

Improving Learning by Understanding the Psychology of Human Memory

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Presented in part at 2013 Annual Autumn Conference of California Mathematics Council Community Colleges (CMC3), <www.cmc3.org>
Conference site: Hyatt Regency Monterey Hotel and Spa on Del Monte Golf Course; 1 Old Golf Course Road; Monterey, California; 93940-4908. 2013-12-14

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Preamble

Motivation for this paper arose from realization that a major error too many students make is assuming that they will adequately with relatively minimal effort be able to recall (when taking a test) information they previously received in a lecture, or saw in a textbook, a hand-out, or in homework. They further err if presupposing that memorization equates with understanding of content they manage to retain or that visual/auditory familiarity implies comprehension.

These mistakes are easy for students of all academic levels and aptitudes because they are reflections of what humans generally do by default. We naturally point attention to what we see and hear, and often give less than deserved consideration to underlying meanings. The result may be superficial perceptions that we realize as such only after suffering a loss. Evidence of this abounds in faulty legal arrangements, unhealthy personal relationships, and purchases of what turn out to be poor quality goods and services.

By addressing misunderstandings on how the human brain is thought by psychologists to function with respect to memory and forgetting, I hope to persuade the reader to appreciate how students can become better learners. This should not be taken to diminish the great importance of reasoning and problem-solving skills. Yet, like all cognitive functions, they are governed by memory. If you are unable to remember well, you will have great difficulty reasoning and solving problems.

This paper will touch on many of the outcomes of human memory research that I hope you will find useful in your classroom work and your personal life. Here are two of many key points to gain:

① Forgetting is natural, and so it usually takes work for us to oppose the forgetting process.

② When retaining certain information is important, and when we want to be able to recall that information accurately in detail in the future, it is wise to attach deep meaning to it and make frequent use of it. Together these actions will help store the information deeper in long-term memory.

While it is hoped that readers will read the paper from start to end, it is viable to jump toward the end where many suggestions for better learning, retention, and recollection are provided. Additionally, the appendices contain useful advice direct to students and sheets of large figures (one on forgetting; one on better remembering) that can be used by instructors with their classes.

Introduction

Definitive, consistent, generalized statements about humans are often elusive in psychology. Individuals differ due to genetic make-up and environmental influences. Conditions of state also play a role. (For example, a sleepy, distracted, or ill participant expectedly may perform differently on memory tasks than when s/he is rested, focused, and in good health). Please keep this in mind as you read the remainder of this paper.

In the last few hundred years, amazing accomplishments have been made in perhaps every area of human knowledge. Triumphs in recent decades include reaching the floor of the Pacific Ocean, looking into space far beyond where human travel is feasible, and mapping the human genome. Yet, the human brain remains a mystery that perplexes us. The more that is discovered, the more questions that arise, and the more that remains to be learned. Therein, the memory function of the brain is an unraveling mystery that seems to be without conclusion.

Although taking a test in school is usually a disliked experience, educators know that the capacity beyond schooling to comment competently, extemporaneously on one's specialty is expected of professionals. Being able to speak intelligently about one's field of knowledge without relying on notes contributes to determining how much credibility potential employers, colleagues, members of the public or the press, and so on will assign to a person.

A test-taker may be prompted to demonstrate mastery of understanding and memory of a subject matter, and show practical use of knowledge in advanced ways in different situations. When tests are looked at in this way, they can be worthwhile training. Of course, the value of a test toward this effort is a function of how well it is written for its purpose. Tests for which students are denied fair opportunity to prepare and/or reasonable notice of what content is fair game generate frustration (and perhaps resentment) and may compel test-takers to consider cheating a justifiable response.

When my tests are returned to students, they are encouraged to learn from their mistakes rather than only look at their overall scores. Essential to the academic learning process is addressing the question, *Why did I answer this problem incorrectly?* A variety of reasons may explain what went wrong. Students should think back to the time during the test and contemplate what happened. They might ask themselves, *Did I read the problem statement carefully? Were unfounded assumptions made? Did I construct a visual aid if helpful? Did I show all of my work? Was my work based*

more on guessing than on trusting what I learned in the course? Did I exercise diligence? Surprisingly, few students I meet have ever raised questions like these. Instead, they group all mistakes in the category of “wrong answer”, stuff the test in a binder or bag, and never look at it again. Thus, they gain little from test-taking and repeat the same kinds of mistakes on future tests. How many of these individuals convince themselves that they will never be good at the subject matter, when a major problem is their misunderstanding of human memory itself?

Other questions that should be addressed pertain to the student’s preparation for the course and the test, homework habits, note-taking, problem-solving skills, and so on. All are also important¹, as is reasoning, a higher-level cognitive function that is challenging in the absence of good memory. The emphasis in this paper is on helping readers appreciate how memory works and overcoming misconceptions about it that negatively impact learning. It is a complicated topic, but hopefully this explanation will be engaging and constructive. Learning is a life-long activity. Even if you are in a position to teach others, we all are students of life and can gain from understanding human memory. With this insight, we can help ourselves better store what we want to remember, retrieve what we need when the time comes to do so, and help those we teach to do likewise.

This presentation cannot cover everything pertaining to human memory, nor is the objective to suggest that learning is all about memorization; the latter is a mistaken notion that some students cling to. Reasoning is a paramount component of higher education, but **memory unquestionably plays a crucial role in reasoning and learning in general**. You cannot say that you have learned something if you do not remember it.

Due to the limited time allocated for the presentation that this paper is the basis of, this written work focuses on the roles of memory and forgetting to the exclusion of other cognitive issues. The more we understand these, the better we can appreciate how to use memory more effectively as a component of learning *in conjunction with other important cognitive abilities*².

This paper is not meant for someone who seeks tricks to improve test performances in the absence of hard work at learning. Misconceptions about human memory will be addressed, suggestions for better learning, studying, and retention will be made, and first-hand accounts of some very productive students will be shared. You do not need to have previously studied psychology in order to understand this discussion.

¹ Like any part of mental or physical functioning, there are legitimate clinical disorders of memory; also cognitive strengths and weaknesses vary from person to person. Even in these cases, however, it is to a student’s advantage to learn how to study effectively and remember what was learned.

² In addition to memory, *cognition* includes perception, attention, knowledge, language, reasoning, decision-making, and problem-solving.

How Much Do You Really Understand?

Have you ever heard an academically struggling student say something like, “But I understand everything” about the course material? In nearly every class at every level at some time a student has made a comparable statement to me especially after performing poorly on a test. Interestingly, it is always someone who does not actually understand most of the material studied, is self-deluded into thinking otherwise, and is astonished at how things went so wrong on a test. Yet, the student making the statement usually appears to be sincere. The easy explanation is that this person is bad at taking tests and cannot improve. Indeed, many of these students say this without entertaining other possible reasons.

My practice is to learn the names of all students in my classes in the first few weeks of a course. Regular attendance and class participation are required, I take attendance every day, and I note every person’s progress on attendance and participation throughout a term. During class sessions, I make ample audience contact and occasionally circulate the room to see how individuals are doing in working out problems assigned. All of this means that when a student comes to see me for help, I already have some sense of her/his performance based on my observations. In the student’s presence, I then match my existing knowledge with a careful look at her/his tests, homework, and class notes. Collectively, these help explain what went wrong. Besides cases where a student should never have enrolled in the course due to being underprepared, other situations are about a person not really understanding what s/he thinks s/he does as a course progresses. This could be due to irresponsibility, and many times it is. Yet, there are also students who do meet most/all of their obligations for learning and yet habitually do not do excel when tested. My next action, then, is helping the student learn how to learn better and remember better.

H. M. Case Study



Figure 1
Henry Molaison (1926–2008)

(Perhaps the most well-studied case of amnesia in recorded scientific history)

Much of what scientists have concluded about the workings of human memory is based on what has been learned about people with various forms of amnesia. Among the most famous cases of memory loss was a man known for half a century in the communities of neuroscience and psychology simply as “H. M.” (Please see Figure 1). Upon his death in 2008 at age 82, “H. M.” was first publicly identified as Henry Gustav Molaison (Carey, 2008).

The failure of drugs to successfully manage Mo-

laison's epilepsy (after a bicycle accident) led a neurosurgeon in 1953 to remove the hippocampus from each hemisphere of his brain. Following the surgery, Molaison had great difficulty remembering newly learned information and some difficulty remembering past events (disorders called *anterograde amnesia* and *retrograde amnesia*, respectively) (Corkin, Amaral, González, Johnson, & Hyman, 1997; Goldstein, 2011, p. 191). Thus, he could do the same crossword puzzle daily or read the same magazines without evidence of familiarity³ and eat lunch without memory minutes later of what had been consumed (Scoville & Milner, 1957). Yet, this profound memory loss did not destroy some other things that he could do in life. For example, his intellect and language abilities were unaffected by the surgery (Eichenbaum, 2002). That might be surprising, because the capacities to read and speak a language definitely require extensive memory! This suggests that not all memories are handled the same way by the brain⁴.

Neuroscientist Suzanne Corkin spent nearly five decades studying Molaison's case. As she explained in a documentary (Holt, 2009), research with Molaison was instrumental in scientists eventually surmising that the brain consists of categories of long-term memory: Explicit (deliberate recall of information that one recognizes as a memory) and implicit (influence of experiences on behavior) (Hammond, 2010; Newhouse, 2007). This distinction will help us to appreciate some problems students have due to the way that they attempt to learn as well as their misunderstandings of the workings of human memory.

After his death in 2008, Molaison's brain was shipped to the University of California, San Diego, where it was painstakingly studied (Deconstructing Henry: The re-examination of the brain of patient H.M. (nd)).

To grasp the impact of what was learned from case studies of Molaison and others with amnesia, we first consider information loss.

Forgetting

In a once-popular party game, a person whispers a short narrative of a sentence or two in the ear of another attendee. That listener then attempts to whisper the exact same wording in the ear of another person. This transfer of information goes on from one person to the next until the final participant hears the story. Normally, when the last player recites the narrative, details in the original story have changed substantially. Of course, there is no easy way to know to what extent every person in the game sincerely tried to accurately

³ Note that in order for Molaison to do a crossword puzzle, he had to remember some things such as each clue at least during the time it took him to come up with the missing word. This shows that not all of his memory capacity was destroyed.

⁴ As further evidence of how complicated the brain and its memory system is, scientists studying Molaison's case determined that each hippocampus is not where long-term memories are stored (otherwise Molaison would have lost all long-term recollections). Instead, the partial role of the hippocampus is to encode information elsewhere for long-term memory.

repeat the wording. Still, the game might be considered a non-scientific demonstration of the natural tendency to forget.

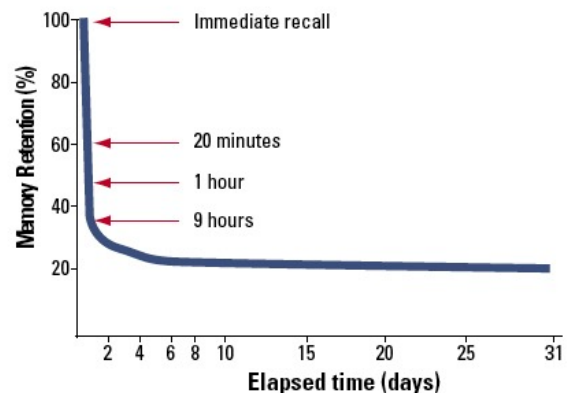
Another example is your personal effort in daily life to repeat information. Are you apt to do it *exactly* as you learned it? Think back to the times that you have heard something funny or shocking. Maybe a short time later you tried to repeat it to someone else, and realized that you were not doing it perfectly (or at the time you thought you were precisely repeating what you heard only to later doubt yourself). At such times, we might be inclined to complete the story by inserting assumed details where information has been forgotten. Those details now become part of the story



Figure 2
Hermann Ebbinghaus (1850 – 1909)
University of Berlin

(Experimental psychologist known for studying human memory and developing his now-famous forgetting curve)

FIGURE 1.
The forgetting curve



The "forgetting curve" was developed by Hermann Ebbinghaus in 1885. Ebbinghaus memorized a series of nonsense syllables and then tested his memory of them at various periods ranging from 20 minutes to 31 days. This simple but landmark research project was the first to demonstrate that there is an exponential loss of memory unless information is reinforced.

Stahl SM, Davis RL, Kim D, et al. *CNS Spectr.* Vol 15, No 8. 2010.

Figure 3
Ebbinghaus Forgetting Curve (Stahl et al., 2010)

(For a larger version of above graph, please see Appendix III)

that we relate to others. Over time, we might have trouble recognizing those inserted details for what they are: fabrications.

Once in a while, a student approaches me to inquire about something s/he thought was said during a lecture or read in

the textbook, only the mathematical information s/he conveys is flawed. When we look back in the student's class notes or the textbook, s/he sees that what was in mind is not what was written down from lecture or is not as explained by the textbook author. That the student took the step of seeking resolution to something puzzling suggests the problem was sincere forgetting. These and many other examples demonstrate that forgetting of new information naturally occurs easily and quickly.

Forgetting a piece of information does not necessarily mean that it is gone from our brains; sometimes the issue is more about failure of recall capacity. Difficulty recalling can be related to whether/how the information was encoded in long-term memory⁵ or how much meaning and importance we associated with it during its collection. One does not have to suffer from dementia or other brain disorder in order to forget. Forgetting is natural and happens to all of us throughout our lives. As we will soon see, forgetting actually has value. We just have to learn how to live with it and train ourselves to be better at remembering what we want/need to.

In the late 19th Century, German psychologist Hermann Ebbinghaus (Figure 2) explored how quickly humans forget (Green, n.d.a). His disciplined manner of conducting experimental research led to quantitative findings that continue to be used today more than a century later. In Figure 3 is a general graph from Ebbinghaus' research⁶ showing that when temporarily exposed to new information that we have little or no previous connection with and that does not incite emotions, we tend to forget it rather quickly⁷. In the absence of trying to remember the new information and assign meaning to it, it may only take about 1 hour to forget half of what was learned. Nine hours later, we might recall just a third of what was learned.

The forgetting curve can be shown to classes⁸ of students as evidence of why they should avoid waiting until the weekend to do a week's worth of homework. By that time, they may have to re-learn everything from the week's lectures. Additionally, it is a lot of material to try to cram into their brains over a short time). Instead, one should start on homework the same day as its relevant lecture or next day at the latest.

⁵ Short-term memory and long-term memory are terms that will be defined and explained later in this document.

⁶ For the full text (translated from German) of Hermann Ebbinghaus' *Memory: A contribution to experimental psychology*, see Green (n.d.b).

⁷ Anderson and Schooler (1991) argue that a forgetting curve can be *loosely approximated* by a function of the form $f(t) = At^B$, where A and B are constant parameters of the model and t is time following initial learning. I have uncovered minimal published research exploring this. Perhaps that is because there is no single forgetting curve that applies to everyone. Even individually, a person's likelihood to forget new information is a function of many variables besides just time.

⁸ If showing the Ebbinghaus forgetting curve to intermediate algebra or higher students, you may wish to ask whether it is a function and why it would make no sense to have multiple points vertically aligned on this curve whose horizontal axis represents time.

Even then, a measure of forgetting is likely to have already occurred. Engaging in some studying of a subject material every day has a reinforcement benefit, especially since classes of today's post-secondary courses are commonly offered only semi-weekly or weekly.

The forgetting curve is not going to be identical for everyone, nor for the same person under varied circumstances, but the graph helps to make the general point that *forgetting is a reality of life that happens rapidly over the first day of exposure to entirely new material that is not quickly and repeatedly used in significant ways*. As the behavior of the function demonstrates, once rapid information loss occurs in the first day or so, the rate of additional loss slows greatly. Thus you may find it easy to remember some details of past information that you have not used much since learning it. Indeed, a segment of new information has greater likelihood of being remembered if it relates to information already known (Radvansky, 2011, p. 15, 43).

Putting aside clinical disorders such as amnesia, there are theories on why we naturally tend to forget in the absence of intentioned effort against it. One idea is that whereas repeated, meaningful use of information results in strengthened connections between various neurons (nerve cells) and easier recall later (Carlson, 2013, p. 436, 437; Goldstein, 2011, p. 190–191; Radvansky, 2011, p. 10), lack of use of that information conversely leads to weakened connections and difficulty with recall.

Another tenable explanation is that we often do not really know or understand something to the extent that we believe we do, but we mistakenly think so due to sensory familiarity with it. That is, when something looks, sounds, tastes, smells, or feels recognizable to us, we mislead ourselves to concluding that we grasp it.

In a court hearing, a witness giving testimony might passionately express conviction as to what was seen, heard, or otherwise sensed at the scene of an event such as a crime, and might recollect accurately to some extent. Yet, even someone of integrity is unlikely to be able to remember full details of what was witnessed. Lawyers exploit this natural deficiency of human memory by focusing attention on that which is not perfectly remembered in hopes of casting doubt in the minds of jurors on the credibility of the witness. This is not difficult to accomplish if jurors are uninformed on the workings of human memory and the role of forgetting.

Additionally, cases abound in the legal system where false, albeit perhaps heartfelt, eyewitness testimony has led to wrongful convictions (Henderson, 2012; Starr, 2012; Thompson, 2012) and innocent people have been imprisoned for many years (www.innocenceproject.org). We could reasonably wonder how many other cases of inaccurate eyewitness testimony have resulted in exoneration of, or reduced charges for, guilty parties (Radvansky, 2011, p. 260).

One way to address the ease with which we forget is to develop a habit of documenting important information as soon as it occurs⁹. An example of this was evident in a BBC docu-

⁹ If mistreated during a financial transaction, you would do well to have an accurate accounting of what transpired. If a

mentary on the Space Shuttle Columbia flight STS-107 disaster. After a wing puncture 17 days earlier during take-off had compromised integrity of the thermal protection system, re-entry to the Earth's atmosphere on 2003-02-01 was where Columbia broke into pieces. When oral communication from NASA's "Houston" control center to Columbia was suddenly no longer responded to, and Flight Director Leroy Cain learned of news reports that Columbia had been seen streaking across the sky in pieces, and portions of the craft had crashed to the ground in various parts of Texas and Louisiana, Cain gave the audible order at 09:12:30 EST to "Lock the doors".

As explained in Last Flight of the Columbia (BBC, 2003; BBC Worldwide, 2010a; BBCWorldwide, 2010b), "Lock the doors" is a formal signal that commences a contingency investigation. This includes not changing computer configurations, not talking to other people, not losing whatever thought one had in mind at the moment of the disaster, and securing the doors to the control room so that no one enters or leaves. The objective is to preserve and document the body of impressions of each employee for investigators to look back at any time in the future. In the footage, Cain's instructions to his control room colleagues included, "No phone calls off-site, outside of this room. Our discussions are on these loops, on the recorded [unintelligible] loops only".

Why was it crucial for flight control room personnel (1) to immediately begin ensuring that all data and documentation were preserved, and (2) to not interact with anyone outside the room? Columbia's breakup and the presumed death of its crew were chilling. Why not allow control room employees a short break or overnight rest and then worry about documenting later that day or the next? Despite being well trained to coordinate Space Shuttle flights, NASA professionals have human memories that are susceptible to forgetting and the potential impact on past memories of new personal thoughts and environmental input¹⁰, as all of us do.

NASA's Johnson Space Center (in Houston) public affairs specialist Kyle Herring served as public affairs officer for space shuttle flights for 8+ years. In our conversation (K. Herring, personal communication, February 7, 2013), Herring said that most data (such as voice communication and shuttle sensor readings) on Earth and in space during missions are automatically recorded digitally and would be difficult to lose. However, the data did need to be secured. Additionally, Herring, who has been present in the mission control room during numerous flights, said that control room personnel were accustomed to taking many handwritten notes throughout take-off and re-entry portions of

witness of an unlawful act, you may choose (or be required) to report to authorities what you saw and perhaps testify in court. If in a vehicular accident or a witness of one, you may need to file reports with one or more governmental or insurance units. In each of these examples, it is sensible as soon as possible to create notes of what occurred. (This is why I always keep notepads and pens in my vehicle). When doing so, resist any urge to "fill in the blanks" if you do not remember certain details.

¹⁰ Had control room employees watched television, talked to friends and family, and so on, their recollections of the disaster could have been damaged.

shuttle missions. During a contingency operation, those paper notes needed to be preserved, annotated for clarity as necessary, and compared with recorded data. Clarifying one's notes would require a team member to combine information from personal memory with that already written so that the notes would make sense to others (and to the author him/herself) then and over the passing of time. Herring concurred that doing this under the "Lock the doors" order has the objective of minimizing potential contamination of the memories of control room personnel.

As retired Princeton University psychologist and Nobel Prize winner Daniel Kahneman explains, it is a reality of human memory is that when we remember an event, we naturally, even unintentionally, influence the details of that remembrance according to our current thoughts and recent experiences (TED Radio Hour, 2013). This reshaping generates a modified version of the memory that replaces the old memory (Abumrad, J. et al, 2007; Radvansky, 2011, p. 287).

Why might we be unaware of how easily we involuntarily alter memories? Ask yourself how often you verify your recollections. Do you not usually *assume* that what you recall is accurate? Suppose you want to evaluate how well you remember the specifics of what was said or done during your interactions with others in person or by telephone. That will be difficult unless you have a reliable record to compare your future mental recollections with, and yet we typically do not record our meetings with other people. Here is something you could try: Suggest to a friend that the two of you independently write down as much detail as possible of what each of you remember of a recent conversation you two had, and then compare your notes with each other. Another exercise: Write down what you recollect today of something you wrote in the past, and then make a comparison. How correct was your recall?

It is unwise for a student to assume that s/he will remember all that was said during a lecture or class discussion. Due to the natural human inclination to forget, students are advised that in addition to keeping their attention on, and thinking about, what a speaker is saying, they should take abundant meticulous notes. However, taking notes is valuable only if the notes are actually used. Some students do a great job of copying on paper what the instructor writes on the board and says, but then make minimal use of the notes thereafter. Over the years, a few students have admitted to me that they never look back at their class notes. This has been discovered at times when such individuals came to me for help once they saw they were doing poorly in a course. Meaningful re-studying of one's notes from class contributes to consolidation of the contents to long-term memory.

Taking notes, rather than relying only on personal memory, is also beneficial to students in their interactions with campus employees. I advise students to always have paper and something to write with. They should document the date, time, place, name of the person they talked to, and what was said. When the discussion ends, they should ask the person if what they have written is correct. This practice reduces misunderstandings on prerequisites, enrollment, qualifications for transferring to a university, financial issues, and other academic matters, and it helps them to accurately re-transmit important information to others as needed.

Memory

Human memory is among the most highly complicated features of the brain. There remains far more to be learned about it in the community of cognitive psychology. Research on this aspect of life is painstaking because when the brain is dismembered, no tangible evidence of memory is apparent. However, today's advanced imaging technology is making the job of understanding human memory easier.

If scientists are still learning so much about memory, it is unsurprising that in a survey of 1 838 adult participants (75%+ with at least some university education) across the United States, Simons and Chabris (2011) discovered disturbing misconceptions about human memory prevalent throughout the sample.

Here are findings (nearly all published in peer-reviewed journals or academic textbooks) on human memory that illustrate its limitations:

- Schmechel, O'Toole, Easterly, and Loftus (2006) found among a sample of potential jurors in the District of Columbia that "beliefs about factors influencing eyewitness memory... [and] about the nature, precision, and permanence of memory... [corresponded to] high rates of incorrect responses". Considering that jurors render decisions greatly affecting the lives of suspects, witnesses, victims, and family and friends of these people, this revelation is sobering.

- Confident-but-inaccurate memories (called *false memories*) can be induced by presentation of misleading information (Ackil & Zaragoza, 2011; Goldstein, 2011, p. 222–226; Zhu, Chen, Loftus, Lin, & Dong, 2010).

- False memories pertaining to childhood recollections are common (Winkielman & Schwarz, 2001).

- Some research participants have created false memories ostensibly to magnify their impressiveness to others. In a university study conducted by Gramzow and Willard (2006), student participants inflated their grade point averages (GPA's) by statistically significant amounts despite having already given the university registrar permission to release their GPA information to the researchers.

- Eyewitness memories are generally not as accurate as we may think (Alonzo & Lane, 2010) and have been shown to alter *other people's* beliefs and memories (Gabbert, Memon, & Allan, 2003).

- "Memory is in a constant state of flux and...what we currently remember is in part due to our experiences and current state" (Radvansky, 2011, p. 287).

- *Flashbulb memories* (remembrances of emotionally charged, eyewitness events) can be more easily remembered in detail (compared to other memories) although not always so accurately despite good intentions (Goldstein, 2011, p. 208–213).

- Flashbulb memories have been known to change over time. Neisser and Harsch (1992) interviewed people via questionnaire within one day of the explosion of the Space

Shuttle Challenger that occurred 77 seconds following its launch on 1986-01-18. At the time, 21% of participants reported first hearing about the disaster on television. About three years later, the *same sample of participants* was given the same questionnaire to complete. This time, 45% (more than double) of participants reported first hearing about the Challenger disaster on television.

- *Introspective memories* come from a focus on the inner self with emphasis on inner sensations and experiences. Research has shown that introspective memories are often faulty (Goldstein, 2011, p. 222–223; Kaasa, Morris, & Loftus, 2011).

- The way a question is asked has the ability to impact a person's recollections (Loftus & Palmer, 1974).

- According to Radvansky (2011, p. 3), scientific evidence does *not* support the notion that memory is like a muscle that simply improves with use. Rather than how much you use your memory being important, how much information is in it is what counts. "Memory is...more like a key collection. The more keys you have, the more locks you can open".

- Harvard University psychologists Daniel Wegner and Adrien Ward found (as reported in the December 2013 issue of *Scientific American Magazine*) that "individuals who believe their memorable facts are stored online are much worse at remembering them". The researchers caution that since "almost all information today is readily available through a quick Internet search [it] may be that the Internet is taking the place not just of other people as external sources of memory but also of our own cognitive faculties" (McDermott, 2013).

Pivotal to learning is *reasoning*, which is the cognitive capacities to reach conclusions (Leighton, 2004) and use existing knowledge to formulate conclusions that exceed that knowledge (Kurtz, Gentner, & Gunn, 1999). Yet, reasoning is very difficult if memory is poor. So although we do not want students to equate education with a process of memorization-regurgitation, information retention is imperative – you cannot learn if you cannot remember.

Psychologist E. Bruce Goldstein (2011, p. 116) defines **memory** as, "the process involved in retaining, retrieving, and using information about stimuli, images, events, ideas, and skills after the original information is no longer present". According to physiological psychologist Neil R. Carlson (2002, p. 356), **learning** is the process by which experiences result in memories; and **memory** is a change in the nervous system (primarily brain and spinal cord) and, hence, a person's behavior. In his more recent writing, Carlson (2013, p. 435) contends that "Experiences [that we remember] are not 'stored'; rather, they change the way we perceive, perform, think, and plan. They do so by physically changing the structure of the nervous system, altering neural circuits..." Experimental psychologist Gabriel A. Radvansky (2011, p. 1, 356) defines **memory** in three ways: The location where information is retained, the thing that stores the contents of an experience, and the mental process by which information is gathered, kept, or fetched.

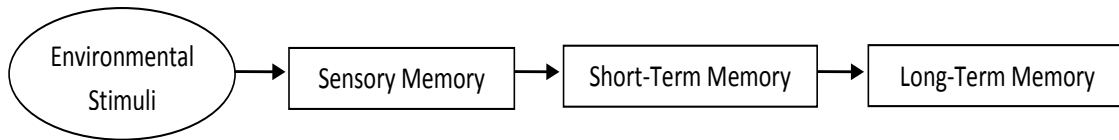


Figure 4
Possible Model of Human Memory

A challenge with studying memory is that we cannot open a human skull and see overt evidence of thought storage in the brain. Instead, we have relied on experiments over the last half century. These have shown that memory is *not* like a filing cabinet, where information entering the brain is arranged in folders of equal ranking, and content retrieved is an exact copy of what entered. Much of life might be easier if human memory worked that way, and the notion of photographic (*eidetic*) memory combined with Hollywood special effects do make entertaining stories for television and feature films, but these are usually rare exceptions (Radvansky, 2011, p. 296) or far more about fantasy than real-life experiences.

Using research studies of the Henry Molaison (“H. M.”) case,

ory, and this activated knowledge is actively manipulated in short-term memory”. **Memory acquisition alters the brain’s neural circuitry, where the extent of detail of a memory corresponds to the way that the information was encoded in the brain.** Nonetheless, so that this paper does not become overly technical, we will use the model in Figure 4.

A university mathematics professor teaching calculus used to talk about the tangent to a point of interest on the graph of a continuous function as a secant line with one of its points fixed on the graph of the function at that point of interest and its second point continuously moving along the curve toward the first point without ever actually reaching it. (We know that when using limit theory to find the instant-

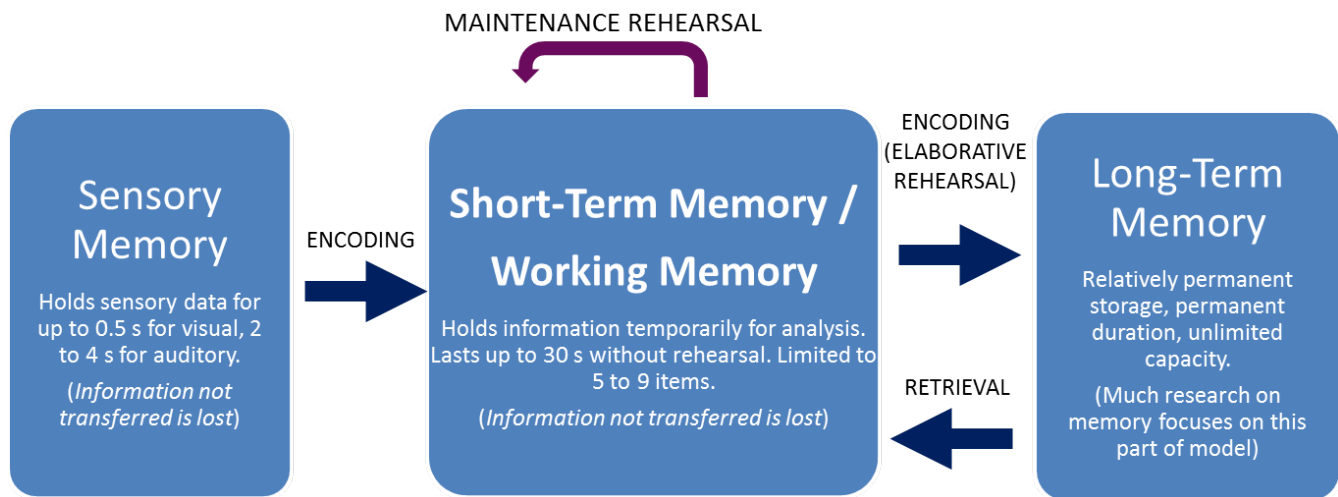


Figure 5
Detailed possible model of human memory based on Atkinson and Shiffrin (1968) and Shiffrin and Atkinson (1969)

many other memory-impaired people¹¹, and memory-typical individuals, scientists (Atkinson & Shiffrin, 1968; Shiffrin & Atkinson, 1969) developed a speculative model (shown in Figure 4) of how human memory generally functions.

The flowchart in Figure 4 implies that what we retain in long-term memory has travelled through earlier stages of memory. Yet, it is not as if information in the brain is like a postal-mailed package transported from one post office to another. Radvansky (2011, p. 13) argues that this model is useful only in a broad sense and that “incoming information...appears to activate knowledge in long-term mem-

neous rate of change of the dependent variable with respect to the independent variable, there is no actual movement of a point coincident with a secant line and the pictorial representation of a function unless we choose to program a computer to demonstrate it). However, the visualization undoubtedly helped students appreciate the idea behind the definition of *tangent line*.

Likewise, we will stick with the aforementioned model in Figure 4 that psychology textbook authors use to explain human memory at an introductory level. Figure 5 shows the model in greater detail (absent “environmental stimuli”; including “working memory”). Each portion of the diagram in Figure 5 will now be explained.

Sensory Memory

Our senses are endlessly exposed to external stimuli. Every-

¹¹ For another well-documented study of amnesia, including its disturbing implications on life and what scientists have learned from it, see the case of English musician Clive Wearing (ashikkerib, 2006a; ashikkerib, 2006b; Wearing, 2005).

thing we hear, see, smell, taste, feel, and so on results in quick delivery of that information to the brain's **sensory memory** in a ceaseless fashion. Unless sensing something familiar or that draws our particular attention, most of that information is quickly and permanently forgotten (Goldstein, 2011, p. 120–123).

As much as we might wish it were possible to remember everything, consider the implications if it were the case: Every second of every day, you would retain recollection of the visual characteristics (size, shape, color, texture, patterns, and movements) of every object you saw, auditory characteristics (volume, tone, pitch, and tempo) of everything you heard, flavor (smell and taste) of every olfactory and gustatory sensation that came your way, feelings (temperature, texture, pressure, and pain) of all that you came in close physical contact with, and on, and on, and on. This uninterrupted flow of sensory data to the brain would quickly be overwhelming if all of it had to be retained indefinitely. It would also be impractical, as usually nearly all of it is unnecessary to continuing with your day and future activities.

Stop reading and spend five seconds looking at and listening to everything in your surroundings. If you had to document all of that information, it might fill several pages. How much of it do you need (or even want) to remember in order to go on with life?

Look at the picture in Figure 6 of a busy street in Tokyo. How many of the aforementioned visual characteristics can you list? Had you been the photographer of the scene in that picture, everything you saw (and heard) would have entered your sensory memory. Yet, unless you recognized any of it, associated any of it with past experiences, made effort to remember any of it, or were emotionally stimulated by something, most of it would stay in your sensory memory very briefly (possibly less than a second) and then vanish.

Suppose you decide that some sensory information that you encounter is worth remembering for longer than a second or two. How would you “move” it to your short-term/working memory and beyond? A student in the audience of a lecture can do this by transcribing the information seen/heard to a notebook on the spot, having (during the lecture) the desire to remember, and (on the spot) mentally connecting the new

information with what s/he already knows. Without doing this, information in sensory memory is normally quickly forgotten or only scattered fragments survive. This may explain why a student whose thoughts are on other things while copying down what is on the classroom board or what the instructor says may feel that little is gained from lectures. (There could be other explanations too).

How can a person be reproducing by hand someone else's writings or speech while giving little thought to the task? This is due to procedural memory, a category of long-term memory that we will soon get to.

In summary, cognitive psychologists suspect that if you know something, that knowledge must have first activated your sensory memory at some time in the past.

Short-Term/Working Memory

Short-term memory is temporary, associated with conscious thought, and estimated to hold 7 ± 2 pieces of information¹² depending on the person's experience with the information and how well pieces of it can be grouped. Some psychologists have said that, though I have been unable to confirm it in the historical record, domestic telephone num-

bers were made to be seven digits in length specifically because this was the average number of pieces of data that people could retain short-term memory of. Also noteworthy is that three-digit telephone area codes throughout the country are non-consecutive for adjacent and nearby regions and usually different enough to make them easier to distinguish and remember.

Whatever you are actively thinking about is in your short-term memory (Martinez, 2010; Radvansky, 2011, p. 66). When

attempting to learn something, there is importance in actively focusing on it. This is not the same as merely hearing. All day we hear a variety of sounds. We are unaware of or forget many of them because our attention is centered elsewhere, and the human brain is capable of basically all but



Figure 6
Ginza (High Fashion Shopping District), Tokyo

¹² For a discussion on this “magical number” (seven), see a journal article written by Harvard University professor George A. Miller over half a century ago (Miller, 1956).

ignoring that which does not interest us¹³.

That a student is physically in the room during a class session does not in itself assure that lecture content will be remembered if his/her attention is divided between the lecture and other things. Of course, regular class attendance is important, but it does little good for a student to be physically present if her/his thoughts are elsewhere. We may not be able to force students to keep their attention on a lecture or classroom discussion, but we can alert them to the misconception that being present is itself the paramount component of learning. Learning is an active process. It tends to take work to learn and to remember.

Sensory information that you focus on will make its way into (that is, stimulate) short-term memory, but to stay in short-term memory, the data need to be rehearsed. Think of the last time that you called a telephone number and heard in the voicemail greeting a different number that you needed to then call. What if you did not have paper and something to write with? Did you start saying the digits of the new number to yourself and repeat the sequence? If so, it was to enable you to retain the number in short-term memory while hanging up and preparing to call the new number. We all know from experience that without this rehearsal, the new number or part thereof is sure to be forgotten. Even with repeating it to ourselves, we might mistakenly transpose digits when making the call because we are taxing the very limited resource of short-term memory.

A similar idea holds when driving in new territory while looking for a destination. Suppose you see your exit on a sign along the highway. Maybe the sign also has other information (verbal and/or pictorial) relevant to your destination that you now rehearse to distinguish from names of other highways, streets, businesses, and other visual imagery that your sensory memory continuously receives while you are driving. Or maybe you stop to get directions from a stranger and immediately begin repeating the directions so that you hold onto them long enough to remember and use them.

Baddeley and Hitch (1974) proposed that the term *short-term memory* did not adequately describe what happens to newly acquired information at this stage. They noted that people are able to understand language and speak it while simultaneously trying to remember a few numbers. (Think of the above telephone number examples. While you were repeating the new number to yourself, you may also have needed to tell a companion what was going on). This led Baddeley and Hitch to coin the term *working memory*. We relate the two as follows: **Short-term memory** is involved with the temporary storage of a few pieces of information. **Working memory** entails manipulation of information during intricate cognitions such as remembering numbers while reading (Goldstein, 2011, p. 132). Radvansky (2014, p. 170) goes further, describing working memory as having the

¹³ This is how you can be at a well-attended social event with different conversations around you, still effectively converse with someone near you, and yet also catch when your name or other information of interest to you is heard in a separate conversation. Psychologists call this the *cocktail party effect* (Goldstein, 2011, p. 85).

duty of regulating attention and moving information in and out of long-term memory.

Some information entering short-term memory can easily be remembered long-term without much effort at consolidation. (Examples: Where you parked your car or something interesting you heard about a topic which you already have familiarity with). Other information will not reach long-term memory without elaborative rehearsal (explained ahead).

A student must learn to master the ability to get important information into long-term memory so that it is accessible for later recollection and use. Here is one explanation of why even a studious person might do poorly on a test problem: Important information (in part or whole) entered sensory memory and activated short-term/working memory, but it never went further than this. During the test, maybe the individual recognized certain aspects of a problem – parts that had previously been consolidated in long-term memory – but had poor recollection of other parts of the problem because insufficient *meaningful* attention was accorded them. Consequently, those other parts never moved beyond short-term/working memory and were forgotten.

In the scientific community, the majority of attention on human memory centers on long-term memory. Information to be retained for lengthy periods needs to get to – that is, activate – this final, dominant stage.

Long-Term Memory

Canadian psychologist Donald Hebb (1949) may be the first to have distinguished between short-term and long-term memories. **Long-term memory** is amazing. Although it does not work the same as memory in your computer, where exact replicas of information are held and can be retrieved in the future in their exact saved forms, we can store vast amounts of information in our long-term memories indefinitely, and much of it can sometimes be recalled faster than you could search for something on a hard disk drive. When did you last think of your favorite childhood friend? Perhaps not in a long time if you two have not communicated for decades. Yet, if that person and you crossed paths today, and you recognized each other, it might take less than a second for each of you to recollect an assortment of information about each other's personality, names of friends and family members, and events that you shared together. It would take much longer than a second just to type the right keywords into the interface of a search engine and press ENTER.

Cognitive psychologists consider long-term memories in categories as shown in Figure 7.

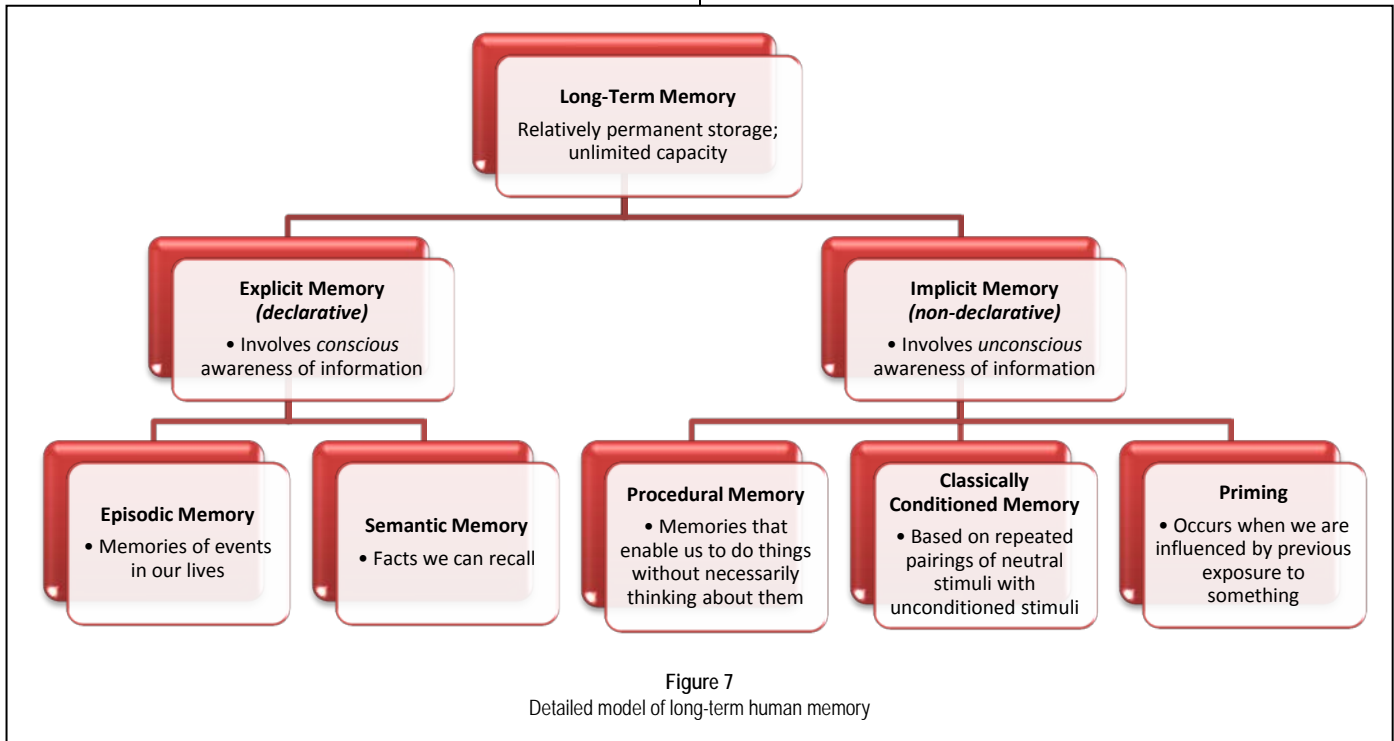
As a quick summary, **explicit (declarative) memories** are generally describable using language and which we actively try to remember, whereas **implicit (non-declarative) memories** are used without need for awareness of their use and are not easily described in words. Within these categories are a total of five sub-categories.

EXPLICIT MEMORY comes in two forms: ① **episodic memory** and ② **semantic memory**. The former are general recollections of life's events; the latter consists of pieces of factual information without regard to the setting during which they were learned. Put another way, episodic memory

is a person's "mental slideshow" and semantic memory is one's "mental encyclopedia" (Radvansky, 2014, p. 174).

Here are personal examples from this author comparing the two forms:

our findings. As team leader, I had responsibility to guide the group in deciding on our solution approach, to ensure that the project stayed on track and we met all deadlines, to handle all professional communication with company engineers and supervisors, to supervise the high school student



I remember my first time driving a car. It occurred in a school-sponsored driver's education course during my final year of high school. This is an *episodic memory*. I do not recall much detail about the experience such as the names of the instructor or other students in the vehicle, the street where this took place, or the type of car we were in. Most of the *semantic memories* related to that event are lost.

I know that the Pacific is Earth's largest ocean. This fact is from my *semantic memory*. However, I do not recall the circumstance in my life when it was learned. It could have been from a teacher in elementary school; it might have been told to me by a parent or friend; maybe I learned it from a book or television. The associated *episodic memory* has been lost.

(Note: In the above two examples, a "lost" memory is not necessarily an entirely forgotten one. With the right *recall trigger*, we might remember that which we previously learned but have trouble recollecting today. Think of the times in your life when you saw or heard something that suddenly took you mentally back to a past event and information that you had not thought about in ages).

I recall my senior mechanical engineering design project for General Electric Aircraft Engines. It was a two-quarter experience during the last of my undergraduate years that included our three team members travelling to the company site, receiving an aircraft engine blade, and using finite element analysis to seek a solution to the problem. We travelled to the company's site again some months later to present

who worked with us, and to take the two primary GE representatives to lunch when they visited our campus. In this example, there are plenty of memories, *both episodic and semantic*, that have stayed with me throughout the years that followed the events. Of course, there are also plenty of episodic and semantic memories from that two-quarter experience that I have forgotten. No one remembers everything!

Semantic memories that have a personal connection tend to be easier to retrieve. Example: After first learning physics and calculus in my final semesters of high school, I still recalled various concepts from those courses despite doing nothing serious again with them until seven years later when the opportunity to enter university came about. Surely the reason for this retention was due to the excitement those subjects brought me as an adolescent. Around the same time I studied accounting in high school, but little of that course content was remembered in the years after that course was over because of how uninteresting the subject was to me.

Additionally, when we associate the learning of new semantic information with the episodic circumstances surrounding its acquisition, we remember easier. Example: Due to the significant role I played in them, I remember more about my own graduation ceremonies than about the ceremonies of other people that I have attended.

Knowledge that we want students to hold onto from the courses we teach is largely in the category of semantic long-term memory. (Though of lesser importance, we understandably are also pleased when they remember the experi-

ences of taking our classes! Those are episodic memories). Again, this paper's focus on memory is not meant to under-emphasize the importance of a student being able to make sensible, reasoned use of knowledge. Solely memorizing facts has limited value in the pursuit of higher academic learning.

IMPLICIT MEMORY is used without our needing to think about it and influences our performances on tasks. It comes in at least three forms:

① **Procedural memories** enable us to act without thinking about them. Although we learned them at some point in the past, we are now able to perform them naturally.

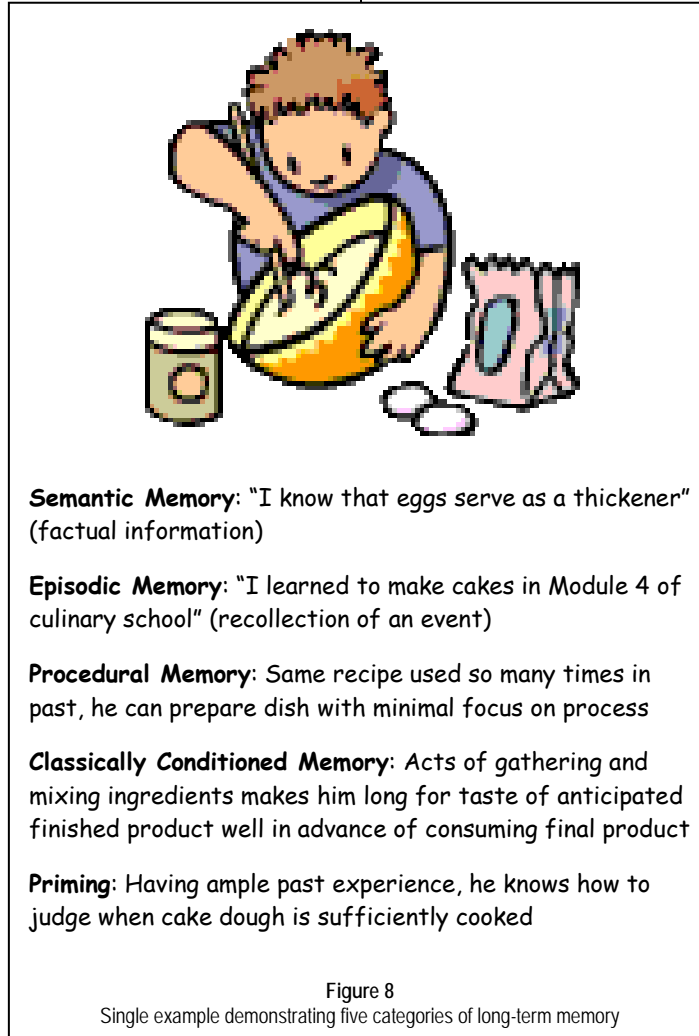
Examples: Tying shoelaces, walking, dressing yourself, using all fingers on a QWERTY keyboard to type a manuscript into a computer, navigating a bicycle, using utensils to eat with, and preparing a very familiar edible dish (that you have made many times before) each might not require you to focus on the task in order to accomplish it once you have mastered it. Moreover, even if you do not remember when in life you learned those various procedures, you are still able to do them.

Example: Have you ever been driving a car and realized that your thoughts had drifted elsewhere for several seconds, and yet your driving did *not* become erratic? If so, procedural memory allowed you to do that. (Of course, this is not mentioned to encourage lack of attention to safe driving).

② **Classical conditioning** is a learning phenomenon that occurs when a neutral stimulus is repeatedly paired with an unconditioned stimulus, so that the neutral stimulus turns into a conditioned stimulus, and you eventually react toward it the way you would normally respond to the unconditioned stimulus. Russian physiologist Ivan Pavlov is famous for having performed experiments with dogs in which a bell that was rang each time prior to the dogs being fed eventually resulted in the animals salivating at the mere sound of the bell in advance of the presence of food.

Example: The main four-note sequence of music in the theme to Rod Serling's "The Twilight Zone" television series may have elicited no special reaction from you prior to first

watching the show. (The music constituted a neutral stimulus). Yet, if you kept hearing those four notes in conjunction with eerie stories (unconditioned stimuli) that the show focused on, the four notes on their own may have automatically induced creepy feelings each time you then heard them without you needing to actually watch an episode of the show. The four-note sequence had turned into a conditioned stimulus.



Semantic Memory: "I know that eggs serve as a thickener" (factual information)

Episodic Memory: "I learned to make cakes in Module 4 of culinary school" (recollection of an event)

Procedural Memory: Same recipe used so many times in past, he can prepare dish with minimal focus on process

Classically Conditioned Memory: Acts of gathering and mixing ingredients makes him long for taste of anticipated finished product well in advance of consuming final product

Priming: Having ample past experience, he knows how to judge when cake dough is sufficiently cooked

Figure 8

Single example demonstrating five categories of long-term memory

Example: Your fiancée/fiancé (an unconditioned stimulus) starts regularly wearing a newly released, uncommon fragrance (neutral stimulus) that you might otherwise have been indifferent to the smell of. Now you instantly think of your sweetheart whenever the fragrance is detected, even when s/he is not present. The fragrance has become a conditioned stimulus.

③ **Priming** exists when we are later influenced by earlier exposure to something.

Example: Your level of risk-taking may be heightened (primed) after reading an adventurous novel.

Example: You can correctly read an unfamiliar word in English if the word contains recognizable letter combinations (such as "ph" or "ly") for which you know (have been primed for) the sounds of various letter combinations. Contrast this to attempting to read a word in a foreign language even when the character set is much like that in

English. Can you properly read these Finnish words: *yliopisto* (university); *yhdeksänsataa* (nineteen)? Assuming you do not speak Finnish, they are difficult to know how to properly pronounce, right?

Example: Over time, a student who does so much analysis of rational functions is able to naturally predict some of a rational function's behavior at the mere sight of its factored form.

For a single example that incorporates all five aforementioned sub-divisions of long-term memory, see Figure 8.

Implicit memories have good and bad sides as part of learning.

Examples: It is good when a student gains enough experi-

ence so that s/he is *primed* to recognize and distinguish equations and inequalities of various types (such as linear, quadratic, radical, and absolute value) and automatically remembers what solution techniques are proper to use. It is unfortunate when, through *classical conditioning*, a student becomes so convinced of being poor at mathematics, that the anticipation of a test generates anxiety before the student sees its contents. It is bad if a student thinks that merely copying lecture notes from a board onto paper qualifies as learning new material, when this could simply be exhibition of the *procedural memory* capacity to transcribe.

Interestingly, many people with amnesia lose explicit memories, but retain implicit memories. Even in severe cases where a person is suddenly incapable of remembering family members and friends, where s/he lives, and her/his own name, the individual probably still knows how to eat in a civilized manner, not to wander as a pedestrian onto a street busy with vehicles, and how speak and read in her/his native language.

We have seen that human memory is complex. It is good that we do not remember everything that enters sensory memory otherwise we would be encumbered with volumes of data that we have no need or desire to store. This means that when presented with information that we want to hold onto, it usually takes work to make it indefinitely and relatively easy to retrieve from long-term memory. Ways to do that effectively is the next topic.

Getting Information into Memory with Easier Retrieval

Equally important to having information in long-term memory is being able to retrieve it when desired. Key here is the *way* that information is encoded to long-term memory at the time that it is learned. Psychologists refer to **coding** as the form (visual, auditory, or semantic) of learned information, and **encoding** as the process of moving information into long-term memory.

Human memory is pliant. Newly learned information is fragile and takes time to consolidate in our brains (Goldstein, 2011, p. 195). This is why people who suffer head trauma may have difficulty remembering what happened shortly before impact (Cantu, 2001). The good side of this reality is that we can replace poor understandings of learned information with improved ones (Stahl et al., 2010); we do not have to forever hold onto incorrect information. The bad side is that learned information (including memories of events) can be unintentionally reshaped over time during recollections without our awareness of it.

There is much truth in the familiar adage, "Practice makes perfect". Reciting that which we want to remember will help us to remember, but the manner in which practicing is done affects recall, because the way we encode information in our brains impacts the way it is stored in long-term memory (Kalat, 2010, p. 379) as well as one's ability to recall the information later. In your own time as an inexperienced student, you may have studied by merely repeating what was read or heard. Maybe you were not so interested in the topic, and your attention easily shifted to something else. Or perhaps you wanted to study the material, but your thoughts

were distracted by a personal problem. Or suppose you read and reread lecture notes and the textbook without making practical use of what you read. Each of these approaches offers poor likelihood of accurate, detailed future remembrances. As your schooling continued, you hopefully discovered that if you instead sought to comprehend what you were studying, tried to understand how the various pieces of a topic pertain to each other, and made use of what you were reading in practice by solving problems, then remembering worked out better and did not require as much effort.

Maintenance rehearsal (please see Figure 5) or reciting is important as a low-level method of recycling information for short-term retention (Radvansky, 2014, p. 184). While human tendency is to focus on auditory and visual coding for short-term memory¹⁴ (Goldstein, 2011, p. 153) due to the dominant, acute natures of our senses of hearing and seeing, this does not ensure that the auditory or visual information will necessarily make it to long-term memory. Stated earlier was an example of calling a telephone number and hearing an automated greeting tell you to call a different number unfamiliar to you. If you have nothing to write the new number down with, you start repeating it to yourself. That may be sufficient to keep the number in short-term/working memory long enough to correctly dial it after hanging up from the first call. Yet, is that repetition sufficient to ensure that you can recall the number at a future point in time after not thinking about it again? Probably it will not be.

A more complex rehearsal method of encoding information into long-term memory for later retrieval is called **elaborative rehearsal** (please see Figure 5) (Radvansky, 2014, p. 184). We usually do this best via semantic encoding (Goldstein, 2011, p. 153–154), when we associate meaning with what we learn and especially if we connect the new information to what we already know. The better we do this, the better encoding that occurs because the information gets stored more deeply and permanently in long-term memory.

Sincere, hard-working students who have trouble remembering what they have studied may be making the mistake of engaging in superficial encoding. They misguidedly think that spending hours studying should be guaranteed to pay off when taking a test irrespective of the type of studying engaged in. It is true that test-taking is stressful, and that may have something to do with why a person incorrectly solves a test problem. Still, I usually find that the same well-meaning student is unable to sufficiently remember the content in question when not in the stressful setting of a test. If nothing else, this probably indicates **shallow processing**, where minimal attention was devoted to the *meanings* of what was studied and how what was learned related to what was already known.

Cognitive psychologists have found through experiments that human memory is superior when a person makes meaningful connections between new newly acquired information and her/his existing bank of knowledge (Goldstein, 2011, p.

¹⁴ *Semantic coding* emphasizes committing information to memory based on its meanings rather than on how it appears or sounds. Semantic coding can take place for short-term memories, but it is less common than auditory and visual coding are.

174), a point stressed in this paper. This should be performed as a regular part of learning. A student should use **deep processing** to analyze meanings and relate new information to that which is already known. These approaches are preferred. However, some level of deep processing can also be accomplished by other techniques. For example, if you are new to matrices, and learn that the convention for stating the size of a matrix is always its number of rows by its number of columns in that order, you might use the beverage name RC Cola to help with encoding in long-term memory. If this way of remembering how to properly give the dimensions of a matrix is accompanied by lots of contemplative practice in doing homework problems, eventually you may not need to rely on a mnemonic.

Some people find success by turning information needing to be remembered into a song. (This is why the English alphabet is recited to elementary school children in a musical way). Another approach is to associate information to be retained with a story. Here is an example that could be used when learning calculus: The product rule of differentiation is like friends Uma and Violet going to an amusement park's game of chance. Both want to participate, but the game only allows one player at a time. So first Uma plays while Violet watches; then Uma watches while Violet plays. Symbolically, this translates into $(u \cdot v)' = u' \cdot v + u \cdot v'$.

Creating visual imagery can aid in remembering. This is certainly true with mathematics. If you are trying to appreciate how the value of $\lim_{x \rightarrow 0} \frac{1}{x}$ depends on which side of zero the approach is made, thinking of the graphical representation of $f(x) = \frac{1}{x}$ near the origin should help.

Traditionally, authors of textbooks at the intermediate algebra and college algebra levels introduce the notion of an inverse function, then the exponential function, and then the logarithmic function. Suppose you are a student learning the logarithmic function in intermediate algebra. You could try to memorize the characteristics of this class of functions as isolated information. Or you might use deep processing to combine what you recently learned about the exponential function with knowledge of the inverse relationship between it and the logarithmic function to make it easier to understand and remember the latter. This approach should also enable better solving of some problems involving logarithmic functions. If you then take college algebra (or pre-calculus), and visit these topics again, you would do well to relate them to what you already know from intermediate algebra. (This shows a benefit of taking a sequence of courses with minimal lapse between them).

Additionally, it is easier to recollect information that you have actively used over time compared to something you passively read and did not then use. Perhaps this is due to the combination of semantic and episodic memories. Students often make the mistake of spending too much studying time solely in reading the textbook and/or class notes instead of balancing reading with practical usage on a daily or bi-daily basis. In mathematics, chemistry, physics, and engineering courses, there usually are ample textbook exercises that necessitate using the lecture and textbook contents. Problems that challenge the student to reason on what has been read and take existing knowledge to new levels of appreciation can help to secure the information in long-term memory and, importantly, make it easier to mentally re-

trieve that information in the future. Attempts to bypass this process by finding the answer in the rear of the textbook or a solutions manual, and then working back to the problem statement, are not helpful at test time when those resources are unavailable. (The same is true if a tutor is essentially doing the student's homework). This is also an awful habit to get into with respect to career employment. In a professional occupation there is no back of a book or solutions manual that has answers to the problems a job requires solving.

Transforming new knowledge into effective practical use requires **user confidence** in the new information, which requires mastery of the information, which requires retention in memory. Helping students accomplish this necessitates well designed instructional methods that counter the natural effect of forgetting (Stahl et al., 2010). Not every student has the aptitude to become a mathematician, scientist, or engineer. Yet, millions of people worldwide learn mathematics, even as high as calculus. Sometimes, reminding ourselves of a fact like this can be a motivator to not give up.

We know from personal experiences how important a positive attitude is to healthy learning. The student who tries to study while telling her/himself how much s/he hates the subject matter is setting up virtually guaranteed failure at future remembering.

Also useful in effective encoding is to **organize information being studied**. If you randomly read paragraphs of new information from different subjects, or different topics in the same subject, how reasonable is it to expect that you will mentally preserve the bulk of what was read? Doing too much of this makes optimal encoding unlikely. Students should get in a habit of dedicating blocks of time to each subject when studying, and set a goal of what to complete. When finished studying, one ought to be able to articulate what was learned and ponder its significance. Documenting these in a notebook near each set of homework exercises can promote a self-disciplined approach to studying. If the student is striving for academic maturity, this history of notes should demonstrate progression. Here is an example of what an intermediate algebra student might write after completing a homework set from a chapter on conic sections:

Finished Section 13.2 "The ellipse". Ellipse equation in standard form: $\frac{(x-h)^2}{a^2} + \frac{(y-k)^2}{b^2} = 1$. If in expanded form, must complete square on each variable. In standard form, denominators are squares. Must actually write square of each positive number, a and b . To sketch ellipse, start at center, (h, k) . (Watch signs of h and k ; they're opposites of what they look like in standard form). From center, plot points a units left/right of center and b units up/down from center. Draw ellipse through those four points. Difference between standard form equations of conics learned so far: Parabolas have only 1 squared variable; circles and ellipses have 2. Circle is just special case of ellipse with $r = a = b$.

As important as it is to effectively encode information into long-term memory, we also need to be able to retrieve it.

Usually, when we cannot remember something previously studied, the problem was difficulty retrieving the information when we needed to, rather than that the information was lost altogether (Goldstein, 2011, p. 181). Think of how often you have had trouble remembering something that you actually *did* know. Maybe it finally came to you when it was too late (such as after a test was over). A **retrieval cue** triggers recall of known information. We all know how well hearing a song with certain personal significance serves as a cue by mentally taking us back in time to personal events we associate with the song such as crushes, tragedies, happy times with friends, and so on. The same can be true with sights, odors, and tastes.

Strengthening our mental cues for information that we want to remember can greatly aid us in not forgetting. Many years ago in a course about mechanical vibrations, I was learning how to derive differential equations of motion for complex, multiple degree-of-freedom systems that included any combination of linear motion, angular motion, rolling, sliding, non-horizontal slopes, non-linear surfaces, springs, dampers, pulleys, and so on. At least one of these complicated problems appeared on each test. Twice on tests I forgot to include a certain reactionary force in my analysis. I eventually fixed this by repeatedly reminding myself that for free rolling of a round object on another surface to occur in these problems, there had to be a force that induced a moment (tendency to rotate) and I must not forget this. Without that force, the object would slide rather than roll. The mental sight of an object rolling on another surface became my visual cue, and that is why I remembered the reactionary force in every relevant problem thereafter. (It helped that as soon as I started a test, I immediately wrote a note to myself on the test paper to not forget the reactionary force).

Due to the principle of **encoding specificity**, cognitive psychologists say the context in which we learn has value during retrieval, and they recommend studying in an environment comparable to the one where learning took place¹⁵. If the exact classroom where that occurred is not accessible, perhaps another classroom is. Or if studying is done in a library, it may be beneficial to try to study in the same location in the library each time.

There is also an argument that striving for consistency in one's mood or awareness at learning and retrieval is worthwhile (Goldstein, 2011, p. 184–185) for the process of recall.

Summary of Techniques to Increase Learning and Long-Term Remembering

According to Radvansky (2014, p. 177), successful performance of human memory involves three steps:

- ① Encoding new information;
- ② Brain retention of said information over time; and

¹⁵ You may have experienced the encoding specificity in daily life if you found that you were better able to remember something if you returned to the place where the information was learned.

- ③ Future retrieval of said information.

The brain is astonishing in its capability to handle many different activities simultaneously, much of which may not require conscious focus. Right now your brain is allowing your eyes to see and read; ears to hear and listen; nose to smell and detect identifiable odors; tongue to detect tastes, textures, volume, pressure, and temperature; lungs to breathe; blood to circulate; and numerous other bodily functions to occur quietly and smoothly. In addition to all of that, your brain controls your memory system. By educating ourselves on the workings of human memory and forgetting, we can help students become better learners and improve at demonstrating on tests what they have learned. These are components of an overall effort toward enhanced reasoning and problem-solving cognitive skills.

Improving use of one's memory is constructive when accompanied by the work needed to *understand* what is being taught. **If students focus on understanding what they are trying to learn, memory thereof will be far less of an issue, because we tend to remember what we understand.** A student may wonder, "Why do I forget what I know when taking tests?" Sadly, for too many people the reality is that what was needed for the test was really not known to a useful extent. Something about a test problem may have been recognizable; but the student did not adequately know what to do with it. Visual familiarity is insufficient. Doing a lot of homework problems may also not be enough in the absence of thinking about what was to be learned from each one. I am very familiar with shoes, because I have worn them every day of my life and have several different pairs. Does that experience in itself mean that I know how to design and manufacture a quality pair of shoes? Of course, the answer is no.

The human brain is highly complex, and much remains to be learned about how it functions. Moreover, not every person's brain reacts the same way. As you may have observed, a method of studying that proves very effective for one person may be of mediocre profit to another. We individually need to find what methods work best for us. It is a personal responsibility that takes self-discipline and lots of time. A student should be committed to helping her/himself in this regard.

Below are highlights of some of what cognitive psychology has gained from research on human memory. Mixed in are suggestions relevant to teaching:

- **Preparation for a course** is essential and is the student's responsibility. It is unreasonable to expect to do well when prerequisite material was last studied long ago and/or was not learned well when it was studied. The difficulty here is that a post-secondary school admissions/counselling system might allow (and even encourage) a student to register for a course merely because the prerequisite course was taken at some point in the past and a passing grade was received.

Example: If a course on learning a foreign language or playing a musical instrument were taken 1+ years ago, and not much use of the language or playing of the instrument were engaged in since then, most people surely would agree that jumping into the next level course without ample refresh-

ment would be foolish. Yet, students frequently make this mistake with mathematics, thereby setting themselves up for disaster.

• **Overloading oneself with responsibilities is bad for effective learning and retention.** Most students at the post-secondary level need to learn to handle a larger set of duties than they had when in high school. However, what set of responsibilities can be managed varies from one person to another. What should be avoided is burdening oneself to a point of incapacity or certain failure in coursework.

• **Forgetting is a natural process that requires effort to counter the effects of.** Forgetting keeps our brains from overloading with superfluous information that our senses take in. Everyone experiences it, not just the elderly or those with cerebral disorders. Even when we want and/or need to remember new information, unless it is emotionally charging or relates to what we already know, or we quickly start working to remember it by affixing meaning to it, forgetting normally begins and progresses rapidly. (Moreover, what we do remember can be contaminated). Over a century ago, psychologist Hermann Ebbinghaus quantified his rate of losing information in a forgetting curve¹⁶ (Figure 3).

• **The way we encode information in long-term memory affects the purity of its future remembrance.** We are more likely to better learn something today and accurately remember it in the future when we attach meaning to it and relate it to our existing bank of knowledge, rather than simply focus on its visual/auditory characteristics or try to retain it in isolation from everything else that we know. This is why it is advisable for students to prepare for lectures. Those who read the section(s) in the textbook to be covered in lecture within 24 hours before the lecture takes place have reported (to me) gaining much more from lectures than if they did not read in advance. They have already seen new terminology and methods once in the textbook; during lecture, they are seeing/hearing them for the second time. (This also means they are more likely to ask a question in class if something is unclear because it is their second exposure).

Perhaps a reason many people forget a new person's name within a few seconds of an introduction is because they attend to visual qualities (age, height, weight, sex, eyes, hair color/style/length, and clothing colors/style/patterns), auditory aspects (accent, word choices/pronunciations, voice volume/pitch, and manner of speaking), and touch-related facets (type of physical contact, temperature, and pressure/firmness of touch) of the other person rather than on the person's name when voiced. Also, it seems natural in those first few seconds when names are exchanged to start deciding what to say to this individual, how much we want to say, and even to what extent we want to converse. These thoughts are distractions from effort at remembering a name.

• **Human memory is unlike a filing cabinet, camera, or photocopier.** What we remember can be faulty.

We normally have to work hard to accurately and fully remember to the best of our abilities. Students should take class notes that they can read and that are complete. (They should also then study their notes, which involves more than endlessly re-reading them). An impaired remembrance can lead one astray.

Examples: Many students remember the product rule for radicals as something like: $\sqrt[n]{A} \cdot \sqrt[n]{B} = \sqrt[n]{A \cdot B}$, but they forget that this equation is an identity only if $\sqrt[n]{A}$ and $\sqrt[n]{B}$ are real. Or they remember $x^0 = 1$, but forget that this is true only when $x \neq 0$. Are these missteps trivial? Suppose the same student goes on to study physics and learns the conservation of linear momentum theory like this: $m \cdot \vec{v}_1 = m \cdot \vec{v}_2$ (linear momentum of a body is conserved between two points in time). S/he will have difficulty if using the theory to explain how a billiard ball's direction of motion changes when it collides with the rim of a pool table. Even if the ball's speed did not measurably alter from before the collision to afterward, its direction did. Hence, its velocity (speed plus direction) vector changed, which means its linear momentum vector changed. Linear momentum before and after the collision are different (unequal), which makes it look like the conservation theory just failed. What the student in this case needs to remember is that a body's linear momentum is conserved *in the absence of external forces on the body*. If external forces exist, then impulse-momentum theory overrides momentum conservation. In this example, an external reactionary force caused by the rim of the table occurred during collision. It is that force that changed the direction of the linear momentum vector.

• **Reciting has some value**, although it alone is usually not enough to ensure that all information will be well encoded in long-term memory. There is nothing wrong with sensibly using flashcards, re-writing one's lecture notes while orally reciting and thinking about the contents, and rehearsing the meanings of what is learned, all *as components of an overall studying strategy*. These methods have merit if done appositely and if one is not distracted (by entertainment sources, for example). Recall, our memories are in a persistent state of flux (Radvansky, 2011, p. 287). It is not uncommon to hear new information today, assume that we will remember it accurately, and later remember it inaccurately.

Example: You meet a new employee at work. A few minutes later, you misspeak the person's name when passing in the hallway. The slipup was unintentional. Though you wish it had not happened, you probably spend no more than a few seconds feeling bad about it.

We tend to casually pass off these occurrences in everyday life when they are common and seem minor. The situation is different for a student who needs to know new information relevant to a course. Then the necessity to remember correctly is imperative. On a quiz about projectile motion in my first course of general physics as a university student, I correctly wrote the necessary equation in symbolic form, but incorrectly substituted the complement of the proper angle. With more personal review of how the angle of interest is properly defined in those situations, then and reciting that

¹⁶ See Appendix III for a large graph of the Ebbinghaus forgetting curve.

information, the mistake could have been avoided¹⁷. Likewise, is it so difficult to correctly remember a new person's name if we make a point of saying (reciting) it a few times as soon as the introduction occurs?

• **Last-minute cramming of new information is unlikely to result in much long-term retention.** The strength of neural pathways in the brain that are involved in encoding long-term memory can be a function of time spent learning and remembering the information. The deception here is that in the short-term of a minute or so, a student may be able to recall some of the new information (just as in the short-term we might retain a new telephone number or address). However, unless we work to keep that information in short-term/working memory, by the time our books are away, we actually receive a test paper, and we start working on the test problems, the information may very well be lost. True, there are times when something read or heard just before the start of a test ends up being needed to solve a test problem, and one or two points are gained as a result. Especially is this possible if what is read connects with knowledge that we are already comfortable with. That is ok (actually nice!). It is the idea of cramming most of one's studying in a short time before a test that is unfair to the brain. Situations like this can and should be prevented with better planning.

• **Proper rest aids in memory encoding.** We cannot expect to perform well on most things without reasonable breaks during the day and adequate, quality sleep at night. In one study, it was found that sleeping after a few hours of learning new material *aided* in consolidation to semantic long-term memory. (That research was performed by Gais, Lucas, and Born (2006) who noted that "Subjects were required to refrain from drinking alcohol and caffeine during the days of the experiments. They agreed to have regular sleep patterns throughout the experiment..." Only 12 participants were sampled. Normally, I would not cite research on such a small sample compared to the size of the statistical population. I chose to include it here due to many years of my own university education in engineering, mathematics, and psychology, where I found agreement with the findings of Gais et al. Notably, I never consumed caffeine, whether from coffee or so-called "energy" drinks, while in school).

• **Memories are modified when recalled.** Each time you remember something, you risk altering the last version of the original memory (Abumrad, J. et al, 2007; Goldstein, 2011, p. 197, 210). The real danger here is that we usually are unaware that a memory is flawed until we compare it with an accurate record (if one exists). Poor memories are problematic when the information must be flawlessly revived such as on a test. To reduce contamination of information, we should first be certain of what we put in our brains. During lectures, I want students' questions to be addressed to

¹⁷ Years later, I still remember making that mistake in defining an angle θ on a physics quiz. To my recollection, however, I never made the same error again in physics or the many engineering mechanics, vibration theory, modern control systems, and dynamics courses that followed. We can learn much from mistakes despite the sometimes unpleasant consequences when they happen. When participating in a class lecture or discussion, no one wants to err. Yet, everyone is there to learn, and better that a student tries and errs than not try at all.

me, not whispered to other students who might then disperse wrong information that might then be overheard by yet more students. If a student voices incorrect information when participating in a lecture¹⁸, I am able to correct it on the spot. This ensures that error-free information is conveyed to everyone present. Also, initial learning should be supplemented with more reading, with thinking about how the new information relates to what is already known, and with practical use of the knowledge in homework problems. Getting this practice keeps a person from relying on a potentially flawed memory¹⁹.

• **Many eyewitnesses passionately, and yet incorrectly, remember events.** Passionate, sincerity in effort at remembering should not be confused with accuracy. Even a well-meaning student may inaccurately remember what was heard in class or read in a textbook. This is why there is value in coming to class prepared for a lecture by reading new material in advance. Also, students should be in the habit of making a note on the spot when something confuses them during studying *that they are unable to figure out on their own*. When a person comes to me for clarification, at times it is impossible for me to help because the student's recollection of the details and from where the confusion arose are vague.

• **Some memories are procedural and can be performed while thinking of other things.** Transcribing in one's native language is a procedural memory. Thus, information seen on a board or heard spoken can be written down while one's mind wanders to other things. In this state, the extent of on-the-spot learning what the instructor is teaching is low. This reemphasizes the importance of students staying focused on the classroom lecture, discussion, or other activity, as well as thinking of how what is being seen and heard relates to their existing knowledge.

• **Illusions of learning.** To study beneficially, Goldstein (2011, p. 189) warns against methods that tend to lead to poor memory despite their appearance of effectiveness:

- (a) **Rereading material** is the dominant study method used by most students (Karpicke et al., 2009) because it *feels* productive. Rereading is also popular because it leads to the familiarity effect, but that

¹⁸ Regular audience participation is required in my classes consistent with my conviction that learning is an active process. I ask the audience questions and encourage students to make inquiries of me. No one wants to make mistakes in front of others. Yet, that understandable concern should not lead to failure to participate. Presumably, every student will eventually seek a career and be faced with job interviews. A student at an interview cannot win over an interviewer by saying that s/he is shy or does not want to talk for fear of making a mistake. Everyone taking a course is supposed to be learning. If one already knew everything, and never erred, there would be little point in formal education. Mistakes can be great learning opportunities if we choose to see them in that way.

¹⁹ Recall: Even if perfectly correct information is dispensed, and even if a hearer of that information originally retains the correct information in its exact form, the Ebbinghaus forgetting curve predicts that future recollections are prone to error.

something is familiar does not per se mean that we understand it; nor does it ensure that we are going to be able to *competently* use the information in the future. Also, rereading results in fluency, where ease of reading increases with repetition. This makes rereading seem more beneficial than it actually is. The method does have value, but in conjunction with other proven study techniques. Radvansky (2014, p.182) makes the sobering point: **Repeated attempts at trying to remember are what produce primary memories, not repeatedly studying the information of interest.** How many students realize this? Probably very few do.

- (b) **Highlighting** is another common approach to studying because it appears to involve active participation in learning. Yet, some students highlight too much content, which defeats its purpose. Moreover, highlighting can be more about the procedural memory role of moving the hand than about astute consideration of what is being highlighted.

Some of the aforementioned ideas are emphasized in a journal article (Stahl et al., 2010) about **interval-learning** in a psychopharmacology graduate studies program. Considering that professionals in psychopharmacology need to learn, to remember in the long-term, and to have mastery of facets of

a plethora of drugs where human safety is a dominating and urgent concern, the article's points on learning and remembering are arguably relevant to other fields of study too.

As shown in Figure 9, merely attending lectures should not be relied on to ensure competent erudition. Even individual student reading as a studying technique may not be enough. However, **discussion groups** (which students can form) and **practical use** of new material (including by properly doing homework exercises) are shown to have great profit with respect to long-term memory. Even better is **teaching others what was learned or making immediate use of new material.**

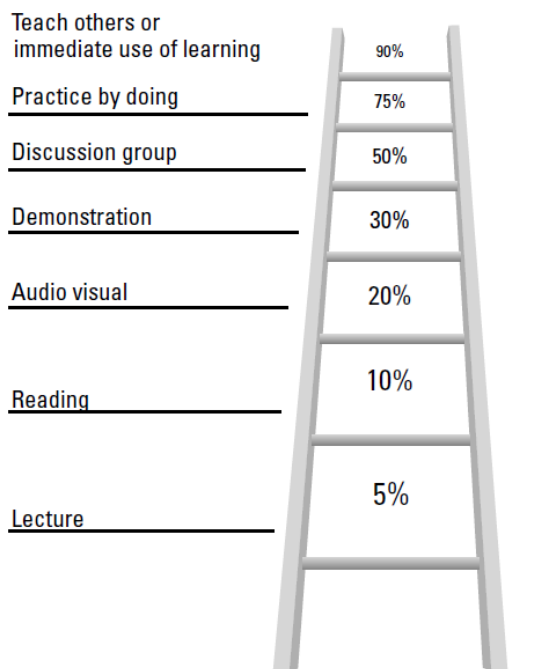
Faculty members can enhance the likelihood of retention of classroom work by incorporating visuals and demonstrations in their teaching when possible.

Learning from one's mistakes is a key component of learning. Seemingly few students do this, and so the same types of errors are repeated in one assignment after another. Here is a list of questions (a few repeated from the introduction) that students would do well to ask themselves about test problems they did not successfully handle:

- (1) Did I read the problem statement carefully twice, taking note of what was given versus what was to be found?
- (2) Did I make unfounded assumptions?
- (3) If it might have helped, did I construct a suitable visual aid that related what was given to what was to be found?
- (4) Did I show my work? (Whether required or not, showing work can help in avoiding mistakes).
- (5) Did I try to guess my way to an answer rather than solving the problem using established ideas and methods learned in the course?
- (6) Did I understand what to do, but rushed to complete the problem without exercising care?
- (7) Did I only partially know what to do? (Partial understandings are of low value. Would you willingly be a passenger in the car of a driver who partially knew how to drive? Would you trust an accountant who sort of understood fiscal matters? Would you hire builders who almost grasped construction techniques?)
- (8) Was I completely lost on this problem? Did I grasp its concepts/rules before the test and study that material? If so, why did I not remember them when needed?
- (9) Did I ask myself if my answer seemed reasonable before finishing a problem?
- (10) If I finished the test with time to spare, did I go back and redo this problem with my existing work covered? (Simply rereading existing work might serve only to convince the student that what s/he wrote is correct).

For homework to help in consolidating information to long-term memory and to be valuable as a study tool, I require

FIGURE 2.
The ladder of learning



Different learning modalities have different retention rates. The lowest rungs on the ladder are, unfortunately, the most commonly used.

Stahl SM, Davis RL, Kim D, et al. *CNS Spectr*. Vol 15, No 8. 2010.

Figure 9
The Ladder of Learning (Stahl et al., 2010)

(For a larger version of above chart, please see Appendix IV)

students to do various things for each problem:

- (1) Write the instructions (just once for each subset of exercises) and problem statement with given information.
- (2) Define any user-created variables.
- (3) Show all work neatly and in an organized fashion. What is written should make sense to other readers and to anyone grading the work. Justify all True/False or Yes/No answers. The basis of the student's answer should be clear to a grader or reader and the student her/himself. (Have you noticed how often a student is unable to figure out what was meant in her/his own work? Of what value will such content be when used for studying?)
- (4) Box final answers.
- (5) Determine what was learned from the problem. Getting the correct answer to a problem is nice, but should not be all that was accomplished. (If the student cannot articulate what was gained, probably nothing was).

Finally, please be aware of this paper's...

Appendix I, consisting of a two-page (printable as a single sheet) document of suggestions written for students on improving study habits and memory of what they learn in school;

Appendix II, consisting of comments in the words of some successful students on what has worked for them in their studying and remembering and what has not;

Appendix III, consisting of a large version of the Ebbinghaus forgetting curve (useful for showing to classes); and

Appendix IV, consisting of a large version of a ladder of learning strategies (also useful to show to classes).

Thank you for reading this introduction to human memory. I hope it has been enlightening. If you have any thoughts to share or questions to ask, please feel free to contact me.

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References

- Abumrad, J., Horne, E., Miller, L., Lerher, J., Capello, D., Pellegrini, S., ...Pourang, N. (Producers). (2007, June 4). *Radiolab* [Audio podcast]. Retrieved on February 4, 2012, from <<http://www.radiolab.org/2007/jun/07/>>
- Ackil, J. K., & Zaragoza, M. S. (2011). Forced fabrication versus interviewer suggestions: Differences in false memory depend on how memory is assessed. *Applied Cognitive Psychology, 25*: 933–942. doi: 10.1002/acp.1785
- Alonzo, J. D., & Lane, S. M. (2010). Saying versus judging: Assessing knowledge of eyewitness memory. *Applied Cognitive Psychology, 24*: 1245–1264. doi: 10.1002/acp.1626
- Anderson, J. R., & Schooler, L. J. (1991). Reflections of the environment in memory. *Psychological Science (Wiley-Blackwell), 2*, 396–408.
- ashikkerib. (2006b, October 11). Life without memory: The case of Clive Wearing, part 1a [Video file]. Retrieved on February 4, 2012, from <<http://www.youtube.com/watch?v=OmkiMlvLKto>>
- ashikkerib. (2006b, October 11). Clive Wearing, part 2a: Living without memory [Video file]. Retrieved on February 4, 2012, from <<http://www.youtube.com/watch?v=Lu9UY8Zqg-Q>>
- Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. In K. W. Spence & J. T. Spence (Eds.), *The psychology of learning and motivation*. New York: Academic Press.
- Baddeley, A. D., & Hitch, G. J. (1974). Working memory. In G. A. Bower (Ed.), *The psychology of learning and motivation* (p. 47-89). New York: Academic Press.
- BBC. (2003). *Last flight of the Columbia* [Transcript]. Retrieved on February 3, 2012, from <<http://www.bbc.co.uk/science/horizon/2003/columbiatrans.shtml>>
- BBCWorldwide. (2010a, July 3). *Space Shuttle Columbia disaster Pt 2: Final descent – BBC* [Video file]. Retrieved on February 3, 2012, from <<http://www.youtube.com/watch?v=6R4ctaCBapM>>
- BBCWorldwide. (2010b, July 3). *Space Shuttle Columbia disaster Pt 3: Final descent – BBC* [Video file]. Retrieved on February 3, 2012, from <<http://www.youtube.com/watch?v=iJaSvssCiRM>>
- Cantu, R. C. (2001). Posttraumatic retrograde and anterograde amnesia: Pathophysiology and implications in grading and safe return to play. *Journal of Athletic Training, 36*(3): 244–248.
- Carey, B. (2008, December 5). H. M., whose loss of memory made him unforgettable, dies. *New York Times*. p. 1.
- Carlson, N. R. (2002). *Foundations of physiological psychology* (5th ed.). Boston: Allyn and Bacon, Pearson Education.
- Carlson, N. R. (2013). *Physiological of behavior* (11th ed.). Boston: Pearson Education.
- Corkin, S., Amaral, D., González, R., Johnson, K., & Hyman, B. (1997). H. M.'s medial temporal lobe lesion: Findings from magnetic resonance imaging. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience, 17*(10), 3964–3979.
- Deconstructing Henry: The re-examination of the brain of patient H.M. (n.d.). The Brain Observatory Retrieved on March 22, 2012, from <<http://thebrainobservatory.ucsd.edu/hm>>
- Eichenbaum, H. (2002). *The cognitive neuroscience of memory*. New York: Oxford University Press.
- Gabbert, F., Memon, A., & Allan, K. (2003). Memory conformity: Can eyewitnesses influence each other's memories for an event? *Applied Cognitive Psychology, 17*, 533–543. doi: 10.1002/acp.1784
- Gais, S., Lucas, B., & Born, J. (2006). Sleep after learning aids memory recall. *Learning & Memory, 13*(3), 259-262. doi:10.1101/lm.132106
- Goldstein, E. B. (2011). *Cognitive psychology: Connecting mind, research, and everyday experience* (3rd ed.). Belmont, California: Wadsworth, Cengage Learning.
- Gramzow, R. H., & Willard, G. (2006). Exaggerating current and past performance: Motivated self-enhancement versus reconstructive memory. *Personality and Social Psychology Bulletin, 32*(8), 1114-1125. doi:10.1177/0146167206288600

**Improving Learning by Understanding the Psychology of Human Memory
(SAIKALI, 2013)**

- Green, C. D. (n.d.a) *Introduction to memory: Hermann Ebbinghaus (1885/1913)*. Retrieved on February 17, 2013 from <<http://psychclassics.yorku.ca/Ebbinghaus/wozniak.htm#f1>>
- Green, C. D. (n.d.b) *Memory: A contribution to experimental psychology*. Retrieved on February 17, 2013 from <<http://psychclassics.yorku.ca/Ebbinghaus/index.htm>>
- Hammond, C. (correspondent). (2010, August 11). *Case study: HM – the man who couldn't remember* [Audio file]. Retrieved on March 22, 2012, from <<http://www.bbc.co.uk/programmes/b00t6zqv>>
- Hebb, D. O. (1949). *Organization in behavior*. New York: Wiley.
- Henderson, S. (2012). Free at last. *Ebony*, 67(11). Retrieved on February 2, 2012, from <<http://www.ebony.com/news-views/free-at-last#axzz2JtLwCzCi>>
- Holt, S. (2009). The man who couldn't remember. *NOVA scienceNOW*. Retrieved on March 22, 2012, from <<http://www.pbs.org/wgbh/nova/body/corkin-hm-memory.html>>
- Kaasa, S. O., Morris, E. K., & Loftus, E. F. (2011). Remembering why: Can people consistently recall reasons for their behaviour? *Applied Cognitive Psychology*, 25, 35–42. doi: 10.1002/acp.1639
- Kalat (2010). *Biological psychology* (10th). Belmont, California: Wadsworth, Cengage Learning.
- Karpicke, J. D., Butler, A. C., & Roediger, H. (2009). Metacognitive strategies in student learning: Do students practise retrieval when they study on their own? *Memory*, 17(4), 471-479. doi:10.1080/09658210802647009
- Kurtz, K. J., Gentner, D., & Gunn, V. (1999). Reasoning. In B. M. Bly & D. E. Rumelhart (Eds.), *Cognitive science: Handbook of perception and cognition* (2nd ed., p. 145–200). San Diego, California: Academic Press.
- Leighton, J. P. (2004). Defining and describing reasoning. In J. P. Leighton & R. J. Steinberg (Eds.), *The nature of reasoning* (p. 3–11). Cambridge, United Kingdom: Cambridge University Press.
- Loftus, E. F., & Palmer, J. C. (1974). Reconstruction of automobile destruction: An example of the interaction between language and memory. *Journal of Verbal Learning and Verbal Behavior*, 13, 585–589.
- Martinez, M. E. (2010). Human memory: The basics. *Phi Delta Kappan*, 91(8), 62-65.
- McDermott, N. (2013). How Google is rotting our memories: Young people today have 'worse memories than their parents'. *MailOnline*. Retrieved on November 19, 2013 from <<http://www.dailymail.co.uk/health/article-2510053/How-Google-rotting-memories-Young-people-today-worse-memories-parents.html#ixzz217w22X2C>>
- Miller, G. A. (1956). The magical number seven, plus or minus two: some limits on our capacity for processing information. *Psychological Review*, 63(2), 81-97. doi:10.1037/h0043158
- Neisser, U., & Harsch, N. (1992). Phantom flashbulbs: False recollections of hearing the news about *Challenger*. In E. Winograd & U. Neisser (Eds.), *Affect and accuracy in recall: Studies of "flashbulb" memories* (p. 9–31). New York: Cambridge University Press.
- Newhouse, B. (Writer). (2007, February 24). *H.M.'s brain and the history of memory* [Audio file and transcript]. Retrieved on March 22, 2012 from <<http://www.npr.org/templates/story/story.php?storyId=7584970>>
- Radvansky, G. (2011). *Human memory* (2nd ed.). Boston: Allyn & Bacon, Pearson Education Incorporated.
- Radvansky, G., & Ashcraft, M. H. (2014). *Cognition* (6th ed.). Boston: Pearson Education Incorporated.
- Schmechel, R. S., O'Toole, T. P., Easterly, C., & Loftus, E. F. (2006). Beyond the ken? Testing jurors' understanding of eyewitness reliability evidence. *Jurimetrics*, 46, 2, 177.
- Scoville, W., & Milner, B. (2000). Loss of recent memory after bilateral hippocampal lesions. *The Journal of Neuropsychiatry and Clinical Neurosciences*, 12(1), 103-113.
- Shiffrin, R. M., & Atkinson, R. C. (1969). Storage and retrieval processes in long-term memory. *Psychological Review*, 76(2), 179-193. doi:10.1037/h0027277
- Simons, D. J., & Chabris, C. F. (2011). What people believe about how memory works: A representative survey of the U.S. population. *Plos ONE*, 6(8), 1-7. doi:10.1371/journal.pone.0022757

**Improving Learning by Understanding the Psychology of Human Memory
(SAIKALI, 2013)**

- Stahl, S. M., Davis, R. L., Kim, D. H., Gellings Lowe, N., Carlson, R. E., Jr., Fountain, K., & Grady, M. M. (2010). Play it again: The master psychopharmacology program as an example of interval learning in bite-sized portions. *CNS Spectrums, 15*, 491-504. Retrieved on February 25, 2013 from <<http://www.cnsspectrums.com>>
- Starr, D. (2012). False eyewitness: "Who are you going to believe? Me or your lying eyes?" *Discover, 33*(9). Retrieved on February 3, 2012 from <<http://discovermagazine.com/2012/nov/04-eyewitness>>
- TED Radio Hour. (2013, May 24). How do experiences become memories? [Audio file]. Retrieved on November 4, 2013, from <<http://www.npr.org/2013/08/30/182676143/how-do-experiences-become-memories>>
- Thompson, S. G. (2012). Judicial gate-keeping of police-generated witness testimony. *The Journal of Criminal Law & Criminology, 102*(2), 329-395.
- Wearing, D. (2005, January 12). The man who keeps falling in love with his wife. *The Telegraph*. Retrieved on February 4, 2012, from <<http://www.telegraph.co.uk/health/3313452/The-man-who-keeps-falling-in-love-with-his-wife.html>>
- Winkelman, P., & Schwarz, N. (2001). How pleasant was your childhood? Beliefs about memory shape inferences from experienced difficulty of recall. *Psychological Science, 12*(2), 176-179.
- Zhu, B., Chen, C., F. Loftus, E., Lin, C., & Dong, Q. (2010), Treat and trick: A new way to increase false memory. *Applied Cognitive Psychology, 24*: 1199–1208. doi: 10.1002/acp.1637

Appendix I

Advice to Students for Better Learning, Studying, and Remembering

- (1) **Know the prerequisite course material.** Just because you are able (even advised) to register for a course does not necessarily mean that you are ready for it, and assessment tests can be poor at determining preparedness. Too many students enter courses lacking an excellent, current understanding of the preparatory material. Without quickly overcoming this deficiency, it is terribly difficult to master the new material. If you are unsure whether you ought to be in a course, talk to the instructor about it *on the first day of the course or sooner*. Why expect to learn and remember what you are unprepared for?
- (2) **Do not overload yourself.** It has become common for students to concurrently work at a job, go to school, and have family obligations. For some people, these collective demands cause their grades to suffer so that they accumulate a poor academic record. They then may drop out of school, end up taking on long-term responsibilities (such as marriage, having children, or enormous debt), and regret forever that they did not go further with their education. Determine how much YOU can handle and be careful about exceeding it. While some commitments are inflexible, perhaps the stress of other responsibilities can be moderated with help from family members; still others may be possible to reduce or remove from your life. Are you working many hours due to necessity or luxury? Could you scale back expenses, work fewer hours weekly, and still survive financially? Alternatively, taking fewer units of classes per term may mean a longer total time to graduate, but may allow you more time to study, get sufficient rest, and, hence, achieve a better academic record.
- (3) **Resist over-confidence or laziness.** Usually, the first part of any course is its easiest. Even so, there may be bits of knowledge that you need to master. Moreover, when the new material comes, you need to be ready for its challenges. A cocky or lazy attitude may serve only to get you behind. It can be scary and frustrating to find that you are unable to keep up with the new material in a course. Cramming to then retain too much material in a short time rarely works out for students.
- (4) **Come to each session of a class on time and prepared.** This includes completing homework exercises from previous lectures, bringing the homework with you to class, reviewing the last lecture, and reading the portion of the textbook to be covered in the coming lecture. Doing the latter exposes to you terminology, concepts, graphs, and methods that you may hear again in lecture. All of these are important efforts toward learning, studying, and long-term remembering.
- (5) **Exercise good classroom comportment.** Choose a seat where you can stay focused. Do not get distracted by frivolous things or socializing with others. Be attentive to the lecture, discussion, or other class activity. Taking good notes (and actually using them when studying) is important; mindlessly copying the board/screen content to your notebook is not much better than simply photocopying someone else's notes. Instead, think about what you are hearing and seeing from the speaker as you write it. How does it pertain to the overall theme of the lecture? How does it relate to what you knew before the current lecture? How does it relate to what you read in the textbook before coming to class? If you are following all of this advice, and something you hear or see from the speaker is unclear, raise your hand and politely ask for clarification.
- (6) **Elaborative rehearsal is crucial to long-term memory retention.** You can supplement in-class attentiveness by reviewing and audibly pondering the deeper meanings of what you heard in lecture. If helpful, arrange a small study group in which people take turns explaining portions of the material to the group and resolving any confusion. If used properly and practiced every day or two, flashcards can also serve effectively as rehearsal. Re-writing your lecture notes while explaining (aloud or to a friend) each part works well for some people. The more you reinforce and reach a level of comfort in talking about the lecture content, the easier it will be to remember and use what you have learned when tested.
- (7) **Start each homework assignment as soon as possible after its lecture.** Unless you quickly and often use what you hear in the classroom and read in the textbook, you begin forgetting new material about as fast as a new automobile loses value following a consumer purchase. Avoid waiting until the weekend to do multiple lectures' worth of homework. The amount of work can feel insurmountable and leave you getting much less out of the exercises than otherwise possible. You may be inspired to take this seriously by finding online, printing, and carrying with you a copy of the Hermann Ebbinghaus forgetting curve and looking at it frequently. As psychologist Ebbinghaus found a century ago, we begin forgetting brand new material almost immediately (if it is not used in meaningful ways and if we do not relate it to our existing knowledge).
- (8) **Do homework in a distraction-free setting.** Put away devices that draw focus from your work. If you are checking your telephone, social media sites and applications, email, and so on every few minutes, think of how little substantive attention is being paid to what you are supposed to be learning. How much can you reasonably expect to remember later? Make a printed weekly schedule of when to do homework for each course. Carry it with you daily and commit to it.
- (9) **Do homework responsibly.** Start homework by reviewing the new ideas and methods (from the lecture notes and textbook) relevant to the current homework. How does this new content relate to what you learned in earlier lectures, sections of the textbook, and homework? Homework should strengthen the learning of new content, but this benefit comes only if you are consistently responsible with it. Example problems show how to make use of a section's material. It may be tempting to "do" each homework problem by looking for an example problem to emulate without really seeking to understand the relevant theory. Any short-term gain from this practice will be of minimal value during a test when no aids are available. For each homework problem, write the instructions and problem statement, and show all work neatly. When helpful, construct a

table or sketch. If you create a variable, define it. If the problem is a True/False or Yes/No type, justify your answer. These practices will make studying for tests much easier, as you should be able to remember your past work better.

- (10) **Learning is as important as getting the correct answer.** In a career occupation, you will encounter difficult problems that take time to work through. So if a solution approach to a homework problem does not instantly come to you, do not rush to give up. Homework is supposed to be challenging. What would be the objective if all problems had easy-to-come solutions? Before rushing to look in the book, your notes, or elsewhere for a quick answer, stop and think. Are you clear on what you are being asked to do and how what is unknown relates to given information? How might you use previously learned content to reason on the current problem? What role do the components of a problem play in affecting the whole? In the world outside of a classroom, there is no answer set in the back of a textbook. There are no solutions manuals. You may have access to supervisors and colleagues at a job, but if you frequently rush to get help from those sources rather than demonstrating that you can work on your own to solve problems, your assessed value to the organization will be lessened.
- (11) **Stop and ask yourself, “What have I learned?” from homework.** When you complete a subset of related homework problems, take a few minutes to consider what you have gained. What do you know now that you did not know before? Could you teach it to others? Are you able to use what you have acquired to do other problems in this or future sets? Be honest. If you have not learned much from doing the homework, this must be addressed. Telling yourself that everything will work itself out is not the remedy. While there are academic things that take time to mentally digest, it should not be that way generally with your work. Meet with your instructor about this to get advice on what might be wrong. Mathematics courses tend to follow a path of connected learning from one section/chapter to the next. If you do not apply yourself well enough to use and remember what was learned from earlier sections, how can you expect to successfully move forward?
- (12) **Instructor “office hours”.** A misunderstanding of current material will interfere with you correctly learning and remembering new material. If your instructor offers weekly time to meet with students, do you make use of it? Unless you have reason to conclude that it would not be helpful, why not see her/him when you need help? When doing so, be prepared to specify what you do understand and show that you have made reasonable effort *on your own* at figuring out what is unclear.
- (13) **When preparing for a test, spend minimal time studying what you already know well.** A mistake of studying is spending too much time reviewing what you already understand, rather than devoting yourself to mastering material that you are troubled by. It is an unproductive psychological avoidance technique.
- (14) **Familiarity ≠ Comprehension.** While there is value in rereading your lecture notes and the textbook, do not get deluded into thinking that visual familiarity equals understanding/retention. Just because something is easier to read does not mean that you are able to reason on it to solve problems as may very well be required during a test. Also, this kind of narrow familiarity tends to not work well when a person is presented with the same material from a different perspective.
- (15) **Spend sufficient time studying early, and space out study sessions.** It takes time to get knowledge into your long-term memory in a way that makes it easily retrievable in the future. Do not wait until a day or two before a test to start preparing. Cramming is generally not as effective as people assume. Consistently studying daily is more conducive to retention.
- (16) **Short breaks during studying.** Getting distracted every few minutes is an extreme. Working many hours without breaks is an extreme. Find a good place in between. Check yourself along the way to see if you are remembering what you have studied and can demonstrate mastery of it without peeking at notes, books, or answers. If comprehension is minimal, your manner of studying is impractical.
- (17) **Anticipate test questions.** If you are regularly in class, taking copious notes, participating, and responsibly doing the homework, then it could be valuable to spend *some* time speculating on possible test questions. Think about content that the professor has emphasized. Can you explain it to others? Are you ready to be tested on it? Could you make practical use of it extemporaneously? Do not make the mistake of assuming that everything will work itself out during a test. If needed, get clarity ahead of time. Be clear on what content you are expected to know for a particular test.
- (18) **If you use a tutor, do so cautiously.** There is nothing necessarily wrong with consulting a tutor, but be careful. Too often, help from a tutor turns into the tutor doing the student’s work. How can you expect what you need to know to enter your long-term memory and be retrievable during tests if you cannot do much without the tutor’s help? Regularly assess whether it is beneficial to your long-term learning to continue receiving tutoring. A tutor should not be a substitute for working on your own. Is the tutor guiding you in a way that gets you to a point of being able to function independently? (Before you use a tutor, have you exhausted the most obvious source of help, the faculty member teaching the course?)
- (19) **Final advice for tests:** Start studying well in advance of a test. Cramming and all-nighters are risky. Get enough sleep the night before a test. Eat properly so that you are alert and nourished. Gather all necessary tools (pencils, erasers, and so on) well in advance of the test date. If possible, arrive to the testing site early so that you are less stressed. Keep a positive attitude even if the subject matter is not one you are fond of. These will promote your capacity to learn, remember, and do well academically.

Appendix II

Student Successes with Academic Learning and Remembering

Although case studies are not substitutes for scientific experiments, they can be of contributing value. I wondered what techniques for retaining information were used by my former top students in their community college studies. So in 2013, I wrote to the 16 most academically successful students of my classes over the past four years to invite them to share with me what strategies for learning and remembering they had found to be useful and to disclose pitfalls they had come to avoid. For each student, my request was emailed to the address I had for her/him back when my class was taken. Eight responses were received. No respondent was coached on what to say. None of these students were taking classes from me when I contacted them; neither is any at the time of this writing. Each was asked for permission to print their submissions and names in this manuscript and its accompanying presentations. Their contributions are greatly appreciated.

Comments are presented in the order received:

Hello, Mr. Saikali. Through my experience in different courses, I have found that hand writing notes along with giving your full attention to lectures help tremendously with memory retention. I rarely look back on these notes unless to look something up, but I find that having hand-written them at least once makes a huge difference. Specifically with math courses, I like to do the practice problems concerning a particular section once immediately after learning the section. Then, I like to go over the same problems before a quiz or test to make sure I haven't forgotten anything in between sections over time.

You have my permission to use any of this information as well as my name if needed.

One important thing to add that I forgot in the last email is that researching why something is the way it is helps me remember much better than simply knowing. For example, understanding what causes gravity will help one remember the things he or she needs to know about gravity much more than simply knowing that gravity exists.

Tony T. (student of "College and matrix algebra")

Good afternoon Mr. Saikali,

Thank you very much for this opportunity; I would more than happy to offer insight into my personal philosophy on memorization and what works for me.

You do have my permission to use everything I am conveying to you on this matter in your oral and written presentations for the coming conference and/or in future presentations, and I give you full permission to use my name to credit the comments if you choose to use them.

My personal two part philosophy on memorization has taken me the full 37 years of my existence to develop into what it is today, and continues to expand each and every day as I learn. As a child, we often hear the phrase "Practice makes perfect". As a young adult, I began to question that old adage once I realized that not everyone is perfect or performs perfectly at any given task. In my particular case, I questioned myself and my own practice techniques in the area of music.

Being a self-taught guitarist for almost 20 years now, the main source of instruction I have utilized has come from literature. Reading, learning, then practicing. The more I practiced, the more I found that if I take my time and play the music perfectly, my speed will develop over time. For example, if I continually practice a certain scale quickly and without attention to detail, my overall playing will be sloppy (think Led Zeppelin sloppiness vs distinctness of Joe Satriani). In my mind, the old adage "Practice makes perfect" then developed into two separate phrases; "Practice makes permanent" and Perfect practice makes perfect".

This leads me into the second and main part of my philosophy, practice. In terms of music again, I have been playing for quite a long time, but there have often been long periods of time in which I was unable to play a guitar (deployments to Iraq and Afghanistan). I found that when I came back, it was as if I had lost a large portion of my playing abilities and musical knowledge. Quickly I learned that consistent practice is the only way to retain the entire skill set.

When it comes to academia and mathematics specifically, I quickly learned several semesters ago how to adapt my philosophy from music and apply it to my study techniques. When working on any math problem, I take my time to ensure I fully understand every aspect of the

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problem and not just regurgitate information I heard in class or read in the text. For example, if I am to apply a trigonometric identity to a problem, I will verify that I fully understand the identity prior to proceeding. I know that by working slowly and correctly, in time I will be able to complete the problems much easier. In the area of consistency, I know that I must allot time in my schedule every other day at a minimum in order to fully learn and retain the information. If I only engage the material during the class and once on the weekends for homework, I will fail. Studying even four times a week for 15 minutes will have much better results than studying for 60 minutes once a week.

I hope this aligns with your presentation. Please let me know if there is anything I can do to further assist.

Mike H. (student of “Trigonometry”)

Good evening Professor Saikali,

It is great to hear from you! How have you been? You actually beat me to the punch, I have been trying to send you a message to see how you have been. I will be honored to assist you in your study.

You do have my permission to use what I convey to you on this matter in your oral and written presentation for the coming conference and/or in future presentations, and you do have my permission to use my name to credit with my comments if you do use what I tell you.

I have tried different study methods since I started my undergraduate career. I have attempted to copy example after example down from a text book and other sources provided by an online instructor; which did not work for me. I was not able to fully understand the underlying concepts and therefore I failed the course. However this did not discourage me, I realized I needed the face to face time with a professor to get a true student-professor connection in order to do better.

Once I was able to enroll into a traditional, lectured course I realized that simply attending a lecture would not get me to the grade of an A. I changed my study method to rely heavily on attempting every assigned problem from the text book and attending the lecture (including asking any questions about the homework during the professor's office hours).

I believe this was much better than only working multiple examples because it gave me continuous review of the material, once during the lecture, then throughout the week while completing the assigned homework problems. By meeting with the professor on a regular basis I was able to breakdown the barrier that naturally existed between the professor and I. By doing this I was able to increase my ability to truly understand the methods and concepts my professor was teaching.

I don't want to forget about sleeping and exercising on a regular basis as well. I had established a regular diet and workout regimen well before the semester started which allowed me to work on the assigned problems regularly and maintain my stress level throughout the work week.

To summarize my thoughts, I believe regular coverage of my course material and discussing some homework problems with my professor was necessary in effective memorization of the concepts and methods presented in lecture. A regular diet, exercise, and sleep plan definitely helped with accomplishing my academic goals by reducing stress from full time employment. Also a balanced life helped, meaning that I was not working a full time job and enrolled as a full time student.

I hope this information is helpful. Please let me know if you need anything else Sir!

Alejandro R. (student of “Trigonometry”)

Hi Mr. Saikali,

Below I have what you requested and I also attached 2 sets of my note taking method (one from my psych class [2pics] and one from my math class [4pics]) that assisted me in my studies:

Consensus: I, Yazmin Hernandez, on 01/12/13, allow Mr. Jeffrey Saikali to use the disclosed information for his conference in February 2013, concerning human memory and improving learning. I allow Mr. Saikali to also use my name to credit the comments I made.

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Comments: Hermann Ebbinghaus's Forgetting Curve played a key factor in forming effective study habits. Understanding that nearly half of one's memory of a certain subject taught can be forgotten the next day if one does not review, inspired me to build the habit of reviewing my notes daily. Also, on the weekends I formed the habit of doing a cumulative review of what I learned that certain week. When a test was nearing, I would also do a cumulative review for the certain subjects covered on the test a week before the actual exam date. As a result, the studying and reviewing of certain subjects became feasible to retain, rather than burdensome.*

In conjunction to the Ebbinghaus's Forgetting Curve, using the Cornell Notes method assisted with retaining the subject. The Cornell Notes method consists of two columns (a 2 1/2' cue column [to add heading/questions/side notes], and a 6" note column), and a summary part. For examples of the Cornell Notes method, please see the given images. This method encouraged me to personalize my notes and to think critically about the subject being taught. I enjoyed personalizing my notes by highlighting them with various neon colors, especially since I'm a visual learner this made the learning and reviewing fun. Lastly, the summary part of the Cornell Note method allowed me to test my understanding of the subject by briefly paraphrasing my notes.*

** Ebbinghaus's forgetting curve and the Cornell Notes method was introduced to me in AVID** during High School.*

*** AVID is an abbreviation for Advancement Via Individual Determination and its mission is to prepare high school students for college readiness*

Please notify me for any further explanations and/or if you have any questions or concerns, thanks. Hope this helps! Praying that your presentation goes well.

Yazmin H. (student of "Intermediate algebra and geometry")

Hi, Professor Saikali!

Congratulations on your acceptance at the mathematics conference! I would be happy to assist you and give you my input on my studying techniques and ways of memory retention.

Honestly, I do not have any specific ways of remembering the topics I study. First off, I put away all of my electronics prior to beginning my work for I have found that it is very hard to focus and remember what I am learning with all of the distractions around me. After doing so, I focus on one topic at a time and use a method of repetition in which I re-teach the subject matter to myself until I fully understand it to where I can remember it. Once I have gone through all of the material being tested thoroughly, I go back and keep reviewing it to make sure it is ingrained into my memory. For me, I think that the most sufficient way for me to remember contents is if I completely understand what I am studying. In doing so, much of the time, I pick apart topics so that it becomes more clear to me. However, aside from studying on my own time, I have found that it really helps when professors quickly review major ideas at the beginning of classes so that it is consistently fresh in our memory.

I hope that my comments give you some sort of assistance, although I know it is not much! I also give my full permission to use any of this information, as well as my name, in your oral and written presentations for any upcoming conferences you may attend. Good luck and I hope everything goes well at the conferences, Professor Saikali!

Thank you,

Avni P. (student of "College and matrix algebra")

Hello Professor Saikali,

Congratulations on your acceptance. I feel honored to have been one of the few chosen students you decided to contact regarding your personal. I would love to participate and provide my input regarding memorization techniques.

Doing homework and practice problems for me work best when it comes to studying for mathematics. They help me understand the concepts better as I do each question. Apart from homework, quizzes are also extremely beneficial because they help understand what partic-

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ular type of problem the professor focuses on. Reviewing them is one my key technique for big tests such as finals and midterms. Repeating and reviewing are extremely helpful for me personally because the more I review and take notes the easier it is for me to memorize the concepts to the point where they become so familiar that having them on a test does not make me uncomfortable. For example, I still remember the unit circle from your lecture because you focused on us memorizing that, also the proper procedure of proving and how to make it organized. We did several examples of both of them to the point where they were engraved in our brains.

I hope my points help out. You do have my permission for using my name if needed. Hope things are going well for you. Thank you.

Sincerely,

Rashi S. (student of “Trigonometry”)

I would love to share my experiences and ideas with you anytime if it is helpful to anyone. I am going to put in points and if you want I can come to your class to have a conversation with you and elaborate each point.

- a) I always revise my notes just after attending the lecture or class. This helps because teachers [sic] instructions are fresh in my mind.
- b) I generally try to do the homework promptly.
- c) Talking of home work [sic] I would like to mention that I do go through the book and solve each and every example before I start with the homework.
- d) I do memorize formulas, graphs, shortcuts depending on the topic and its requirements.
- e) Before any test or quiz I try to do extra problems from different book/books. This helps in getting used to all types of questions and language.

I will keep adding to this input if I remember something which I would like to share or missed in my previous emails. You have my permission to use my name and material in your presentations. Do let me know if you need any other help.

Regards

Ruma S. (student of “Elementary algebra and geometry” and “Intermediate algebra and geometry”)

Hello Professor Saikali!

I would be more than happy to share with you my comments and you do have my permission to use them in your written and/or oral presentations my study skills. You do have my permission to use my comments and my name.

After I pretty much bombed my first test in your class, I freaked out. I had taken this course twice already and failed. But I was determined to not fail your class because, quite frankly, I couldn't afford the time to fail it. So, I continued doing the homework pretty much every day after class and a few evenings a week, if there was a lot. I tried my best to always have my homework completed for the next class. But what I found to be particularly the most helpful to me was to re-write my notes. Every day after class, I would go straight to the library and re-write all of my notes from class and reference the textbook as well. Sometimes the author would explain a topic in a way that I understood better than what was taught in class and vice versa. Usually what was taught in class was easier for me to understand, but referencing the textbook helped me define it more. Then when it would come to test time I would read through my notes on each section and the textbook, do the chapter reviews and practice tests.

I have learned that flash cards do not work for me at all!

I hope this helps you Mr. Saikali and please let me know if you need me to clarify or elaborate on anything. I am catching a plane at 6:30am tomorrow so I will be unreachable most of the day, but available until 10pm tonight.

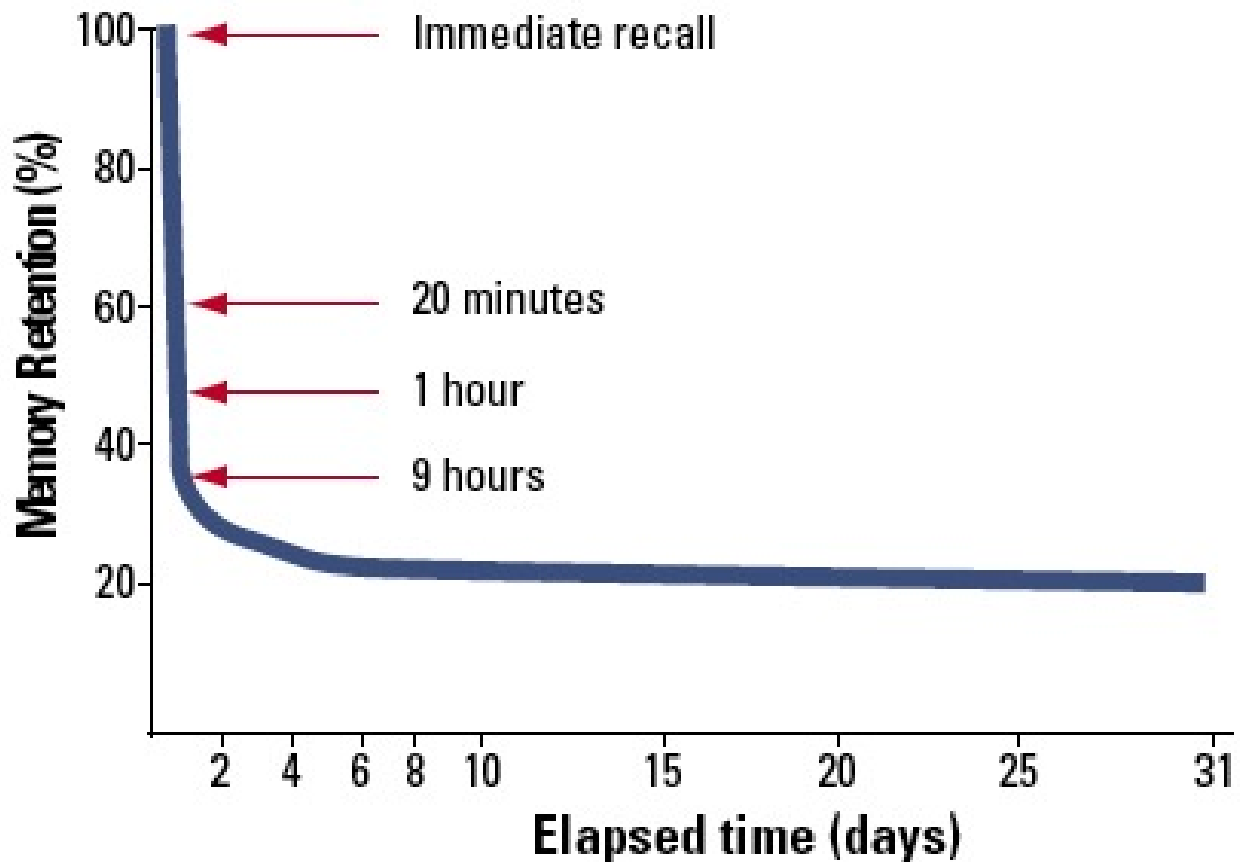
Take care,

Dani G. (student of “Intermediate algebra and geometry”)

Appendix III

Hermann Ebbinghaus Forgetting Curve

FIGURE 1.
The forgetting curve



The “forgetting curve” was developed by Hermann Ebbinghaus in 1885. Ebbinghaus memorized a series of nonsense syllables and then tested his memory of them at various periods ranging from 20 minutes to 31 days. This simple but landmark research project was the first to demonstrate that there is an exponential loss of memory unless information is reinforced.

Stahl SM, Davis RL, Kim D, et al. *CNS Spectr.* Vol 15, No 8. 2010.

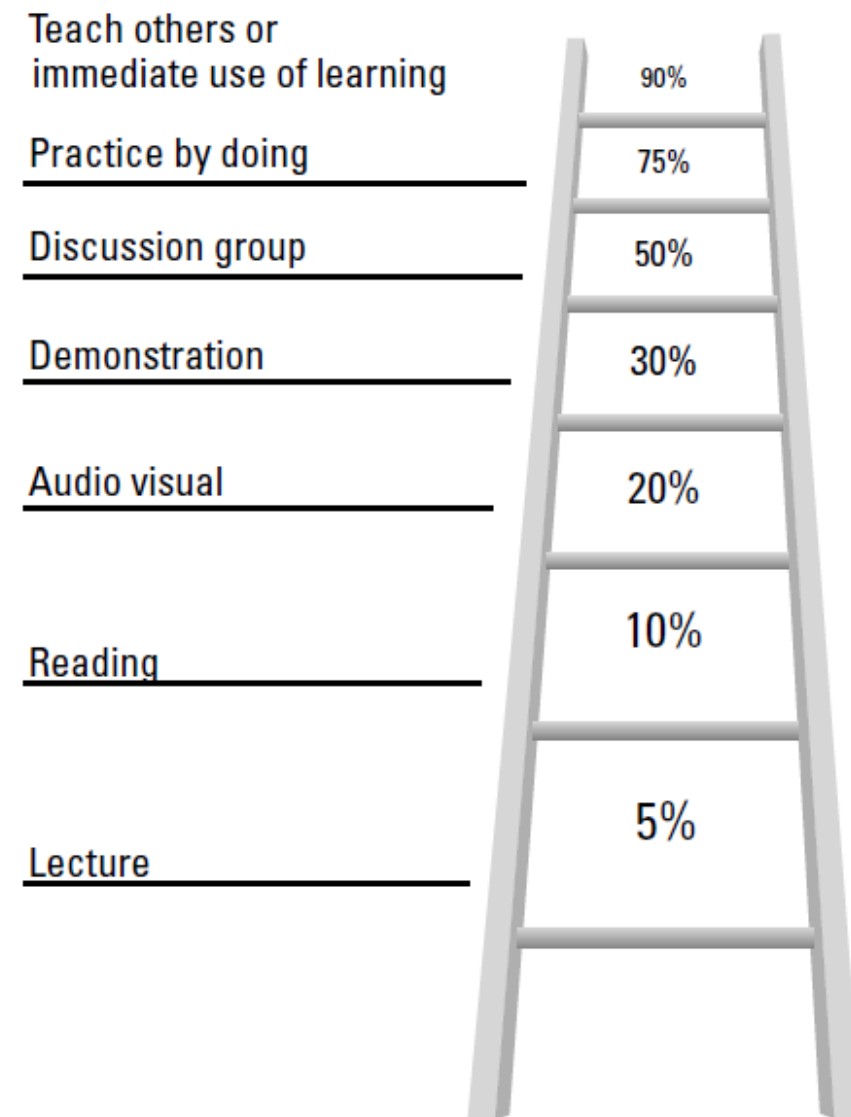
Stahl, S. M., Davis, R. L., Kim, D. H., Gellings Lowe, N., Carlson, R. E., Jr., Fountain, K., & Grady, M. M. (2010). Play it again: The master psychopharmacology program as an example of interval learning in bite-sized portions. *CNS Spectrums*, 15, 491-504. Retrieved on February 25, 2013 from <<http://www.cnsspectrums.com>>

Direct URL accessed on February 25, 2013: <<http://www.cnsspectrums.com/asp/articleDetail.aspx?articleid=2783>>

Appendix IV

The Ladder of Learning

FIGURE 2.
The ladder of learning



Different learning modalities have different retention rates. The lowest rungs on the ladder are, unfortunately, the most commonly used.

Stahl SM, Davis RL, Kim D, et al. *CNS Spectr.* Vol 15, No 8. 2010.

Stahl, S. M., Davis, R. L., Kim, D. H., Gellings Lowe, N., Carlson, R. E., Jr., Fountain, K., & Grady, M. M. (2010). Play it again: The master psychopharmacology program as an example of interval learning in bite-sized portions. *CNS Spectrums*, 15, 491-504. Retrieved on February 25, 2013 from <<http://www.cnsspectrums.com>>

Direct URL accessed on February 25, 2013: <<http://www.cnsspectrums.com/asp/articleDetail.aspx?articleid=2783>>