms. The three concepts are variation, selection, and inheritance. And, of course, your ideas about inheritance or selection (if you have them) are built upon a vast underlying network that begins at low levels with your ability to make sense of letters and words. Learning through reading combines with other networks that associate time spent on your uncle's farm or a trip to the Galapagos. In this way, knowledge is massively associated with itself when it's encoded into the neural patterns of long-term memory.

Furthermore, we can begin to appreciate the critical nature of the lower level building blocks that comprise schemas. If they are in error, the larger concepts constructed from them will also be mistaken. This is misinformation, a situation where the associations are strong but some fraction of the underlying information nodes are not true.

Cognitive triggers that switch on learning

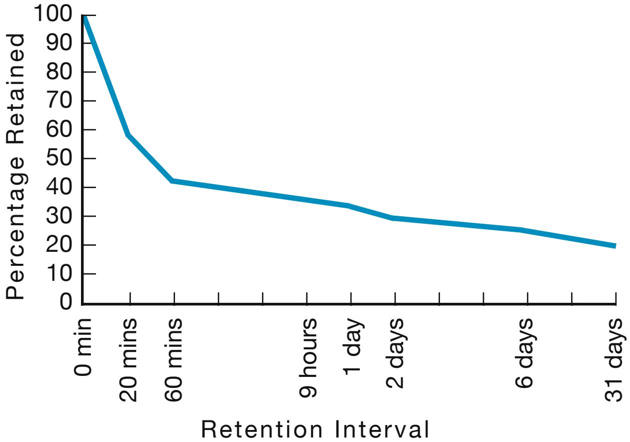
amplifire was designed with the intent of activating certain cognitive triggers that turn on learning and memory. The triggers were derived from decades of experiment and observation. They are incorporated into proprietary algorithms within the amplifire platform. This paper will describe the neuro-psychological triggers that support learning and memory within one part of the mental trilogy—the cognitive domain. They are:

- Repetition—the rehearsal process that is one of the most effective ways to create long term memory.
- Elaboration—information associated with meaning forms far stronger and more easily retrieved memory.
- Retrieval—when memory is actively retrieved, it is strengthened.
- Priming—when knowledge is assessed before exposure to learning materials, memory is fortified.
- Context—the study environment affects the testing outcome.
- Feedback—timely information, especially in the face of error, augments memory formation.
- Spacing—the timing between re-study and testing is crucial.

Repetition

In the 19th century, Ebbinghaus demonstrated that a first pass at learning creates a memory trace which is vulnerable to rapid forgetting. He discovered that memory improves through repetition that flattens out the forgetting curve.

> *"That which is learned with difficulty is better retained... it would be safe to prophesy such an effect from the greater number of repetitions."*
> *—Hermann Ebbinghaus, 1870*



Ebbinghaus' Forgetting Curve

From the cognitive viewpoint, the psychologist Donald Hebb postulated in the 1950s the underpinnings of repetition's effect on memory formation by showing how it strengthens the synaptic connections between neurons. He pointed out that "neurons that fire together, wire together." Material that is repeatedly brought into working memory in the prefrontal cortex is sent to the hippocampus for storage. Each repetition strengthens the pattern of neurons in the hippocampus that represents the information—the name of the first Spanish explorer in the New World, or the orientation of the Panama Canal. Psychologists have a formal name for this method for storing memory—*maintenance rehearsal.* As we shall see, there are other forms of mental rehearsal that have equal and even greater ability to strengthen memory.

Elaboration

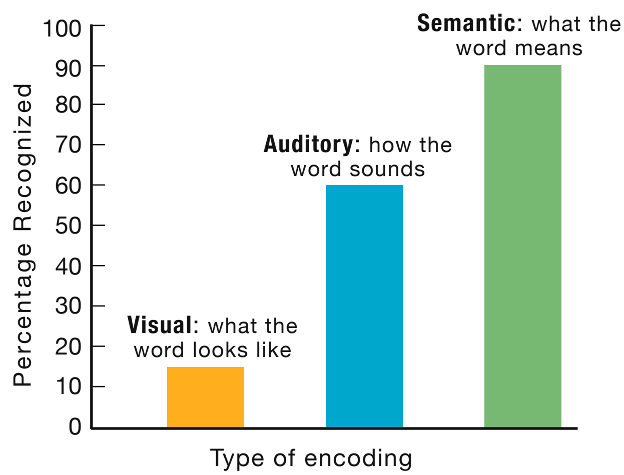
> *"The one who thinks over his experiences most, and weaves them into systematic relations with each other will be the one with the best memory... All improvements of the memory lies in the line of elaborating the associates."*
> *—William James, 1890*

The great American psychologist, William James is describing the cognitive process formally known as elaborative rehearsal. Research studies demonstrate elaboration's power over memory. In one such study, people easily remembered words that had the attributes of *living or non-living* while quickly forgetting words that were merely *capitalized*.

Imagine a zebra. Working memory and its thinking capabilities activate associated nodes with the meaning of the word—stripes, Africa, prey, horses, grasslands and so on. The lettercase of the word ZEBRA does not require that kind of contemplation. Elaboration is an exchange between working memory and long-term memory. Working memory retrieves related nodes of information from various storage locations throughout the brain and temporarily manifests them in the work space of the prefrontal cortex. The elaborative process strengthens the existing network of associated patterns that give *meaning* to the word zebra. It results in Hebbian learning—the memory trace of the item being considered strengthens as previously existing synapses are organically fortified.

Elaboration has an especially powerful effect on the nodes of information that are closest to one another (in a pattern of connected neurons). We saw this when considering the meaning of a fire engine and its myriad associations; some close, others distant—red, siren, vehicle, rose, sunset, apple.

Below, we can see precisely the kind of power that elaboration holds over our ability to form memory that sticks. When people are asked about visual and auditory traits, those turn out to be poor substitutes for conceptual meaning if the goal is learning and memory.



The effect of meaning on long-term memory

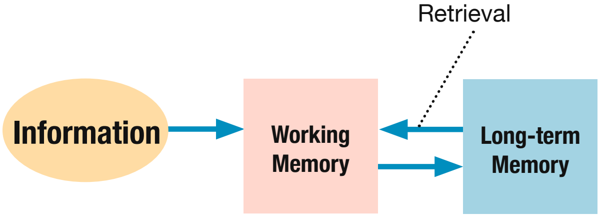
Using the processes built into ***amplifire***, learners are guided to associated chunks of knowledge by varied pathways that require the mind to elaborate the information. The original memory trace encodes into storage with far greater strength than it would by just reading a book or listening to a lecture. Those classic methods for creating memory are important, but not enough, in themselves, to create exceptional memory and long-lasting learning.

> *"When we specifically wish to remember, when*

learning is intentional rather than incidental, we can increase the likelihood of having a strong and long-lasting memory by bringing elaborative encoding processes to the learning task."
—Kandel-Squire , Memory-from Mind to Molecule

Retrieval

Perhaps the most powerful technique for durably memory was experimentally demonstrated in 2008 by Roediger and Karpicke—the testing effect. Recall first, that retrieval is one of the components of working memory and the process of thinking. A memory is encoded, stored, and later retrieved. It turns out that the act of retrieving a memory profoundly affects encoding, storage, and it's own later retrieval—a virtuous cycle of learning that ***amplifire*** puts to good use.



Working memory retrieves information stored in LTM

Roediger and Karpicke found a correlation between testing and memory that was nothing short of astonishing. Students were given a passage containing scientific words and concepts and asked to memorize the general information in one of three ways:

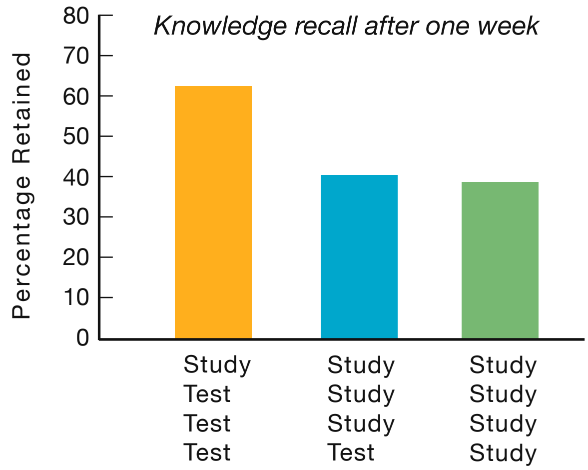
1) Study: The passage was read four times.

2) Single test: The passage was read three times and memory was tested once.

3) Repeated test: The passage was read just once and memory was tested on three occasions.

All three methods proved effective when the final test of memory was performed five minutes after completion. The repeated study method was the winner with 82% retention while the repeated test method came in last with 70% retention.

But, the roles were radically reversed when memory was tested again one week later—much closer to the real time-frame of student learning and high-stakes testing. The repeated test method was far more effective at 62% retention while the repeated study method came in at 39%.



These results, termed the "testing effect" are simply astonishing, and more so because many education professionals working today would be utterly certain that reading a passage four times would outperform mere testing.

Priming

In the classic definition of perceptual priming, very brief exposure to a stimulus, like a list of words, has an effect on later recall even though the subject has no conscious awareness of the stimulus. If a subject briefly sees the word 'table,' when later asked to write down words beginning with 'tab,' they are far more likely to think of the word table, but don't know why.

In 2010, experiments revealed a dramatic priming-like effect that further magnifies the importance of testing. Psychologists discovered that pre-testing prior to study primes the mind for the information in dramatic fashion.

Before studying the material, one group of students was pre-tested on a complicated passage involving the biology of vision. Since the material was unknown to them, they had to guess at the answers. Another group of students learned the material in the normal manner—they studied extensively. When recall was tested three days later, the students who had pre-tested outperformed the students who had studied extensively.

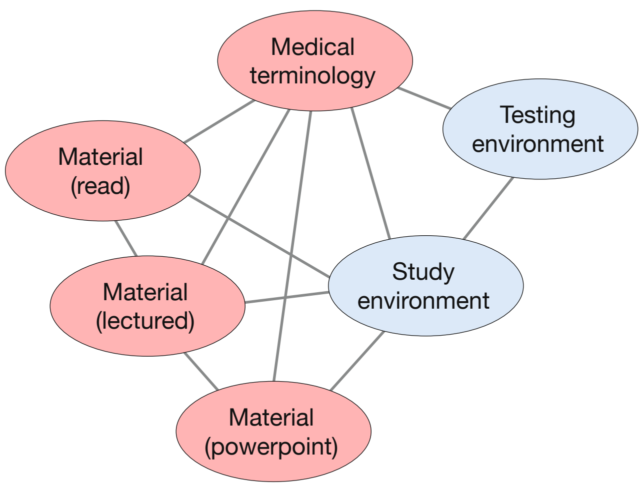
"Pupils actually learn better if conditions are arranged so that they have to make errors. Specifically, people remember things better and longer if they are given tests so challenging that they are bound to fail. This phenomenon has obvious applications for education."
—Roediger and Finn, reporting in Scientific American Mind, 2010 on a study by Richland, Kornell, and Kao

Indeed, as Roediger implies, these findings have major consequences if the goal of students, parents, and society is to successfully transfer knowledge into the mind.

Context

Everyone experiences moments when a cue in the environment stimulates the retrieval of a related memory. The smell of pine trees conjures up images of summer camp thirty years ago. Cues in the present call forth related experiences from the past. We know how this works because we have seen that memory is a network of associated nodes of information. The experience being encoded in working memory (e.g, a song or smell) activates and retrieves an associated node stored in long-term memory. This kind of memory activation is called *context dependent memory.*

Unexpectedly, context is very important when a student is learning material that will later be tested. In one experiment designed by Smith, Bjork, et al, subjects in either of two rooms were given 80 words to study and remember. The rooms differed in location, color, size, and smell. Subjects who were later tested in the same room could remember 49 words on average. Subjects tested in the different room remembered just 35 words. Context could improve memory by 40%.



Context dependent memory—study conditions influence testing.

The explanation for the context effect lies in the networked structure of stored information. When a student studies the definitions of medical terms, the associated information nodes contain not only words, pronunciation, meaning, and usage, they also hold information related to the environment in which they were studied.

Feedback

The Darwinian point of view suggests that organisms that are better at applying learning towards life-sustaining activities and avoiding life-threatening situations will be more successful over time.

In this light, Dr. James Bruno, one of the inventors of ***amplifire***, set about to create a learning protocol which uses a very tightly constructed feedback loop so that learners can confidently commit correct knowledge to long-term memory. Just like the creatures that use information to their advantage, this allows learners to learn deeply from experience.

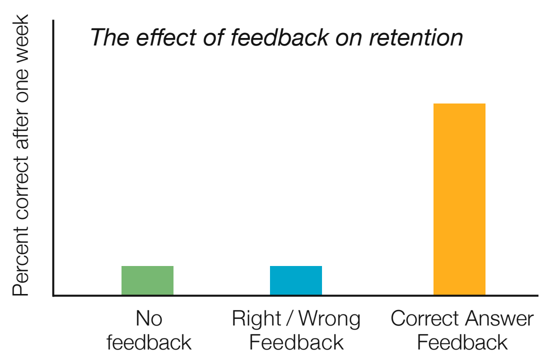
> *"Just as medical testing provides detailed feedback to the patient and the hospital and is used to monitor health and to suggest strategies for improving health. Likewise, educational testing should monitor learning and create appropriate intervention to enhance student performance." —James Bruno, UCLA*

Recent experiments have continued to validate Dr. Bruno's original idea. In a paper entitled "The Effect of Feedback on Long Term Recall," Pashler, et al demonstrated the profoundly positive effect that timely feedback has on retention. Feedback was the only variable in their experiment.

A few hundred test subjects were asked to learn new words from the Lugandan language. Lugandan was chosen because the subjects would have no previous knowledge of the words or their meaning. Teaching was deliberately incomplete so that some errors would surely creep into memory and show up in the test results.

The subjects were taught the new words, and were then immediately tested on their recall (Test 1). Some received feedback in the form of the correct answer. Others received simple feedback as to whether the answer was "correct" or "incorrect". Yet others received no feedback at all. Subjects were then tested again one week later to see what effect feedback would have on long term memory (Test 2).

The results were breathtaking. As shown below, subjects who answered the question incorrectly, but then received the correct answer as feedback retained almost 500% more information than students who were either presented the words "Correct" or "Incorrect", or received no feedback.

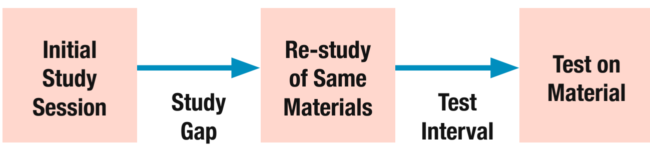


Similarly extraordinary results from the same researchers have now been demonstrated across a variety of subjects.

Spacing

Numerous experiments have demonstrated that long-term memory is greatly enhanced by distributing the learning sessions over time. In psychology this is called either distributed practice or the spacing effect, and it was first noticed by none other than Ebbinghaus in the 1880's.

The spacing effect shows that "cramming" information in one massed setting is about the worst of all possible ways to learn anything for the long term. Studies show that an optimal timing period exists between study sessions but that it greatly depends on the interval until the test. Here's how a spacing experiment sets up the gap between two study sessions and the interval before the test.



The structure of a spacing experiment (Pashler, et al.)

In a recent experiment of this design conducted by Pashler, Rohrer, et al, the results showed that, in general, the effect of spacing on memory is significant. The research reveals that the optimal study gap to test interval is 10% to 20%. That breaks down in the following practical manner:

If the time to the test is 1 week, the optimal study gap between initial study and re-study is 1 day.

If the time to the test is 1 year, the optimal study gap is 3 weeks.

One thing has become very clear from this research—when restudy takes place too closely following the initial study session, there is little effect on memory. As the researchers have noted, an astonishing 300% gain in memory can be achieved if the proper study gap to test interval is utilized.

> *"The benefits of spacing seem to grow ever larger as retention intervals are lengthened; thus, for one-year retention, a one-month spacing produces a three-fold or greater increase in memory as compared to a day or even a week of spacing."*
> *—Pashler, et al, Spacing Effects in Learning, 2008*

Concluding Thoughts

We have seen that the nearly infinite psychological complexity of a human being can be simplified into three domains of the tripartite self. Cognition, emotion, and motivation are the components of this mental trilogy. In this paper we have concentrated on the cognitive, the thinking part of the mind, and illustrated a variety of triggers that interact with working memory and long-term memory storage and retrieval.

amplifire creates a learning environment where a student's working memory, the seat of cognition, is exposed to repetition, elaboration, retrieval, priming, context awareness, and feedback. These five cognitive triggers work together to symbiotically boost their respective abilities and strengthen encoding and storage processes. Learning is quicker and memory is better.

Next up

Next, we'll turn to the power that emotion holds over, not only our day-to-day lives, but in determining what is memorable and what is not. The implications for education are critical. Emotion is the way that an organism with a nervous system applies value to incoming information. If it is deemed valuable, it is encoded, stored, and it can be remembered. On the other side of the equation, darker emotions can unleash compounds that interrupt the brain's ability to store information.

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