How To Improve Memory

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Abstract

Memory is important in learning and is built over time and practice. Not all memory strategies are built equally. Recent evidence in both neurological and practical settings suggests that specific strategies can increase memory performance. Compared to traditional block studying, strategies such as the testing effect, spacing effect, interleaving, chunking, and the method of loci significantly improve the efficiency of encoding new memories.

Our abilities to handle novel situations and utilize critical thinking depends heavily on our ever-expanding memory. While activities like problem solving and learning require persistence and effort, studies suggest there are ways to optimize our time and increase our efficiency to remember new things. Since the late 1800's, research has been uncovering how our memory works. Psychological theories on memory paved the road for our understanding of memory, and many classrooms conducted applied research to test the efficacy of different learning techniques. Recently, neurological studies on memory are also corroborating the evidence seen in older psychological studies.

A prominent method for learning is the testing effect, which indicates that practicing knowledge with test-based questions improves learning significantly. While exams may serve as a gauge for people's knowledge in the classroom, researchers have begun to realize their potential as an effective and robust learning method. The testing effect is seen through improved long-term memory, when the memory is retrieved during studying. Studies have shown that short answer questions enhance long-term memory the best, while other testing methods like multiple choice questions or simple recall were not as effective (McDaniel et al., 2007). Methods like repeated studying and rereading proved less valuable than just one intermittent test (Carpenter, 2009).

Recent neurological studies show increased activity in the brain from the testing effect, more so than other studying methods. For example, in learning Dutch-Swahili translations through the testing effect, participants' left inferior parietal and left middle temporal lobes activated in fMRI (van den Broek et al., 2013). The same activity was not seen in traditional studying strategies, like repeating the lesson (van den Broek et al., 2013). In another study, for learning associations between nouns, the testing effect activated hippocampal regions, the prefrontal cortex, and the posterior cingulate cortex, which are brain regions involved in memory retrieval cues (Wing, 2013). On the other hand, these brain regions were much less active in the restudy condition, suggesting that the testing effect is more effective at utilizing brain resources to encode memory (Wing, 2013).

The testing effect proved robust in many different kinds of examinations and different subjects (Agarwal et al., 2008). Even tests that are quite different from the actual examination proved beneficial for memory (Carpenter, 2009). Evidence leads many experts to believe that the testing effect can improve learning and problem solving in addition to memory. When it comes to learning and memorizing new things, a simple test or two can be very helpful. The important implication is that even a bad testing session is more effective than rereading notes or textbooks.

While tests may substantially improve memory, it is not necessary to overload oneself with large exams. Researchers would most likely suggest the opposite, that by spacing material into reasonable learning sessions we can achieve a higher retention for the particular subject. This idea was first proposed by Hermann Ebbinghaus, who suggested that memory follows a forgetting curve, when information fades from memory over time. This loss of retention is best counteracted by learning and reviewing during separate occasions, rather than learning in only one sitting (Ebbinghaus, 1913). This strategy for maximum retention became known as the spacing effect. It is the relationship between memory acquisition and the spacing of time to review the material. When studying is spaced out, information tends to encode better in long term memory. In other words, memory is improved significantly with the help of spacing.

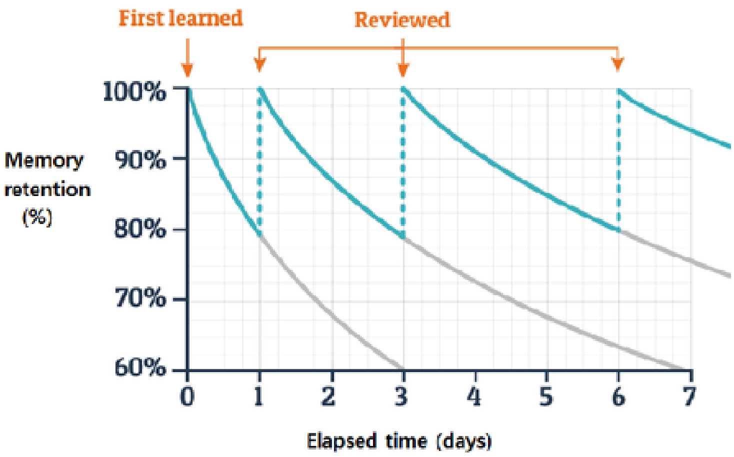

Figure 1. A schematic of the forgetting curve. The curve gradually lengthens with each review session, representing better retention with each review (Chung & Heo, 2018).

Spacing has seen success in a variety of practical situations, especially the classroom setting. For example, in a study conducted on 5th graders, students were required to learn difficult English vocabulary in one of two strategies: one taught in mass study (everything at once) while the other re-taught (spaced repetition) after a 7-day gap (Sobel & Kapler, 2010). The students performed equally well after the first session of learning, but 5 weeks after the last learning session, those with spaced repetition performed significantly better (Sobel & Kapler, 2010). Another example was seen in a study with children who were tasked to remember certain toys.

Children who were allowed to play in between learning each toy were able to memorize the toys at a significantly better rate compared to children who learned the toys all at once (Vlach et al., 2008). Despite greater distraction for children playing between each learning session, their brains were able to consolidate information better (Vlach et al., 2008).

Recently, neurologists have studied memory, like the forgetting curve and the spacing effect, in the brains of animals. The hippocampus appears to be crucial in retaining memory. In one experiment (Snyder et al., 2005), rats were tested on a water maze. They were required to learn and memorize the location of a platform in the maze. Rats were also injected with 5-bromo-2-deoxyuridine (BrdU), which labels newly synthesized cells. Compared to normal rats, those with their hippocampus damaged through irradiation performed significantly worse in the water maze only after a few weeks, and showed decreases in BrdU in neurons, meaning less formation of new neurons (Snyder et al., 2005). It is hypothesized that new neurons in the hippocampus were not necessary for learning, since mice with a damaged hippocampus performed equally well with normal rats (Snyder et al., 2005). However, new neurons are necessary for retention of memory, as seen by a drastic forgetting curve without them. A second experiment was conducted, where two groups of rats either learned a water maze in either a single mass session (all at once) or with spacing. The rats with spaced learning performed significantly better than those without, and spaced repetition were correlated with more BrdU labeled cells in the hippocampus, suggesting neurological changes due to the spacing effect (Sisti et al., 2007). Overall, these studies point to the impact of the spacing effect on the preservation of new neurons, which in turn helps retain more information.

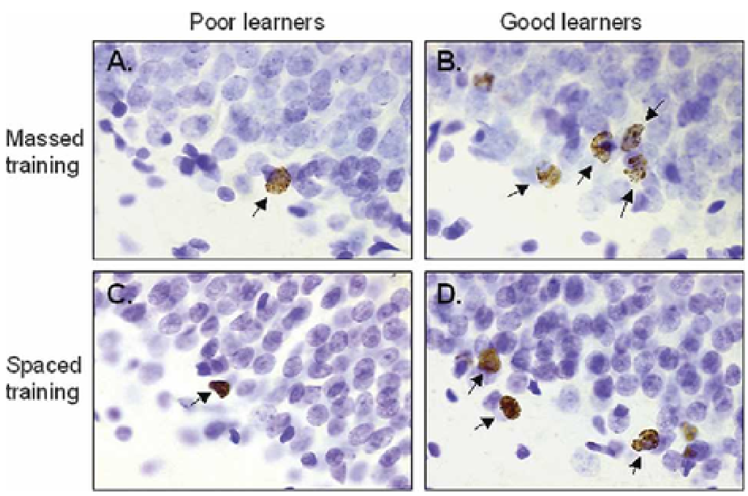

Figure 2. Learning correlated with BrdU-labeled cells (Sisti et al., 2007).

In recent years, it is found that even the spacing effect can be further improved upon in strategies that make learning and memory consolidation more efficient. A similar but relatively new approach of learning is interleaving, or mixing subjects together while learning. For example, one can learn both math and English concepts in the same hour, alternating between the two subjects every couple of minutes. Many interleaving techniques inevitably introduce spacing effects. Concepts from one subject are separated in time in order to sandwich concepts from a different subject. However, even while controlling for spacing, studies suggest that interleaving promotes stronger associations with similar concepts and stronger differentiation between different concepts (Kange & Pashler, 2011). Basically, interleaving helps improve and sharpen memory.

In one study, subjects were tasked to learn and identify paintings by the artists. One group was shown 6 paintings of each painter all at once. A second group had mixed the orders of paintings. Both groups were then administered distractor tasks to perform. When tested for the paintings later, the mixed group performed significantly better at identifying painters (Kornell & Bjork, 2008). Another study followed up with a similar setup. This time, the two groups were tested with no mixed order, but the spacing of time between each painter and painting pair was changed. This resulted in no significant difference in performance. In the same study, another setup included mixed orders, which were shown either simultaneously or spaced with time. Again, the two groups performed equally well and also out-performed the previous two groups (Kang & Pashler, 2011). Based on these findings, it appears the spacing effect was not responsible for improving in associations. Rather, interleaving is responsible for improving the ability to differentiate and associate pieces of information.

Not only does interleaving improve associations and differentiations, it has been shown to improve test performance in a practical setting. For example, in the following study (Rohrer & Taylor, 2007), interleaving improved math scores for students practicing math problems. Spacing was not controlled for (students were not doing multiple math problems at the same time), which resembles a more practical classroom setting. The students were split into three groups. One group learned and practiced math through mixed topics (interleaving). Another group practiced through blocked review, practicing one concept at a time. A third group also used a blocked review but included overlearning, meaning they completed multiple problems testing a single concept at a given time. Referred to as the masser group, they solved twice as many problems as the original block group. The interleaving group overall did the same amount of problems as the masser group but spread at intervals the same size as the original block review. When tested, the masser group performed only slightly better than the original block group. However, the interleaving group performed significantly better than both groups. This suggests that additional practice is only useful for learning if spaced and mixed.

Studies on the neurological basis of interleaving are novel. In one study, (Lin et al., 2011) participants were required to perform serial (ordering) tasks, requiring some but minimal upper body motion. In order to do so, participants must learn a specific sequence. One group learned through block training, and another through interleaving. The participants were studied under fMRI blood-oxygen-level-dependent signals (BOLD) and excitability in the primary motor cortex (M1) through transcranial magnetic stimulation. During retention (learning phase), BOLD in prefrontal and sensorimotor regions and M1 excitability were higher in the interleaving group. Initially, the interleaving group performed tasks with slower reaction time than the block training. However, after 5 days, the interleaving group experienced faster reaction times. M1 excitability was still higher, but BOLD in prefrontal regions were weaker compared to the block training group. These results suggest that interleaving produces higher activity in parts of the brain for learning, as seen by BOLD. Over time, the brain incorporates the information. This makes retrieval more efficient, requiring less activity in brain regions as seen by decreased BOLD. M1 excitability shows higher activation of relevant brain regions in completing tasks. It is plausible other areas of the brain are also easily excitable when activated through interleaving.

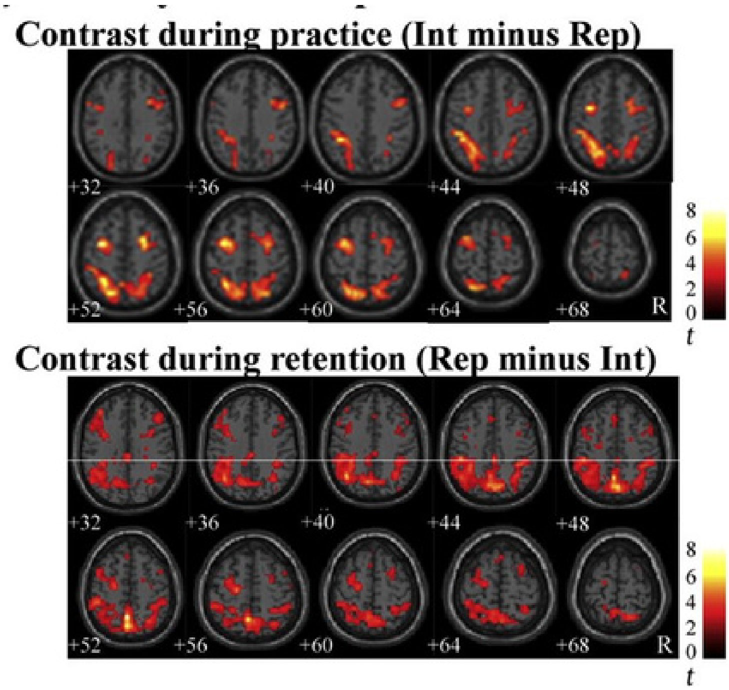

Figure 3. Increased blood flow was higher during practice in individuals with interleaving (top image, bottom row). During the retention phase, interleaving showed less blood flow activity compared to the control (bottom image, bottom row). Presumed that interleaving is more efficient, requiring less effort during retention (Lin et al. 2011).

The incorporation of ideas and information into long term memory is incredibly important. To effectively use one's memory, one must also be able to retrieve information and use it. Much of that brain power relies on working memory, which is closely tied to short term memory. Additionally, any new pieces of information must first go through the short term memory before it can be stored in the long term memory.

The working memory allows the brain to act on or even modify information. For example, the brain can imagine breaking a chair without one actually breaking the chair in real life. Short-term memory cannot incorporate an infinite amount of information at the same time, however. In a very famous historical paper, George Miller estimates the limit to be 7±2 pieces of information (Miller 1956). However, the limit is actually not definite. Some pieces of information, known as chunks, contain multiple pieces of information together as one group. The chunk does not yet have a rigorous definition in the scientific community, but it is thought to be a group of information that the brain handles as one entity. In other words, a single chunk will consist of many pieces of information while taking less space in working memory. However, chunks do not completely bypass Miller's estimate. Further studies have shown the capacity of the brain to handle up to 4±1 chunks (Crowan, 2010), which is clearly less than Miller's original estimate. Because chunks themselves contain more information, each chunk takes up more space in working memory than a single item.

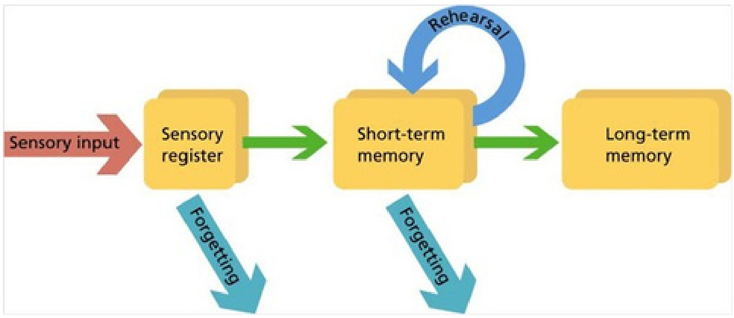

Figure 4. Basic schematic of encoding and retaining memory (Esteve 2016)

In a recent study conducted, participants were required to memorize a sequence of numbers. Depending on how many numbers were contained in each chunk, the maximum chunks the brain can handle varied. When chunks were only one number each, the limit was about 7. When chunks became very long, around 5 numbers each, the brain could only handle about 3-4 chunks (Mathy & Feldman, 2012). This corroborates the idea that the brain has a capacity for working memory, even when chunking. Despite this, chunking still helps carry more information in working memory than individual pieces of information alone.

The ability to use chunking effectively improves memory usage and memory consolidation dramatically. For example, studies conducted show that chess players rely on chunking entire movesets in a given board, like helping players remember where individual pieces are on a board, given only a few seconds to see the board (Linhares & Brum, 2007). It is also shown that pattern recognition in games like chess correlates with skill (Linhares & Brum, 2007).

Some neurological insights into chunking have corroborated with previous studies on its efficacy. For example, in one study (Bor et al., 2003), participants were required to memorize spatial patterns. One group had a disruption in learning at a random point in time. Another had a disruption specifically in between two different sets of information, establishing meaningful chunks in the participants' memory. The second group performed much better, and in fMRI brain scans, their prefrontal cortex was also lit up more (Bor et al., 2003). Chunking produces higher activity in brain regions important for processing information, chunking and improving short term memory. Ultimately, with chunking, higher activity allows for better consolidation of information.

While most memory and learning techniques were developed recently, there are some ancient techniques still used today, like the method of loci. Also known as the "memory palace," people would imagine putting pieces of information in each "room" of a building they are familiar with. Retrieval of memory simply requires finding the right "room." The technique was first used by ancient Greeks to memorize speeches, and now it is used in memory competitions, allowing people to effectively memorize large chunks of information (Dresler et al., 2017). Additionally, the memory technique is just as effective when using locations in virtual reality as in with real locations (Legge et al., 2012). The memory technique is uniquely a mental construct, but it provides tangible improvements for information consolidation.

Using the method of loci effectively requires practice and training (Legge et al., 2012). To test for the effectiveness of the memory palace, a study was conducted on older subjects to practice memorizing a list of words. The subjects were trained in the method of loci during the study. The adults who were asked to utilize the memory palace technique performed significantly better at remembering words compared to the control (Gross et al., 2014). On pieces of paper, those who used the method of loci remembered words in the correct order, and even left spaces in between for words they forgot (Gross et al., 2014).

Neurological correlates also indicate the effectiveness of the method of loci. For example, in a neurological study conducted on memory athletes and control participants, those who utilized the method of loci performed significantly better than other strategies, like active or passive learning, even up to at least 4 months later (Dresler et al., 2017). In an fMRI scan done on the participants during memory consolidation and retrieval, those who trained with memory of loci had heightened activity between visual lobes, temporal lobes, and default mode networks (Dresler et al., 2017). It is believed that the method of loci promotes increased connectivity between different parts of the brain, promoting memory consolidation.

Evidence-based research in effective memory techniques is relatively new. While some methods were well-known since ancient times, most have only been uncovered recently. Neurological studies on the effects of memory techniques are currently ongoing but already substantiate the techniques. Despite the significantly improved performances from these techniques, many participants in these studies believed traditional studying strategies were more effective. As researchers begin to understand more of these memory techniques, it is crucial that people learn to understand the importance of these techniques as well. Learning new material can require effort, but there are always strategies to make learning and memorizing easier and more efficient.

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